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An Assessment of Four-Hour Sample Durations Used to Determine Full-Shift Noise Exposures in a Foundry

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AN ASSESSMENT OF FOUR-HOUR SAMPLE DURATIONS USED TO DETERMINE FULL-SHIFT NOISE EXPOSURES IN A FOUNDRY

by

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ABSTRACT

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Full-shift sampling, usually eight hours, is traditionally performed to assess daily occupational noise exposure. This sampling approach is inefficient, and costly for repeated, long-term exposure evaluations. This study assessed the use of four-hour sample durations and subsequent data analysis to determine daily occupational noise exposures in a foundry. The four-hour sample durations were extracted from full-shift samples and analyzed on their ability to provide valid data for estimating mean daily noise exposure levels without significantly affecting sampling precision or accuracy. Results of this study indicate four-hour sample durations can be used successfully to estimate full-shift noise exposures provided certain criteria are met. Findings of this study may reduce the sampling time and number of samples required to make decisions regarding employee noise exposures.

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CHAPTER ONE

INTRODUCTION

In order to understand occupational noise sampling, a background knowledge of noise exposure is necesssary. Noise has been defined as "unwanted sound" (National Institute of Occupational Safety and Health [NIOSH], 1973, p. 299). Noise is a physical hazard which emanates from urban and rural areas, occupational and non-occupational sources, making noise America's most widespread nuisance (Clark, 1992).

The connection between noise and hearing loss has been known for centuries (Berger, Ward, Morrill and Royster, 1986, p. 1). Noise-induced hearing loss (NIHL) is most commonly associated with workplace noise but in reality is caused by any repeated, excessive exposure over a period of years (Clark, 1992). Although hearing ability declines with age (presbycusis) in all populations, excessive exposure to noise produces hearing loss higher than that resulting from the natural aging process. Continuous exposures typically between 90 and 140 dBA damage the cochlea in the inner ear metabolically rather than mechanically as in acoustic trauma, resulting in a bilateral sensorineural hearing loss. NIHL remains entrenched in the NIOSH's list of the ten leading work related diseases and injuries of the United States (NIOSH, 1987, p. 1). NIHL is also in the top five categories of adverse health effects occuring in foundries where this study was conducted (NIOSH, 1985, p. 1). Although NIHL is one of the most common occupational "diseases", it is often underrated because there are no visible effects and, except in very rare cases, there is no pain.

The course of NIHL is insiduous. The first sign is usually that other people do not seem to speak clearly as they used to. The noise-exposed person has typically asks others to repeat themselves more so than normal. As the loss becomes progressively worse, there is a gradual decrease in communication with family and friends and a loss of sensitivity to the environment. Hearing loss is not the only effect of occupational noise. There are a number of nonauditory effects upon workers which include communication interferences, decreased job safety, and increased stress. Noise interferes with speech and becomes a communication problem when it masks speech necessary to carry out a job or to ensure employee safety. There are many stories about workers who, because they were unable to hear warning signals, were seriously or fatally injured. In fact, because of these types of incidents, some employers have installed visual warning devices.

Without the adequate attenuation of occupational noise, workers will often report increased stress in the form fatigue, irritability, and sleeplessness which is attributed to the noise (Berger et al, 1986, p. 9).

The Occupational Safety and Health Administration (OSHA) sets legally enforceable occupational standards and exposure limits under the OSH Act of 1970. These limits are established to protect the vast majority of workers exposed repeatedly to stressors such as noise during an eight-hour workday and 40-hour workweek, day after day, without exhibiting adverse health effects. Permissible exposure limits (PELs) are components of OSHA Standards for toxic and hazardous substances; usually expressed in eight-hour time-weighted average (TWA_8) concentrations. The OSHA PEL of 90 dBA is the criterion level used for compliance purposes for eight-hour exposures. Noise sampling is performed to acquire data to make formal comparisons with organizational guidelines and government standards for acceptable exposures (Hawkins, Norwood, and Rock, 1991, p. 1).

STATEMENT OF THE PROBLEM

One of the strongest incentives for employers to conduct noise surveys has been federal regulations, the most important being the OSHA Hearing Conservation Amendment (U.S. Department of Labor [USDOL], 1983, pp.

9735-9738). In this amendment, OSHA has promulgated PELs that require sampling data to demonstrate compliance with these government standards. Non-compliance as cited by OSHA officials can result in fines and penalties ranging from minor to serious, depending on the violation(s). However, the amendment neither suggests nor recommends a method that ensures compliance with the Act. OSHA has reported its intent to develop and promulgate a "Generic Monitoring Standard" but has yet to do so (OSHA, 1988, pp. 37591-37595).

This absence of a noise sampling protocol leads employers to oversample worker populations to ensure that sufficient data is obtained to make decisions regarding health effects, OSHA compliance, and risk management. Oversampling can be costly, time-consuming and labor-intensive.

Since an employer's time and resources for measuring and evaluating occupational exposures are usually limited, a more efficient sampling method is desirable. A sampling method that eliminates wasting time and resources and prevents oversampling a worker population.

PROPOSED STUDY

This study utilizes four-hour sample durations to quantify full-shift occupational noise exposures in a ferrous foundry. Traditionally, eight-hour (or full-shift) sample durations are used to quantify daily occupational noise exposures of workers. For assessment purposes, eight-hour samples will be collected on foundry workers in three target populations. Continuous four-hour sample durations will be extracted from these samples, analyzed, and compared to the full-shift data to determine the validity of their use.

This sampling method is based on previous research which utilized continuous, four-hour sample durations rather than full-shift (eight-hour) samples and subsequent data analysis to assess daily employee noise exposures in a heavy equipment garage (Brunn, Hutzel, and Campbell, 1986).

STATEMENT OF THE PURPOSE

The purpose of this study is to assess the validity of data generated by four-hour sampling durations to represent daily, full-shift, TWA exposures of specific worker populations. Results of this study may significantly reduce the time needed for sampling and minimize the number of samples necessary to determine occupational noise exposures. This in turn may allow more job tasks to be evaluated by an employer in a reduced period of time and at lower costs.

It is hypothesized that four-hour samples with subsequent data analysis will not be statistically significantly different from the full-shift parent data and sufficient for making decisions regarding occupational noise exposure.

ASSUMPTIONS

The assumptions involved with this study include the following:

1. Employees will not influence data that would in any way misrepresent normal noise exposures.

2. Employees will not tamper with audio dosimetry instruments.

3. The proposed sampling method is not intended to replace full-shift sampling, only to serve as a supplementary or alternate method.

4. Noise levels in the foundry are both continuous and fluctuating.

DELIMITATIONS

The delimitations involved with this study include the following:

1. The study will be conducted at a single foundry.

2. Target population members were sampled in a method of convenience rather than selected at random.

LIMITATIONS

The limitations involved in this study include the following:

1. The number of study subjects and resulting samples are small due to foundry size and reduced operations.

2. Audio dosimeters used had an operating range between 80 and 140 dBA.

APPLICABILITY

The proposed sampling strategy and data analysis system can serve as an alternate or supplementary, cost-effective exposure assessment tool for employers to determine noise exposure in a specified worker population. The proposed sampling method can be applied to other physical and chemical agents in the workplace provided the agent exposure variability is uniform throughout the workshift, and the peak exposure period is included in the sample (Brunn et al., 1986).

DEFINITION OF TERMS

Alpha (α). - The significance level. (Shott, 1990)

Attenuation. - The reduction of sound pressure levelin decibels as one moves further and further from a noise source. (Berger, Ward, Morrill, & Royster, 1986)

A-Weighting Curve. - A frequency selective weighting filter that is an approximation of equal loudness perception characteristics of human hearing for pure tones. (Berger, Ward, Morill, & Royster, 1986)

Burner. - Foundry worker who performs arc-air gouging or oxygen-propane burning.

Casting. - The pouring of molten material into a mold and permitting it to solidify to the desired shape. (Plog, 1988)

Central Limit Theorem. - A statistical theorem that states that the sample mean has an approximate normal distribution when based on sufficiently large random samples from any large population with a finite variance. (Shott, 1990)

Chipper. - Foundry worker who perform pneumatic grinding and chipping using a pneumatic chipping hammer.

dBA. - Sound level in decibels read on the A-scale of a sound level meter. (Plog, 1988)

Dosimeter (dose meter). - An instrument used to determine the full-shift exposure a person has received to a physical hazard (e.g. noise). (Plog, 1988)

Exposure. - Contact with a chemical, biological, or physical agent (e.g. noise). (Plog, 1988)

Exposure Assessment. - The determination or estimation (Qualitative or quantitative) of the magnitude, frequency, duration, and route of (noise) exposure. (Hawkins, Norwood, and Rock 1991)

mew (μ). - The population mean. (Shott, 1990)

Noise. - Any unwanted sound. (NIOSH, 1973)

Noise Induced Hearing Loss. - The terminology used to refer to the slowly progressive inner ear hearing loss that results from exposure to continuous noise over a long period of time as contrasted to acoustic trauma or physical injury to the ear. (Plog, 1988)

Normal Distribution. - A continuous distribution with a bell-shaped frequency curve given by a mathematical formula. (Shott, 1990)

Peak Exposure. - The highest exposure or the highest group of exposures experienced by workers during some defined exposure duration (usually short time periods). (Hawkins et al., 1991).

Permissible Exposure Level (PEL). - Defined in 29 CFR 1910, Subpart Z, General Industry Standards for toxic and hazardous substances; usually an 8-hour time-weighted average (TWA) concentration. (Hawkins et al., 1991)

Sampling. - The separation of a portion of an ambient atmosphere with subsequent analysis. (Plog, 1988)

Paired *t* Test. - A statistical test of the hypothesis that two populations means that is based on paired samples. (Shott, 1990)

Two-tailed probability. - Probability calculated from areas in both tails of a distribution. (Shott, 1990)

Time-Weighted Average (TWA). - Refers to (noise) concentrations which have been weighted for a certain time duration, usually eight hours. (Plog, 1988)

Welder. - Foundry worker who performs shielded metal-arc or gas metal-arc welding.

CHAPTER TWO

BACKGROUND OF STUDY

Literature will be discussed in this chapter which provides a background knowledge of occupational noise assessment. This information is essential in evaluating whether four-hour sample durations can be used successfully to represent full-shift occupational noise exposures.

OSHA Legislative History

In 1969, shortly before OSHA came into being, the Department of Labor issued a noise standard under the authority of the Walsh-Healey Public Contracts Act. This standard was established to protect employees from noise-induced hearing loss (NIHL) resulting from excessive occupational noise exposure and applied to all employers having contracts with the federal government. In 1971, the standard became an OSHA Standard and law for all workplaces in the U.S. to ensure employees a safe and healthy workplace. In January 1980, OSHA adopted an amendment to the Occupational Noise Standard for General Industry, 29 CFR 1910.95 (USDOL, 1983).

The Hearing Conservation Amendment was published by OSHA on January 16, 1981, and the revised version in

1983, which has not been altered since. The purpose of the amendment was to clarify the meaning of an effective Hearing Conservation Program (HCP) by specifying minimal components (Middendorf, Luster, Williams, and Smith, 1983). The OSHA Hearing Conservation Amendment requires that whenever an employee is exposed to noise levels exceeding an eight-hour time-weighted average (TWA_8) of 85 dBA, the employee is to be included in a continuing, effective Hearing Conservation Program (HCP) (USDOL, 1983). In addition to other components, HCPs must include an assessment of noise exposure.

Occupational Noise Assessment

Quantifying continuous workplace noise exposures requires an effective exposure assessment strategy. As with any health hazard, it is important to characterize the hazard accurately and to identify affected employees. Common noise sampling instruments are sound level meters (SLMs) and audio dosimeters. Although both instruments provide information on noise levels, an audio (noise) dosimeter is the best way to measure a worker's daily noise exposure and was used for this study (Hynes, 1975). Time-weighted average (TWA) noise exposures were computed from the dose, in percent, by the formula

$$TWA = 16.61 \log_{10} (D / 12T + 90)$$

where D = dose % and T = time (hours). The dosimeter used can store data and integrate data over time to give TWAs at specified time intervals. Occupational noise exposure surveys requires that the data be obtained using a slow meter response, an A-weighting, and be measured in the ear area, along with documentation of the times spent at the levels encountered.

A strategy for conducting occupational exposure assessments has also been published by the American Industrial Hygiene Association (AIHA) (Hawkins et al., 1991, p. 1 - 8). A critical component of the AIHA strategy is to develop a basic characterization of the workplace. This characterization, which is essentially a qualitative exposure assessment, groups workers together forming target populations based on job exposure profiles (JEP) and job cycles. This JEP approach to noise exposure monitoring enables employers to efficiently assess employee noise exposures, determine if a HCP is required, and to identify employees whom may potentially be overexposed. Overexposed workers are identified as workers whose noise exposures exceed the OSHA PEL of 90 dBA.

Noise Sampling Costs

Assessing potential noise exposures in a ferrous foundry environment is a challenging task due to noise fluctuations within or between days which occur because of varying environmental noise levels, production level changes, worker mobility, and differences in individual work habits. The need to generate valid data to accurately assess worker health risks is essential. These intraday and interday workplace exposure variations can only be evaluated by repeated sampling (Brunn et al., 1986).

Repeated sampling requires a significant investment in time and resources by an employer. Especially when utilizing today's advanced sampling systems. Regulatory flexibility permits employers reasonable latitude in the design and selection of exposure mitigation strategies which is essential to assure economic efficiency (Petersen, Sanderson and Lenhart, 1986). However, sampling for noise remains complicated and expensive (Damiano, 1989). One reason for this may be the labor and associated costs involved in collecting samples. Excessive full-shift sampling is time-consuming, costly, and counterproductive to maximizing the cost-efficiency of the Hearing Conservation Program (HCP).

A previous study (Brunn et al., 1986) suggests that four-hour sample durations can be used successfully to estimate true mean daily occupational noise exposures with a preselected limit of error. Certainly, a less time-consuming and expensive sampling method is desirable for employers who usually have limited financial resources allocated for health and safety. Since employee noise exposures must be determined, an employer's resources may best be used to quantify representative exposures to job categories and specific worker populations. Management efforts toward control or abatement can then be directed. Utilization of the proposed sampling method for noise exposure could be implemented to obtain the maximum amount of data from these job categories and worker populations in a short period of time, at the lowest cost, and yet provide statistically significant results.

Location

This study was conducted in the cleaning room of a ferrous foundry. The layout of this area is illustrated in Appendix A, Figure A-1. The cleaning room is comprised of pneumatic chipping-hammer booths, arc-air gouging stalls, radiography rooms, an oven, and a blast room as well as several laydown areas. This large room has several entryways, no windows, and a railway used by railcars to transport castings. The entire cleaning room is a posted high noise area. Due to the nature of this work, engineering controls such as enclosures are not practical. Foundry workers wear hearing protection in the form of protective ear muffs along with other appropriate personal protective equipment (PPE).

Exposure Data Distribution

Occupational noise exposures may vary considerably. This creates the need to use statistical data analysis to estimate the parameters of exposure distributions and to compare these distributions to appropriate standards (Francis, Selvin, Spear, and Rappaport, 1989). Before sample data can be statistically analyzed, there must be knowledge of the frequency distribution of the results or some assumptions must be made (U.S. Department of Commerce, 1975, p. 3). Occupational noise exposures are usually distributed normally (Brunn et al., 1986). Separate works by Brooks and Brunn (1984) and Behar and Plenar (1984) have also shown that the distribution of A-weighted decibel noise levels in a particular environment usually are distributed normally. Normal distributions resemble symmetrical bell-shaped curves.

Target Population And Job Cycles

Two important considerations in this four-hour sampling method are target populations and job cycles. A target population is a group of employees who perform the same work and have similar noise exposures. The job cycle is the total length of time it takes in days, weeks, or months for the target population to perform all the routine tasks. The three target populations working in the ferrous foundry who were sampled include the chippers, welders, and burners. The sample population consists of two welders, five chippers, and two burners. There is a total of 9 foundry workers included in this study whom are being sampled daily.

The chippers use hand-held pneumatic, portable chipping hammers and grinders to remove imperfections and embedded sand from the outer layer of the casting. The welders perform shielded metal-arc welding (SMAW) and gas metal-arc welding (GMAW) to fill in pits or grinded out areas in castings. Although both types of welding are not usually high noise operations, they require associated high noise activities such as needle-gunning and grinding. The burners perform arc-air gouging and oxygen-propane burning to cut risers from castings and to cut scrap. The burners also periodically use table saws to cut risers, and feed gates from the castings in preparation for the chippers.

Determination of these target populations are based on job classification codes, work tasks, and historical noise exposure data. Historical noise sampling data obtained in the foundry provided essential information for determining target populations and estimating potential exposures. Previous noise exposure data in the cleaning room indicated daily TWA exposures between 88-104 dBA for chippers, 99-104 dBA for burners, and 88-93 dBA for welders (Newport News Shipbuilding & Dry Dock Company [N.N.S. & D.D. Co.], 1986, 1992). These historical noise sampling data (N.N.S. & D.D. Co., 1986, 1992) suggests that the selected target populations were homogenous exposure groups. The job duties for the target populations had not changed since the last sampling survey. However, with declining personnel numbers, all foundry workers contributed wherever production needs existed. Job descriptions for the individual target population members were identical and they performed essentially the same functions. The job cycles for the target populations were determined to be five working days. This was determined by interviewing the foundry foreman of the target populations and observations of the foundry work and workers.

Number of samples

Determining the number of samples required to have a specified level of confidence in the estimation process is difficult because sample size estimation is usually a function of the population variance (Brunn et al., 1986). Ultimately, the number of samples required for each target population is controlled by the limits of sampling and analytical error. It is likely that five to fifteen data points are needed for each job description to reduce uncertainty to acceptable levels (Thornton, 1986). One data point is equivalent to one full-shift sample. A maximum of twenty data points per target group is expected to yield sufficient data for making decisions regarding this sampling method. However, if the 95% confidence level could not be achieved within twenty data points which represent four weeks of sampling, the sample collection period would not be extended.

Paired-Samples Confidence Intervals For Differences Between Population Means

Samples obtained by something twice are called paired-samples. Since the four-hour sample data are extracted from eight-hour samples, the result is two nonindependent samples of observations. In general, nonindependent samples result when two measurements of the same quantity are taken on the same subject. Whenever such an experimental design is used, the variability of the results is sometimes greatly reduced (Shott, 1990, p. 84).

When paired samples are used, the appropriate procedure for obtaining confidence intervals for the difference in population means (i.e. $\mu_1 - \mu_2$) is the paired-samples procedure. The paired-samples confidence intervals for differences between population means procedure constructs confidence intervals at selected percentage levels which show the percentage of all possible samples producing confidence intervals which include $(\mu_1 - \mu_2)$ or zero. These confidence intervals are based on upper percentage points from a set of distributions called *t distributions*. *t distributions* are a type of symmetric distribution which resemble the standard normal curve. When a confidence interval for the difference between population means contains zero, it cannot be said that the population means are statistically significantly different.

Paired-samples confidence intervals are based on the following assumptions: 1) paired-samples are used; 2) unbiased sampling of differences; 3) sample differences are independent of each other; and 4) sampling of differences is conducted on a normal population.

Hypothesis About Differences Between Population Means

When paired-samples are used to test the null hypothesis, the *paired t test* must be considered. This test requires the same assumptions as the paired-samples confidence interval for the differences between population means stated earlier. The *paired t test* is a statistical test of the hypothesis that the difference between two population means are equal. The null hypothesis about differences between population means using the paired t test can be stated as

$$H_0: \mu_1 - \mu_2 = \Delta_0$$

where μ_1 equals the population mean of full-shift samples, μ_2 equals the population mean of selected four-hour samples, and Δ_0 is not statistically derived but is determined based on the objective of study. In this case $\Delta_0 = 0$, so the null hypothesis is

$$H_0: \mu_1 - \mu_2 = 0$$

This is the same as

$$H_0: \mu_1 = \mu_2$$

The usual alternative hypothesis is the two-sided alternative

$$H_A\colon \mu_1 - \mu_2 \neq \Delta_o$$

and when Δ_0 is 0,

$$H_A\colon \mu_1 - \mu_2 \neq 0$$

Level of Significance

In testing a given hypothesis, the maximum probability with which we would be willing to risk a Type I error is called the level of significance (α). A 95% significance level was selected for this study and is commonly used (Shott, 1990, p. 107). Since a .05 or 5% significance level is chosen in designing this hypothesis test, there are about 5 chances in 100 that we would reject the null hypothesis when it should not be rejected. In other words, we are 95% confident that we have made the right decision. A Type II error is made by not rejecting a null hypothesis when it should be rejected.

CHAPTER THREE

METHODOLOGY

This chapter discusses the methodology used to conduct this study which assesses the validity of of utilizing four-hour samples to determine full-shift occupational noise exposure. The methodology consists of three sections; sampling, data analysis, and hypothesis testing.

Objective

The objective of this study is to determine if four-hour noise sampling durations provide valid data for estimating mean daily full-shift noise exposures. It is hypothesized that these data do not differ significantly from the full-shift parent sample data from which they were extracted.

SAMPLING

Occupational noise sampling is performed when studying noise exposure and its relation to possible adverse effects on the auditory mechanism (Pierce and Parker, 1986). Noise sampling serves as an effective approach to identify and protect exposed employees.

Sample Description

A sample of convenience was used to sample noise exposure among the three target populations in a systematic manner. The three target populations include the burners, chippers, and welders. These workers were simultaneously sampled throughout the entire workshift (excluding lunch) every workday over the course of the one week job cycle for four weeks.

Selected Four-Hour Sample Period

A continuous four-hour sample extracted from the full-shift sample was used to evaluate the proposed four-hour sample duration. The selected sample period being evaluated was from 7:00am to 11:00am. A morning sample period was selected due to the first shift working hours of 7:00am to 4:00pm with a lunch break from 12:00pm to 1:00pm. Obtaining a four-hour sample after lunch is not possible. At the end of each day's sampling, all sampling results were entered into a computer data file.

DATA ANALYSIS

Data analysis provides daily updates of sampling results as they are added sequentially to previous sampling results for each target population. Extracted four-hour samples will be compared statistically to their full-shift parent samples.

Minimizing Samples

To demonstrate how the number of samples are minimized, the following sample dosimetry data was used. These data were analyzed using the procedure taken from a previous study (Brunn et al., 1986) for calculating confidence intervals using the formula

$$\bar{X} \pm t * (s/\sqrt{n})$$

Where: *$\bar{X}$ = mean TWA values of the sampling distribution

t = value from t distribution with (n-1) degrees of freedom and a $(1 - \alpha)$ confidence level

n = number of samples

s = standard deviation of the sampling distribution

*Since decibels (dB) are log values, arithmetic addition of dB will give incorrect results. However, for the purpose of clarifying confidence interval calculations (and not determining dose exposures), arithmetic addition was used.

Week 1: 101.7, 104.4, 103.6, 101.0, 100.2, 96.5, 98.3, 95.3, 102.5, 93.6 dBA

Where: $\overline{X}$ = 99.7

s = 3.2

n = 10

A 95% confidence level on the sample mean is:

$$99.7 \pm [2.262*(3.15/\sqrt{10})]$$

or 99.7 ± 2.25

Because the error around the mean (2.25) is greater than the dosimeter error of ± 2 dBA, there is not yet sufficient information to estimate the population distribution with the desired level of 95% confidence. Therefore, more sampling is required. Analysis of the data collected during the following day still did not reduce the error around the mean to less than ± 2 dBA, so sampling was continued another day. Cumulative statistics for the data collected were as follows:

$\overline{X}$ = 99.9

s = 3.16

n = 14

A 95% confidence interval on the mean was:

$$99.9 \pm [2.160*(3.16/\sqrt{14})]$$

or 99.9 ± 1.8

Now, sampling could be stopped because the error on the estimate of the mean daily noise level was within acceptable limits (1.8 < 2.0). There was now enough information to estimate the distribution of daily noise levels with the desired level of accuracy using the fewest samples.

During the four weeks of sampling, audio dosimetry data for the target populations were recorded and stored in a computer data base. Thus, sampling was continued for each target population until the 95% confidence level for the four-hour samples were less than ± 2 dBA.

Paired-Samples Confidence Intervals For Differences Between Population Means

These data were analyzed using the paired-samples procedure (Shott, 1990, p. 84). Paired samples confidence intervals for differences between population means procedure is carried out by converting the differences for each pair of noise TWAs into one single sample of differences. If the noise exposure data for the eight-hour samples are denoted by μ_{1i} and the data for the selected four-hour samples μ_{2i}, the difference can be calculated by

$$d_i = \mu_{1i} - \mu_{2i}$$

for each pair. The mean of the sample of differences is denoted by $\bar{d}$. The standard deviation of the differences by s_d. It can be shown that the population mean of the differences is equal to $\mu_1 - \mu_2$ and that

$$\bar{d} = \bar{x}_1 - \bar{x}_2$$

The point estimate of $\mu_1 - \mu_2$ is $\bar{d}$.

It can be shown that a 95% confidence interval for $\mu_1 - \mu_2$ is given by the formula

$$\left(\bar{d} - (t_{.025,n-1})\ s_d/\sqrt{n},\ \bar{d} + (t_{.025,n-1})\ s_d/\sqrt{n}\right)$$

where t is obtained from the *t distribution* table (using degrees of freedom and the specified significance level) and n is the number of differences.

A 95% paired-samples confidence interval for the differences between full-shift and four-hour population means can be calculated from the following data,

$$\left(\bar{d} - (t_{\alpha/2,n-1})\ s_d/\sqrt{n},\ \bar{d} + (t_{\alpha/2,n-1})\ s_d/\sqrt{n}\right)$$

where $\bar{d}$ = 2.5, and s = 0.9,. The significance level (α) is 0.05, so $\alpha/2$ = 0.025 and $t_{.025,9}$ = 2.262. Using the above formula, the 95% confidence interval is

$$(-0.4 - (2.262)(0.9/\sqrt{10}),\ -0.4 + (2.262)(0.9/\sqrt{10}))$$

$$(-0.4 - .64,\ -0.4 + .64)$$

$$(-1.0,\ 0.2)$$

This confidence interval is interpreted in the usual way which is, we are 95% confident that all possible samples will produce population means with differences between the above endpoints.

HYPOTHESIS TESTING

As mentioned previously, the objective of this study is to determine if four-hour noise sampling durations provide valid data which do not differ significantly from the full-shift parent sample from which they were extracted. If we want to decide whether an eight-hour sample duration differs significantly from a four-hour sample duration, we formulate the hypothesis

$$H_O: \mu_1 - \mu_2 = 0$$

where μ_1 equals the population mean of full-shift samples, μ_2 equals the population mean of selected four-hour samples. This is the same as

$$H_O: \mu_1 = \mu_2$$

A hypothesis alternative to the null hypothesis is

$$H_A: \mu_1 - \mu_2 \neq 0 \qquad \text{or}$$

$$H_A: \mu_1 \neq \mu_2$$

Paired t Test

The *paired t test* is performed by converting the two paired samples (i.e. the daily full-shift and four-hour time-weighted average mean data into one sample of differences ($\bar{d}$), where $\bar{d}$ is the sample mean of differences), as described for the paired-samples confidence intervals for differences between population means. It can be shown that the population mean of the differences is equal to $\mu_1 - \mu_2$ and the sample mean of the differences is equal to $\bar{x}_1 - \bar{x}_2$. Thus, the sample mean of the differences is the estimate of $\mu_1 - \mu_2$. The paired t statistic is given by

$$t = \frac{\bar{d} - 0}{s_d / \sqrt{n}}$$

where $\bar{d}$ is the sample mean of differences, s_d is the sample standard deviation of the differences and, and n is the number of differences. It can be shown that the *paired t statistic* has a *t distribution* with $n - 1$ degrees of freedom if the null hypothesis is true. The *p-value* for the *paired t statistic* is the two-tailed probability

$$P\,(\ t \text{ statistic} < -\,|t_{calc}| \ \text{ or } \ t \text{ statistic} > |t_{calc}|\ )$$

where t_{calc} is the calculated value of the *paired t statistic*. This *p-value* is the probability of getting a *paired t statistic* greater than or equal to the calculated *t statistic* if the null hypothesis is true. Approximate *p-values* can be obtained from the *t distribution* table (Appendix B, Table B-1). This table involves upper-tail probabilities rather than two-tailed probabilities which we are interested in. But the t distribution is symmetric so the approximate value of *P(t statistic)* can be multiplied by 2 to get the approximate *p-value*.

For example (Shott, 1990, p. 122), let us use a .05 significance level to test the null hypothesis that there is no significant difference of mean daily TWAs between four-hour and full-shift sample durations of a selected target population. The differences have a mean of -16.8 and a standard deviation of 13.4, so the calculated *paired t statistic* is

$$t = \frac{-16.8}{13.4/\sqrt{10}} = -3.96$$

Looking in the row for 9 df in Table B-1 (in Appendix B), we find that 3.96 is between the adjacent numbers 3.690 and 4.781, which correspond to the upper-tail probabilities 0.0025 and 0.0005. Multiplying by 2,

we get

$$0.001 < \text{two-tailed } p\text{-value} < 0.005$$

We reject the hypothesis of equal population means at the 0.05 significance level. Less than 5% of all possible samples produced *paired t statistics* at least as extreme as -3.96, if the null hypothesis is true.

Summary

The proposed sampling method uses noise dosimetry measurements of at least four-hour durations extracted from full-shift samples, repeated over a period of time to arrive at the mean estimate of the true daily exposure for employees working in the same noise environment. From the paired-sample data, confidence intervals were constructed for differences between the four-hour and full-shift sample means. The *paired t test* was used to test the null hypothesis and is based on *t distributions*. This hypothesis test produced *p-values* which are probabilities that when compared with a significance level, decide if the null hypothesis should be rejected.

CHAPTER FOUR

RESULTS

Minimizing Samples

Audio Dosimetry was performed on all three target populations which include the burners, chippers, and welders. Sampling was performed until the 95% confidence level for the four-hour samples was less than ± 2 dBA. The minimum number of four-hour and full-shift samples for the three target populations are displayed in Tables 1 and 2. The number of four-hour samples required to achieve the 95% confidence interval about the mean and within acceptable limits for the burners', chippers', and welders' population was 16, 35, and 10 respectively. The number of full-shift samples required were 12, 35, and 40 respectively. The greatest disparity with regard to both sample durations occurred in the welders' population. The number of four-hour samples for the welders' population was 10, which represents five sampling days or one complete job cycle. On the other hand, during the entire sampling period (i.e. 20 sampling days), the full-shift samples for the welders had not achieved a 95% confidence interval about the mean to less than the dosimeter error of ± 2 dBA.

Table 1. Four-hour summary data of the three target populations.

4-HOUR SAMPLES

	NO. OF SAMPLES	DAYS SAMPLED	ARITH. CUMUL. AVG.	s	95% C.I.
BURNERS (2)	16	8	99.3	3.8	2.0
CHIPPERS (5)	35	7	98.8	5.7	1.9
WELDERS (2)	10	5	88.9	2.5	1.8

Table 2. Full-shift summary data of the three target populations.

FULL-SHIFT SAMPLES

TARGET POP.	NO. OF SAMPLES	DAYS SAMPLED	ARITH. CUMUL. AVG.	s	95% C.I.
BURNERS (2)	12	6	98.3	2.6	1.7
CHIPPERS (5)	35	7	98.2	6.0	2.0
WELDERS (2)	40	20	86.0	7.1	2.3

Paired-Samples Confidence Intervals For Differences Between Population Means

Ninety-five percent paired-sample confidence intervals for differences between population means (μ_1 - μ_2) or zero were calculated for the three target populations. These confidence intervals are listed in Table 3. Data used for these calculations are based on the minimim number of four-hour samples required to achieve 95% confidence intervals about the sample mean to less than the dosimeter error. For the burners' and chippers' target populations, 95% of all possible samples will produce confidence intervals which include zero.

Data from the welders' population indicate that 95% of all possible samples will produce confidence intervals that do not include zero. Also, since both endpoints are negative, I am 95% sure that the full-shift population mean is less than that of the four-hour sample population mean.

Table 3. Paired-samples 95% confidence interval for differences between target population means.

TARGET POPULATION	**95% CONFIDENCE INTERVAL ($\mu_1 - \mu_2$)**	**$\mu_1 - \mu_2$ EQUALS**	**DOES 95% CI INCLUDE $\mu_1 - \mu_2$**
BURNERS (2)	(-1.0 , 0.2)	0	YES
CHIPPERS (5)	(-1.6 , 0.3)	0	YES
WELDERS (2)	(-5.0 , -1.6)	0	NO

Paired t Test

The *paired-t test* was used to test the null hypothesis that

$$H_0: \mu_1 - \mu_2 = 0$$

Since a two-sided test was used, the *p-value* for the *paired-t statistic* is a two-tailed probability. The *p-values* for all three target populations are listed in Table 4. as well as the calculated value of the *t statistic* (t_{stat}). The approximate *p-values* for the burners' population are between the calculated *t-statistic* values of .10 and .20. Approximate *p-values* for the chippers' populations are between .02 and .03. Both populations' *p-values* are not as extreme (i.e. neither greater than nor less than) or equal to the calculated value of the *t statistic*. In other words, 95% of all possible samples produced *paired t-statistics* not as extreme as -1.42 and -1.30 respectivly if the null hypothesis were true. Therefore, the null hypothesis could not be rejected at the .05% significance level.

In the welders population, the *p-value* is greater than .001. Therefore, the hypothesis of equal population means at the .05 significance level is rejected. Less Than 5% of all possible samples produced *paired t statistics* at least as extreme as -4.24.

Table 4. Paired-Samples t Test.

TARGET POP.	t_{stat}	**APPROXIMATE TWO-TAILED p-values** (t_{calc} **< p-value <** t_{calc})	FAIL TO REJECT OR REJECT at α=.05
BURNERS	-1.41	0.10 < p-value < 0.20	Fail to Reject
CHIPPERS	-1.30	0.20 < p-value < 0.30	Fail to Reject
WELDERS	-4.24	p-value < 0.001	Reject

where t_{calc} = is the computed .05 critical value obtained by using the t distribution table.

t_{stat} = calculated value of the *t statistic*

CHAPTER FIVE

DISCUSSION

Number of Samples

The number of four-hour samples required to successfully achieve a 95% confidence interval about the sample mean to less than the dosimeter error of ± 2 dBA was greater in the case of the burners (16 to 12), equal in the case of chippers (35), and less than in the case of the welders (10 to 40). In all cases, the total sampling time using four-hour samples was less than that of the full-shift samples, even if the number of samples was higher.

In this study, it was shown that there is no statistically significant difference between mean daily TWAs for four-hour sample durations and full-shift samples in the burners' and chippers' target population. There was a statistically significant difference four-hour sample durations and full-shift samples between mean daily TWAs in the welders' population. This could be attributed to the fact that one of the welders spent a significant amount of time in the grinding area (see Figure A-1, Appendix A) where the chippers work, away from the other welder who works in the rather isolated welding booth adjacent to the grinding area.

Two important considerations of using a four-hour sample strategy were target populations and job cycles. One factor in determining target populations studied was occupational noise exposures. Although both welders had similar job exposure profiles, a move from one work area to another, where high noise operations were taking place had had a significant effect on anticipated exposures.

Four-hour sample durations for the welders reached acceptable tolerance limits after the one week job cycle. Full-shift samples for the welders did not achieve a confidence interval about the sample mean to less than or equal that of the dosimeter error during this study which was 20 sampling days. In this case, four-hour sample durations with subsequent analysis were successful in estimating mean daily TWAs to within acceptable tolerance limits (i.e. less than or equal to the dosimeter error of ± 2 dBA) and could be utilized for periodic monitoring whereas full-shift samples could not.

The dosimeter error of ± 2 dBA functions as the best estimate of mean daily noise exposure and is achieved when a confidence interval about the sample mean is minimized to less than or equal to that point. Once the error on the estimate of mean daily noise exposure was within acceptable limits with the desired level of accuracy, sampling was terminated for that particular target population.

Thus, shorter samples of four-hour durations, taken and analyzed sequentially provided valid data for estimating the three target populations' mean daily TWAs using the fewest samples with minimum error. Nevertheless, utilizing four-hour sample durations to represent mean daily TWA noise levels should serve as a supplementary sampling method rather than a replacement for eight-hour sampling. In the case of initial noise exposure determinations, partial-period sampling is not appropriate and should not be used.

Statistical Error

In general, there are three sources of variation associated with noise exposure estimates: 1) instrument and sampling error; 2) analytical error; 3) and environmental fluctuations (NIOSH 1977). Environmental fluctuations are usually large compared to the other two sources of variation. Interday environmental fluctuations are determined by repeated sampling and interday fluctuations are accounted for by calculating daily TWAs.

Instrument and analytical error can be described by a *coefficient of variation* (*CV*), which is the standard deviation divided by the mean. The CV_t is a value that represents the average sampling and analytical error associated determining noise exposure. Since a noise dosimeter combines both sampling and analytical functions, the comparable CV_t for the noise dosimeter can be considered to be the limits of the dosimeter measuring error which is ± 2 dB(A).

Therefore, a good estimate of the daily mean daily noise exposure is obtained when a confidence interval about the sample mean is minimized to the point where the interval is less than or equal to the dosimeter error.

All four-hour and eight-hour samples for the three target populations produced mean daily TWAs that were calculated to have instrument and analytical error CV_t within the limits of the dosimeter measurement error except for the eight-hour welders' target population. This target population group exceeded the dosimeter measurement error, requiring additional sampling to be performed beyond the established four week sampling period.

Paired-Samples Confidence Intervals For Differences Between Population Means

The paired-samples confidence intervals calculated for the burners and chippers indicate that 95% of all samples will produce confidence intervals that include

$\mu_1 - \mu_2$ or zero. Five percent of all possible samples will produce confidence intervals that do not include zero. Thus, we are 95% sure that the paired-samples confidence level for the differences between population means, does contain zero. So, since zero is within the these confidence interval points, we are 95% sure that the differences between the four-hour and full-shift samples are not statistically significantly different.

This was not so in the case of the welders. Paired-samples confidence intervals calculated for the welders indicate that 95% of all samples will produce intervals that do not include or zero. So, the differences in population means for the four-hour and full-shift samples are statistically significantly different. One reason may be that although, the welders perform the same functional tasks, these tasks are not performed in the same location. The layout of the cleaning room (see Appendix A, Figure A-1), illustrates various group work areas. One of the two welders sampled performs welding as needed (approximately 50% of the time) in the layout area next to the chippers while the other welder is stationed almost exclusively in a welding booth in a separated and somewhat isolated area of the cleaning room. This work arrangement is unique for the welders' population and perhaps the reason why the variability about the sample means did not achieve a 95% paired-samples confidence level about the sample mean less than the dosimeter error during this study.

Paired-samples confidence intervals are based on the following assumptions; 1) random sampling of differences, 2) paired samples, 3) independent differences, and 4) sampling of differences from a normal population. A systematic sampling schedule was utilized rather than random sampling. However, as long as the sample is not biased, the sample need not be a random sample (Shott, 1990, p. 84). Paired-samples were used for this study. Daily samples were independent of each other. For example, full-shift TWA results obtained on the first day of sampling, told us nothing about the TWA results on the fifth sampling day. The sample differences obtained were all from populations with normal distributions.

Paired t Test

Since paired-samples were used for this study, the *paired t test* is appropriate to test the null hypothesis that there is no statistically significant difference between eight-hour and four-hour sample mean daily TWAs. In general, sample data for the burners, chippers, for the length of this study, yielded approximate *p-values* (see Appendix B, Table B-2) which did include $\mu_1 - \mu_2$ or zero. In other words, $\mu_1 = \mu_2$. For these cases, we fail to reject $H_0: \mu_1 - \mu_2 = 0$ at the .05 significance level. Thus, we are 95% sure that mean population TWA data differences for the four-hour and full-shift sample durations equaled zero. This means there is no statistically significant difference between the four-hour and full-shift sample durations for these sampled populations. So, four-hour sample durations rather than full-shift samples can be utilized as a cost-effective sampling strategy to assess these entire worker populations which does not significantly affect sampling precision or accuracy.

The null hypothesis of equal population means is rejected at the 0.5 significance level for the welders' population. Approximately 95% all *p-values* produced *t statistics* not as extreme as the calculated *t statistics* if the null hypothesis is true. A 95% paired-samples confidence interval for $\mu_1 - \mu_2$ is given by the interval estimate (-5.0, -1.6) which does not include zero. In other words, $\mu_1 \neq \mu_2$. Thus, there is a statistically significant difference between four-hour sample durations and full-shift samples. In this case, four-hour samples cannot provide valid data to represent full-shift noise levels without significantly affecting sampling precision or accuracy.

Whenever decisions are made based on a hypothesis test, a Type I error or Type II error are the two mistakes that can be made. Since the significance level of .05 was determined by the researcher, the probability of making a Type I error was controlled. Unfortunately, since the sample size is fixed, the only way to reduce the chance of making a Type II error is to reject the null hypothesis more often which increases the chance of making a Type I error.

Noise Exposure Distribution and Peak Levels

Visual observation of the daily noise exposure histograms indicated no regular patterns or periods of noise levels above normal. A sample histogram is illustrated (in Appendix A, Figure A-2). Historical noise exposure data of the four target populations suggested that noise levels throughout the workshift are distributed evenly (Newport News Shipbuilding, 1992). Research (Brooks and Brunn, 1984) has shown that in environments where the exposure variability is uniform throughout the shift, and the peak exposure period is included in the sample, a four-hour sample duration can be used with negligible loss in precision.

Peak noise levels in the workplace could not be determined from the noise exposure data reports. The audio dosimeters used store the highest sound level

(L_{max} dB) value, averaged over a one second time period. This maximum sound level is indicated on the display by a solid L_{max} dB annunciator and on the noise exposure report. These maximum noise levels were not useful for the purpose of identifying or confirming peak noise periods of the workshift. Since the L_{max} values represent less than one second of data, these values are not displayed on the noise level histograms (which display a minute scale) and thus cannot be observed. Also, these L_{max} values may account for an instantaneous sound (e.g. dropping a piece of metal) which does not reflect a peak exposure period. However, careful review of the acquired noise histograms indicated no sustained abnormally high noise levels or peak exposure periods, suggesting no definite high risk exposure period.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

This study assessed the validity of utilizing four-hour continuous sample durations on the basis of whether they provided valid noise dosimetry data. Results of this study indicated no statistically significant difference among four-hour and full shift sample durations of mean daily TWAs for the burners' and chippers' target population as stated in the null hypothesis. There was a statistically significant difference among four-hour and full-shift samples of mean daily TWAs for the welders' target population. However, four-hour sample durations and subsequent data analysis could still be used as a valid, cost-effective sampling approach for this target population.

Four-hour sampling durations took into account noise exposure variability in the workplace for the entire shift as well as job cycle characteristics. This was accounted for by estimating the actual distribution of daily worker noise exposures and use of a predetermined tolerance for error. Monitoring of long-term exposures was accomplished efficiently and at lower costs with the use of four-hour samples, repeated a sufficient number of times so that the mean of the sampling distribution for each target population fell within the limits of sampling and analytical error. Once the error of the estimated mean was within acceptable limits, the population distribution of daily exposure levels can be estimated and inferred to unsampled members of a specified target population for a particular hazard.

Overall, the proposed four-hour sample strategy used in conjunction with the subsequent data analysis, provided valid data for estimating mean daily noise exposure levels without significantly affecting sampling precision or accuracy. Thus, a full-shift's noise exposure level was acquired with approximately half of the workshift being sampled which meets the objective of economic efficiency which is desirable for employers and can be used for noise exposure assessments, compliance purposes, record-keeping requirements, epidemiological studies, and as a cost-effective approach to better identify and protect employees. Since employers have the regulatory flexibility, as well as economic incentives for maximizing the efficiency of their Hearing Conservation Program, this sampling strategy will eliminate wasting time and resources oversampling a population.

Several recommendations can be made for future similar studies. First, increasing the sample size would improve the statistical validity as well as increase the benefit to the target populations from which the study results will be applicable. Secondly, it is recommended that prospective employers perform an assessment in terms of exposure variability uniformity throughout the workshift and peak exposure periods to determine whether four-hour sample durations may be appropriate. Finally, prospective workplaces should assess if four-hour sample durations can be used for other hazardous physical or chemical agents in the workplace.

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FOUNDRY

FLOOR PLAN

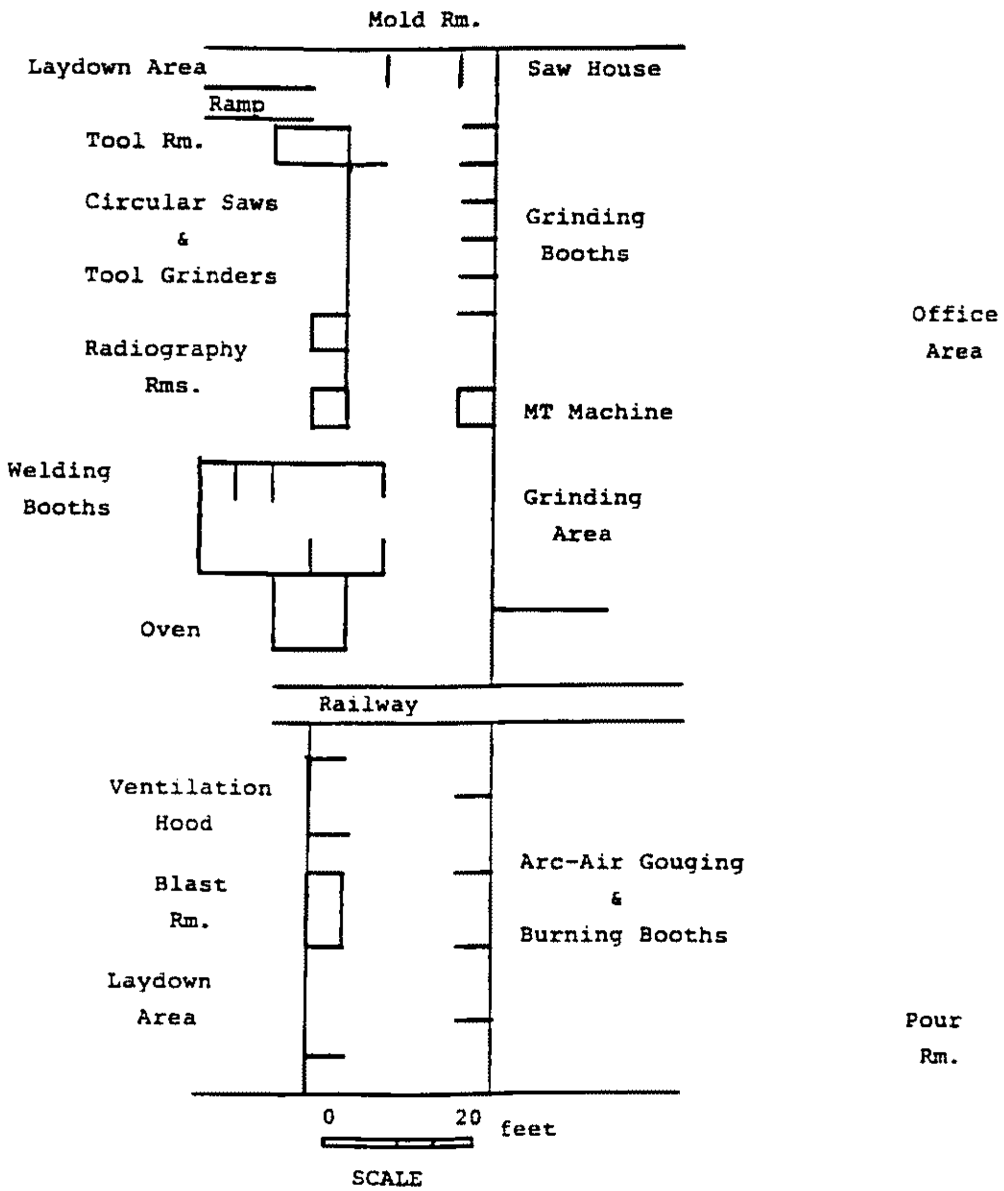

Figure A-1. Foundry Floor Plan

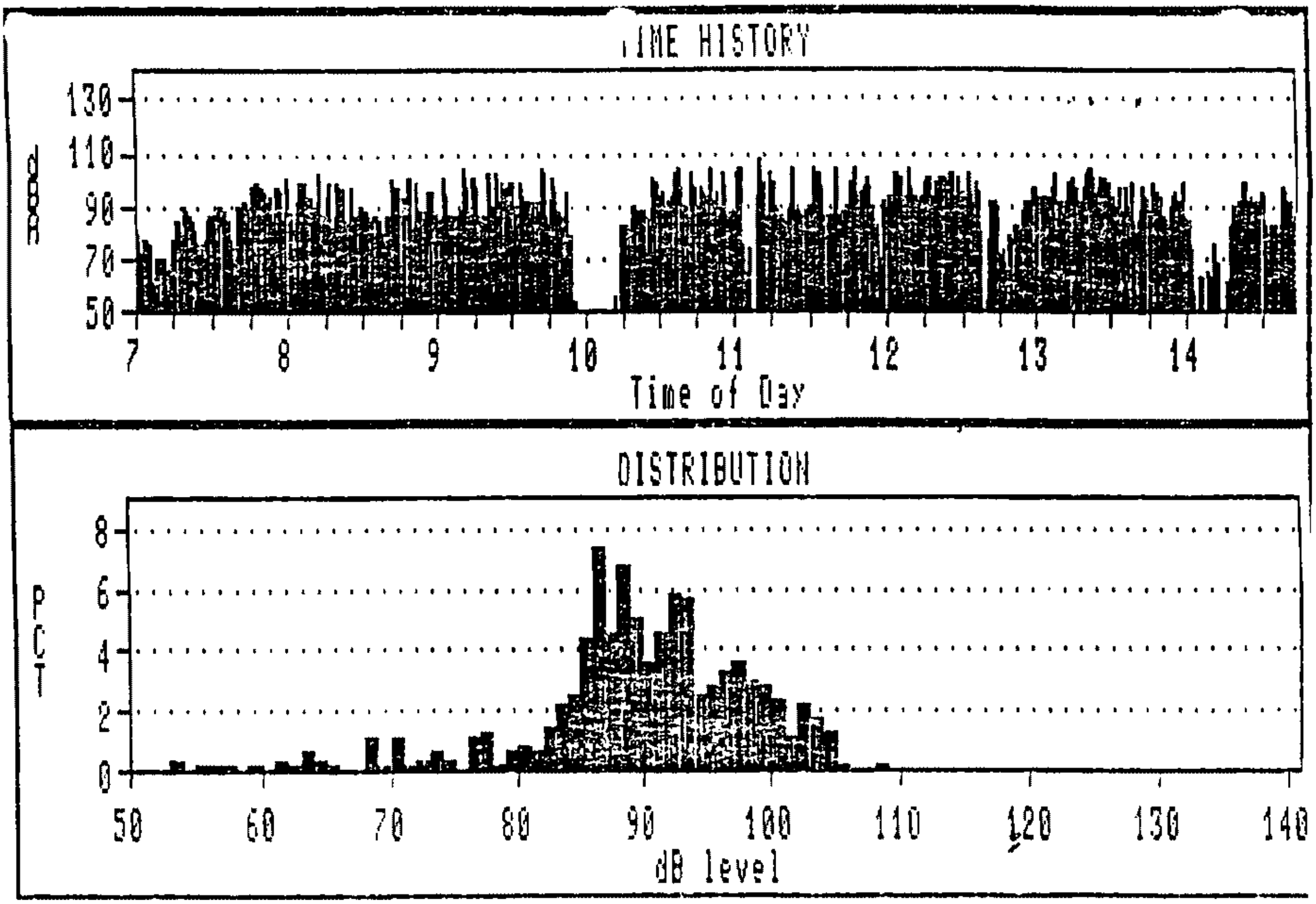

Figure A-2. Sample Noise Histogram

UPPER PERCENTAGE POINTS FOR t DISTRIBUTIONS

Upper-Tail Probability

df	0.40	0.30	0.20	0.15	0.10	0.05	0.025
1	0.325	0.727	1.376	1.963	3.078	6.314	12.706
2	0.289	0.617	1.061	1.386	1.886	2.920	4.303
3	0.277	0.584	0.978	1.250	1.638	2.353	3.182
4	0.271	0.569	0.941	1.190	1.533	2.132	2.776
5	0.267	0.559	0.920	1.156	1.476	2.015	2.571
6	0.265	0.553	0.906	1.134	1.440	1.943	2.447
7	0.263	0.549	0.896	1.119	1.415	1.895	2.365
8	0.262	0.546	0.889	1.108	1.397	1.860	2.306
9	0.261	0.543	0.883	1.100	1.383	1.833	2.262
10	0.260	0.542	0.879	1.093	1.372	1.812	2.228
11	0.260	0.540	0.876	1.088	1.363	1.796	2.201
12	0.259	0.539	0.873	1.083	1.356	1.782	2.179
13	0.259	0.537	0.870	1.079	1.350	1.771	2.160
14	0.258	0.537	0.868	1.076	1.345	1.761	2.145
15	0.258	0.536	0.866	1.074	1.341	1.753	2.131
16	0.258	0.535	0.865	1.071	1.337	1.746	2.120
17	0.257	0.534	0.863	1.069	1.333	1.740	2.110
18	0.257	0.534	0.862	1.067	1.330	1.734	2.101
19	0.257	0.533	0.861	1.066	1.328	1.729	2.093
20	0.257	0.533	0.860	1.064	1.325	1.725	2.086
21	0.257	0.532	0.859	1.063	1.323	1.721	2.080
22	0.256	0.532	0.858	1.061	1.321	1.717	2.074
23	0.256	0.532	0.858	1.060	1.319	1.714	2.069
24	0.256	0.531	0.857	1.059	1.318	1.711	2.064
25	0.256	0.531	0.856	1.058	1.316	1.708	2.060
26	0.256	0.531	0.856	1.058	1.315	1.706	2.056
27	0.256	0.531	0.855	1.057	1.314	1.703	2.052
28	0.256	0.530	0.855	1.056	1.313	1.701	2.048
29	0.256	0.530	0.854	1.055	1.311	1.699	2.045
30	0.256	0.530	0.854	1.055	1.310	1.697	2.042
40	0.255	0.529	0.851	1.050	1.303	0.684	2.021
60	0.254	0.527	0.848	1.045	1.296	1.671	2.000
120	0.254	0.526	0.845	1.041	1.289	1.658	1.980
∞	0.253	0.524	0.842	1.036	1.282	1.645	1.960

df	0.02	0.015	0.01	0.0075	0.005	0.0025	0.0005
1	15.895	21.205	31.821	42.434	63.657	127.322	636.590
2	4.849	5.643	6.965	8.073	9.925	14.089	31.598
3	3.482	3.896	4.541	5.047	5.841	7.453	12.924
4	2.999	3.298	3.747	4.088	4.604	5.598	8.610
5	2.757	3.003	3.365	3.634	4.032	4.773	6.869
6	2.612	2.829	3.143	3.372	3.707	4.317	5.959
7	2.517	2.715	2.998	3.203	3.499	4.029	5.408
8	2.449	2.634	2.896	3.085	3.355	3.833	5.041
9	2.398	2.574	2.821	2.998	3.250	3.690	4.781
10	2.359	2.527	2.764	2.932	3.169	3.581	4.587
11	2.328	2.491	2.718	2.879	3.106	3.497	4.437
12	2.303	2.461	2.681	2.836	3.055	3.428	4.318
13	2.282	2.436	2.650	2.801	3.012	3.372	4.221
14	2.264	2.415	2.624	2.771	2.977	3.326	4.140
15	2.249	2.397	2.602	2.746	2.947	3.286	4.073
16	2.235	2.382	2.583	2.724	2.921	3.252	4.015
17	2.224	2.368	2.567	2.706	2.898	3.222	3.965
18	2.214	2.356	2.552	2.689	2.878	3.197	3.922
19	2.205	2.346	2.539	2.674	2.861	3.174	3.883
20	2.197	2.336	2.528	2.661	2.845	3.153	3.849
21	2.189	2.328	2.518	2.649	2.831	3.135	3.819
22	2.183	2.320	2.508	2.639	2.819	3.119	3.792
23	2.177	2.313	2.500	2.629	2.807	3.104	3.768
24	2.172	2.307	2.492	2.620	2.797	3.091	3.745
25	2.167	2.301	2.485	2.612	2.787	3.078	3.725
26	2.162	2.296	2.479	2.605	2.779	3.067	3.707
27	2.158	2.291	2.473	2.598	2.771	3.057	3.690
28	2.154	2.286	2.467	2.592	2.763	3.047	3.674
29	2.150	2.282	2.462	2.586	2.756	3.038	3.659
30	2.147	2.278	2.457	2.581	2.750	3.030	3.646
40	2.123	2.250	2.423	2.542	2.704	2.971	3.551
60	2.099	2.223	2.390	2.504	2.660	2.915	3.460
120	2.076	2.196	2.358	2.468	2.617	2.860	3.373
∞	2.054	2.170	2.326	2.432	2.576	2.807	3.291

Table B-1. t Distribution Table