Field research on the assessment of community impacts from large weapons noise

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INTRODUCTION

Large weapons noise, which is often referred to as blast noise, is the noise produced by detonation of explosives and projectiles and by artillery and armor muzzle blast. These noise events are of short duration, typically a fraction of a second to a few seconds. The spectrum is rather broad, with acoustical energy typically concentrated at frequencies between 1 and 100 Hz. High-energy impulsive noise from military weapons can be very loud at distances of many tens of kilometers. Ground-to-ground propagation of blast noise is strongly influenced by atmospheric temperature and wind structure. Experiments have shown variation of more than 50 dB (Schomer et al. 1978) in received noise levels, all factors held constant except for weather. A data range of 50 dB implies a standard deviation in received noise level on the rough order of 8 dB (assuming the data lie predominantly within 3 standard deviations about the mean) due to changes in atmospheric meteorological parameters that influence sound propagation.

Conventional noise impact assessment procedures are based on the "equal energy hypothesis", i.e. that annoyance response depends on the total sound exposure dose averaged over 1 year, without regard to details of how that sound energy is distributed in time or on the magnitude of individual noise events. There is no difference between 100,000 noise events spread over a year or a small number of high-energy events all occurring in 1 day. An example of this problem is given in Figure 1, which shows peak and average annual contours for 100,000 small events occurring in one year and 20 large events occurring sporadically throughout the year. The equal energy principle is an efficient annoyance predictor for traffic noise, where each day's exposure consists of hundreds of sound events that are of similar magnitude from day to day. With so many events, the brain fails to retain a memory of individual events (Björkman 1991) and only remembers the impression of the general din. For blast noise, the sounds are intermittent, with a few noisy days typically interspersed within a larger number of quiet days. The noise level is highly variable because of the large range of sound energy emission from various weapons and as previously stated, can vary over a range of 50 dB due to variation in meteorological conditions. Experience strongly indicates (Pater 1976) that noise complaints correlate quite strongly with blast noise level; though it is not known to what extent complaints lodged by individuals represent general community annoyance. It is hypothesized that dynamic annoyance response to noise events may depend strongly on the instantaneous noise level, and may have bearing on long-term community annoyance response. Luz and others (Luz et al. 1994) found that 5-point-scale annoyance ratings to individual blasts by known complainants correlated quite strongly with blast level.

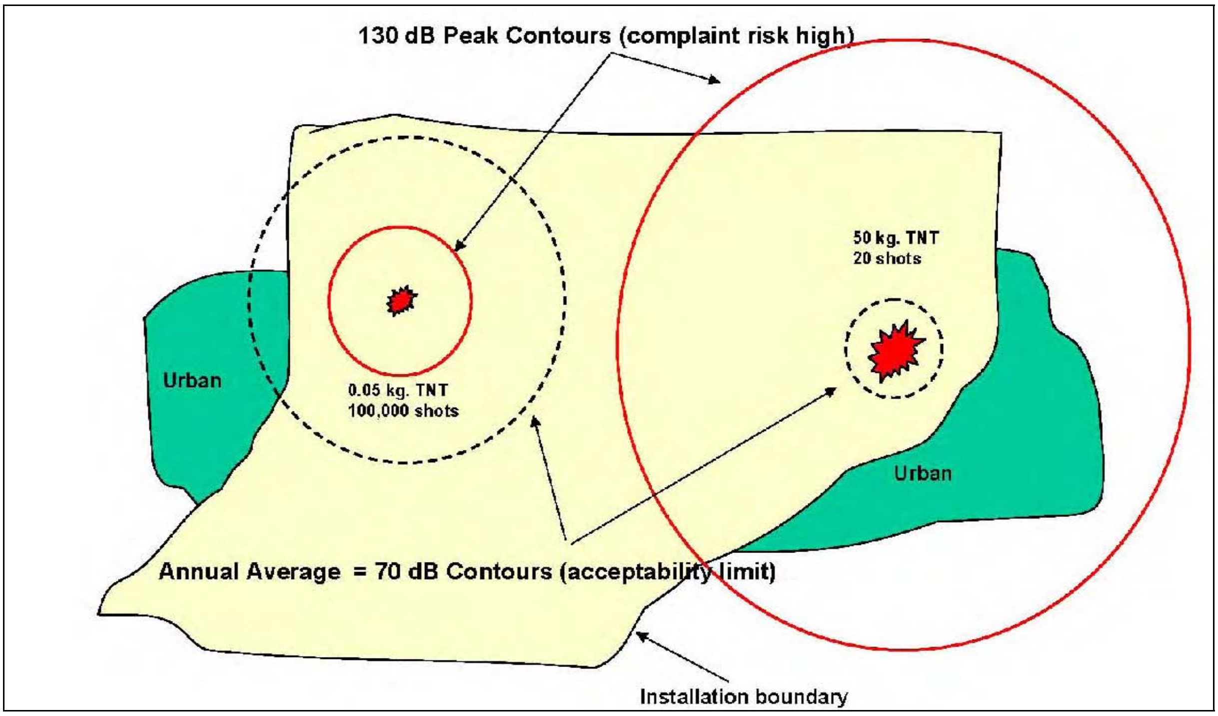

Figure 1: Peak and average annual contours for 100,000 small events (left) occurring in one year vs. 20 large events (right) occurring sporadically throughout the year

Current blast noise assessment procedures do not fully meet the military's noise impact management needs. In the United States, noise impacts are typically assessed in terms of the annual time-averaged sound exposure level to predict the percent of the community that is highly annoyed. This has proven to be unsatisfactory for infrequent and highly variable blast noise events. Individual event noise levels from military testing and training activities can be loud enough to elicit negative community response, yet when event sound exposures are averaged over a year's time, the time-averaged level may meet established acceptability criteria. That is, the average C-weighted Day Night Level (CDNL) contours may predict an acceptable amount of community annoyance in areas that routinely receive a large number of blast noise complaints. Citizens and decision makers often ask for noise descriptors that describe what they actually hear; they find cumulative or time-averaged noise level metrics to be confusing and irrelevant, perhaps even misleading or disingenuous. Department of Defense stakeholders are using a revised interim methodology in which average level criteria are supplemented by individual event peak noise level criteria that indicate noise complaint risk as described in Army Regulation 200-1 (2007).

Further guidance is required since cumulative measures, such as the yearly average CDNL do not account for change in response due to the intermittency of testing and training activities that produce blast noise, and single event criteria do not account for aspects such as number and timing of noise events. It is also unknown what extent complaints made by individuals are a valid indicator of community attitude. To guide selection of more reliable impact assessment methodology the U.S. Army Engineering and Research Development Center (ERDC) and Strategic Environmental Research and Development Program (SERDP) have launched a series of field studies aimed at enhancing the understanding of human response to military blast noise to develop a methodology to accurately predict human response to blast noise, and to recommend guidelines that can be universally used to protect military training and testing capability as well as minimize noise impacts on residents of military installations and adjacent communities. These 5 field research projects include: 1) "Sleep

Disturbance" from blast noise to determine preferred times to conduct nighttime training, 2) "Complaint Risk" from blast noise to recommend improved guidelines to better manage testing and training firing schedules, 3) "In-Situ" diary studies with individual residents who experience blast noise to measure near-real-time in-home annoyance responses, 4) "General Survey" studies with community members who experience blast noise to measure community response and how it changes with time and noise environment, and 5) "Correlation of Complaints and Annoyance" to determine the interrelationship between blast noise level, complaints, and annoyance.

METHODS

Study 1. Sleep Disturbance

Training during the hours of darkness is a necessity for the military and often a common cause for complaints as seen in Europe and North America. For example, Rylander and Lundquist (1996) found that of the 399 Swedish citizens surveyed living in the vicinity of eight ranges, half chose the evening and about a third chose the night as the time of day when heavy weapons noise was most annoying. About 10 % stated that shooting made it difficult to fall asleep at night and about the same percentage stated that shooting awakened them. In the United States evidence of the problem of nighttime training noise is in the numerous restrictions imposed at most testing and training installations. Although some information about sleep disturbance from heavy weapons blasts has been available from a laboratory study with tape-recorded 120 mm tank gun blasts by Griefahn (1989), there had never been a field study of sleep disturbance among people routinely exposed to the sounds of tank gunnery training. This is likely due to the difficulty in finding an installation willing to sponsor such a field study and because periods of intense night firing at any one range are sporadic.

In order to better understand the impact of blast noise on residents living near U.S. military installations a field study was conducted by Engineering Research and Development Center in 2004. To ensure the highest possibility of success in the field study, it was preceded by a laboratory study of actimeter reliability using reproduced tank gun blasts which approached (but did not meet) the full spectrum of a real tank gun blast (Luz et al. 2008). It was important to have the highest possible reliability in the measurement instrumentation, which was limited to a wrist-worn actimeter with a button to signal awakening. Following this successful equipment "shakedown" and "dry run," the field test was conducted among 33 subjects living between 1.8 and 8.9 km from 120 mm tank gun firing points and exposed to blasts during their sleeping hours in the range of 102 to 124 dB linear peak sound pressure level (SPL). This paper has been submitted for publication (Nykaza et al.) and further details can be found in an ERDC technical report (Nykaza et al. 2006).

There were two important findings to come out of this research. It was found that residents were less likely to awaken from blast noise disturbances during the middle of the night (between midnight and 0200) and that the threshold of awakening during the shoulder hours, which was between 2100 and 2300 and between 0200 and 0400 hours, was approximately 115 dB linear peak SPL. The first finding was significant because it contradicted the current guidelines that all nighttime firing be conducted up until midnight and ceased thereafter. The second finding showed agreement with Pater's complaint risk criteria (Pater 1976) which states that there is a moderate risk of complaints when received blast noise events fall in the range of 115 to 130 dB linear peak SPL.

Study 2. Complaint Risk

The complaint risk study, which is ongoing, has two purposes. The first is to improve the performance of a real time blast noise monitoring system which has been operating for over 15 years at a testing installation. The second is to improve the ability to predict complaints from the noise measurement data generated by this system.

Improving the blast noise monitoring system had to be completed before the second purpose could begin. Three technical improvements were made. 1) A time drift in the noise monitors and server was corrected. Each noise monitor was found to have a unique time drift, which was a consequence of the clock time drift on the server that updated the clocks on the noise monitors each night. The original program on the server often malfunctioned and did not download or update each clock on every monitor each night. This problem was solved by installing a new server, writing a new downloading software program, and synchronizing to the server to the National Institute of Standards and Technology (NIST) time server. 2) Algorithms were developed to determine the likely source location and shot time of the improperly time-stamped data (Nykaza & Donaldson 2007) and simpler algorithms were implemented to determine the likely source and location of data gathered after the implementation of the new server and download program. These algorithms facilitated identification of the noise sources that most likely elicited a given complaint among many firings and false triggers that might occur on a given day. 3) An additional 33 noise monitors were added to original 18 monitors used in the 2001 study in order to cover the 64 by 64 km study area.

For each complaint received by the installation, the sound level at the complainant's home was estimated by interpolating or extrapolating on the basis of geometrical spreading from the received levels of noise monitors located within a 10 km radius of the complainant. The importance of the technical improvements was underscored by success in linking complaints with measured levels. In comparison to an earlier study conducted at the same installation in which only 35 % of complaints could be linked to measured levels (Luz 2001), 90 % were linked in the current effort. Further details on the preliminary results of this study can be found in a paper accepted for publication (Nykaza et al. 2008a).

Thus far, there are three statistically-significant findings: 1) first time complainants were linked to a higher level than repeat complainants as seen in Table 1, 2) complainants who were complaining about a single loud noise event were linked to a higher level than complainants who complained about multiple events as seen in Table 2, and 3) complainants who complained about noise events that occurred during the day were linked to a higher level than complainants during the evening as seen in Table 3. As previously mentioned, this study is on going and the results presented here are based upon a mere 40 complaints. At the time of the writing of this paper there are an additional 114 complainants yet to be analyzed which should provide the statistical strength of subsequent analyses. This study also finds agreement with the Pater (1976) complaint risk criteria and it is expected that future analyses will be able to define the importance and interaction of the number of events, level of events, and timing of events.

Table 1: Comparison of first complainants verses repeat complainants with Mann-Whitney nonparametric test

	Sample Size	Median Un-weighted Peak Level (dB)
First Time Complainants	26	120
Repeat Complainants	10	107

Table 2: Comparison of single-shot complaints verses multi-shot complaints with Mann-Whitney nonparametric test

	Sample Size	Median Un-weighted Peak Level (dB)
Single Shot Complaints	8	125
Multiple Shot Complaints	18	117.5

Table 3: Comparisons of the time of day complaints were filed with Mann-Whitney nonparametric test

	Sample Size	Median Un-weighted Peak Level (dB)
Complaints During Working Hours (7 AM to 5 PM)	20	121
Complaints During Evening Hours (5 PM to 10PM)	6	111.5

Study 3. In-Situ

An upcoming In-Situ study, with an estimated start date of 2009, will examine how people respond to individual blast events in near real-time. A cross-sectional sample of residents who live near military installations will be selected to participate. Microphones and accelerometers will be set up outside and inside residents' homes to document the stimulus (i.e. blast noise, vibration, rattle) and personal digital assistants (PDAs) will be used to record the residents' response. Based on experience from a pilot study involving four persons routinely exposed to blast noise in their homes (Luz et al.1994) and International Commission on Biological Effects of Noise recommendations (Fields et al. 2001), subjects will be asked to rate the annoyance of each noticed event on a five-point scale (not annoying to extremely annoying). The study will be conducted over a 9-month period at two installations, involving approximately 25 subjects at each site to capture a statistically significant data set and to sample the range of variation in received noise level due to seasonal weather changes.

The strength of the In-Situ study is detailed data regarding the variation of subject response to variable stimulus levels (dose response functionality). This study will incorporate research procedures commonly used in diary studies to mitigate the extent to which the increased awareness and attention to blast events may skew their responses.

Digitized measurements of the time history of the blasts taken outdoors in the vicinity of the subject's home will allow for comparisons between various predictors of blast noise annoyance suggested by different national regulations and/or researchers, such as C-weighted sound exposure level (SEL), A-weighted SEL, A-weighted SEL adjusted for the difference between C and A (Vos 2001), C-weighted SEL adjusted for the difference between C and A (Buchta 1996), peak level, or various combinations of weighted 1/3 octave bands. Measurement outdoors will ensure that all significant blasts will be registered, including the ones which the subjects do not notice.

To further understand each subject's detectability threshold, outdoor-to-indoor house transfer functions will be obtained for each residence. In addition to the transfer function, vibration measurements of each blast will be taken from a wall, window and corner of the side of the house facing the range. Based on the 1994 pilot study, it is anticipated that peak vibration levels from these three measurements will be highly correlated. Statistical analyses (e.g. multiple correlation) will be used to determine whether a combination of sound and vibration measurements improves the prediction of annoyance beyond the prediction based on sound alone.

Study 4. General Survey

An upcoming General Survey study (estimated start date of 2009) will be unique in that the variation with time of the noise environment will be accurately known throughout the community by co-locating this protocol with the In-Situ study. Community response will be measured at 3 intervals during the study via social survey. By contrast, previous blast noise surveys conducted in the U.S. correlated a single value of the annual time-averaged noise level with a one-time annoyance survey. These studies took place in the 1980's at Fort Lewis, Washington (Schomer 1985) and at Fort Bragg, North Carolina (Schomer 1982). Lessons learned from other surveys conducted in the vicinity of heavy weapons ranges, such as the Grafenwoehr Training Area in Germany (Buchta et al. 1986) and Holsworthy Artillery Range in Austrlia (Bullen et al. 1991) have been incorporated into the survey questions along with the ICBEN recommendations.

The General Survey utilizes a questionnaire that will be administered several times in coordination with the In-Situ Protocol, but will sample a different set of subjects in the population each time. Professional interviewers will conduct in-person interviews at randomly selected households in the study areas. A cross-sectional representative sample (different households each time) will gauge the level of response among community residents at each point in time, and a panel sample of households (the same households surveyed each time) will illuminate changes in household response over time. The survey will be conducted at approximately 3-month intervals with the representative cross-sectional samples of households, and at approximately 6-month intervals with the panel sample of households. Unlike similar past studies in this category, exposure will be extrapolated and interpolated from measurements made along a grid and not projected by computer models. With the opportunity afforded by direct measurement, it should be possible to track the effect of short term changes in average exposure in relation to changes in annoyance.

Study 5. Correlation of Complaints and Annoyance

A study of the correlation between the annoyance of individual complainants and general community annoyance is scheduled to begin in the summer of 2008 at the same installation as the complaint risk study above. One of the primary goals of this research is to determine if individual complainants are representative of the general community annoyance. It is possible that unnecessary testing and training restrictions have been implemented because of the complaints of a few noise-sensitive complainants. On the other hand, complaints may be a useful indicator of the general community response. The relationship between complaints and community response will be tested by surveying residents in the vicinity of recent noise complaints within a week of a complaint. The survey questions designed in the General Survey study will be used for uniformity between tests, and the surveying area will include a random sample of 10 residents living within the vicinity of complainants. Of the five studies, this is the riskiest, since the research team has no control over the pattern of firing, the density of houses around the complainant, the number of people who will be home at the same time as the complainant or the willingness of potential interviewees to be interviewed.

CONCLUSIONS

The objective of the research outline above is to collectively enhance the understanding of human response to blast noise, and to recommend guidelines that can be universally applied and used to protect military training and testing capability as well as minimize noise impacts on residents of military installations and adjacent communities.

The multi-study approach is already yielding practical results for the management of noise from heavy weapons training. These include: Low likelihood of awakening when the outdoor level of blasts is below 115 dB peak SPL, less likelihood of awakening to blasts at any level between the hours of midnight and 0200, and importance of predicting complaints on the basis of sound level, number of events, and timing of events rather than on sound level alone.

As these studies continue, information on whether some other measure besides the C-weighted SEL and the CDNL can yield better predictions of impact on the community is anticipated. Further information on the In-Situ, General Survey, and Complaint Annoyance Correlation studies can be found in two Pater et al. papers (2007).

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