construction
engineering
research
laboratory

U.S. ARMY CORP. LIBRARY

INTERIM REPORT N-61
October 1978

PREDICTING NOISE IMPACT IN THE VICINITY OF
SMALL-ARMS RANGES

For Reference

Not to be taken from this room

by
J. McBryan

Approved for public release; distribution unlimited.

The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official indorsement or approval of the use of such commercial products. The findings of this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

*DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED
DO NOT RETURN IT TO THE ORIGINATOR*

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-IR-N-61	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PREDICTING NOISE IMPACT IN THE VICINITY OF SMALL-ARMS RANGES		5. TYPE OF REPORT & PERIOD COVERED INTERIM
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. McBryan		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. Box 4005 Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 4A76270A896-03-005
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE October 1978
		13. NUMBER OF PAGES 30
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Copies are obtainable from National Technical Information Service Springfield, VA 22151		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) day/night average sound level (L_{dn}) sound-exposure level (SEL) calculation prediction		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report describes the data collection and reduction methods used to determine equations to provide sound-exposure level (SEL) vs distance curves for impulsive noise at Army small-arms ranges. It also describes (1) the method for calculating SEL per round at any distance for M14 and M16 rifles, a .45 caliber pistol, and a M60 machine gun, and (2) the tabular procedure for predicting the day/night average sound level (L_{dn}) at Army small-arms ranges. This in turn allows for prediction of noise impacts on or adjacent to Army installations.		

FOREWORD

This research was conducted for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A762720A896, "Environmental Quality for Construction and Operation of Military Facilities"; Task 03, "Pollution Control Technology"; Work Unit 005, "Development of the Integrated Installation Noise Contour System." The QCR number is 3.01.007. Mr. F. P. Beck, DAEN-MPE4, is the OCE Technical Monitor.

The work was performed by the Environmental Division (EN), U.S. Army Engineer Construction Engineering Research Laboratory (CERL). Dr. R. J. Jain is Chief of EN.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

DD FORM 1473	1
FOREWORD	3
LIST OF TABLES AND FIGURES	5
1 INTRODUCTION	7
Background	
Purpose	
Approach	
Mode of Technology Transfer	
2 DATA COLLECTION	7
Close-in Measurements	
Far-Distance Measurements	
3 DATA REDUCTION AND RESULTS	10
Data Reduction	
Frequency Plots	
Results	
4 NOISE IMPACT PREDICTION METHOD	17
5 CONCLUSIONS AND RECOMMENDATIONS	17
APPENDIX A: Presentation of Data	19
APPENDIX B: Tabular Prediction Procedure	28

TABLES

Number	Page
1 Summary of Measurement Sites and Distances	8
2 Summary of Laboratory Data Reduction at Mid and Far Distances	14
3 Summary of Close-in, Single Round Measurements	17
B1 Number of Rounds vs $dB_{N_{TOT}}$	28
B2 Distance vs dB_{dist}	29
B3 dB_{dist} vs Distance	29

FIGURES

Number	Page
1 Close-in Measurements	9
2 Typical Equipment Setup	10
3 Equipment Used During Measurements	11
4 Typical Far-Distance Measurement Setup	12
5 Spectral Content Setup	13
6 Typical M14 Grouping	15
7 Typical M16 Grouping	15
8 Spectral Record of M16 Rifle (less than 50 m)	15
9 Spectral Record of M16 Rifle (greater than 300 m)	15
10 SEL Per Round vs Distance	16
A1 Fort McClellan: Range 22	20
A2 Fort Leonard Wood: Range 33	22
A3 Fort McClellan: Range 51	23
A4 Fort McClellan: Range 13	23
A5 Fort McClellan: Range 25	24
A6 Fort McClellan: Range 19	25

FIGURES (cont'd)

Number	Page
A7 Fort Knox: Record Range	26
A8 Fort Lewis: M60 Range	27
B1 Contour of Small-Arms Firing Range	30
B2 Planning L_{dn} as a Function of N_{TOT} and Distance	30

PREDICTING NOISE IMPACT IN THE VICINITY OF SMALL-ARMS RANGES

1 INTRODUCTION

Background

Department of Defense (DOD) Technical Manual TM 5-803-2, *Environmental Protection: Planning in the Noise Environment* requires that noise-sensitive facilities be sited in low-noise areas. The standard by which both DOD and the Environmental Protection Agency (EPA) measure an activity's noise impact is the day/night average sound level or L_{dn} .¹

In order to predict L_{dn} levels of existing or proposed small-arms ranges and/or to determine appropriate locations for noise-sensitive land uses with respect to existing small-arms ranges, it is necessary to be able to predict the L_{dn} generated by small-arms ranges as a function of distance. To do this, the following must be determined:

1. The sound energy in decibels (dBs) or sound exposure level (SEL)* produced by each round fired.
2. The number of rounds fired.
3. Whether the rounds are fired during the day (0700 to 2200 hours) or during the night (2200 to 0700 hours).

Purpose

The overall objective of this study is to provide data for the prediction of noise impacts on or adjacent to Army installations.

The purpose of this report is to provide SEL vs distance curves for existing small-arms ranges, and to provide the means by which L_{dn} levels for small-arms ranges can be predicted and used by Army master planners, facility engineers, and environmental officers as guid-

¹Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, 55019-74-004 (USEPA, March 1975); *Environmental Protection: Planning in the Noise Environment*, TM 5-803-2 (Department of Defense [DOD], 15 June 1978); *Guidelines for Preparing Environmental Impact Statements on Noise*, Committee on Hearing, Bioacoustics, and Biomechanics (CHABBA) Working Group 69 Report (National Academy of Science, February 1977).

*SEL is the time integral of the square of the sound pressure using the A-frequency weighting over the time period of the event.

ance in selecting sites for new small-arms ranges near existing housing or noise-sensitive land use areas, or sites for new housing adjacent to existing small-arms ranges.

Approach

A literature search was conducted to identify the existing SEL data base. Tests were then developed to extend and supplement this data base. Noise levels of existing small-arms ranges were measured at distances equivalent to the probable sites of family housing or other noise-sensitive land uses. Noise levels of typical small arms in the Army inventory—M16 and M14 rifles, the .45 caliber pistol, and the M60 machine gun—were measured close-in (20 to 50 m) at a number of angles to test the directionality of the weapons; mid-distance (100 to 200 m) and far distance (approximately 1500 m) levels were also measured (Chapter 2).

Data were analyzed to determine the typical SEL per round at a known distance (Chapter 3). Chapter 4 outlines the method used to predict noise levels in the vicinity of a small-arms range. Appendix A presents the results of the laboratory data reduction and the layout of each small-arms range measured by this investigation. Appendix B presents the tabular procedure recommended for use by Army personnel for selecting suitable sites for new small-arms ranges or new noise-sensitive land uses in the vicinity of existing small-arms ranges.

Mode of Technology Transfer

Results of this study will be issued as a TAG letter and incorporated into TM 5-803-2, *Environmental Protection: Planning in the Noise Environment*.

2 DATA COLLECTION

The literature search conducted by this investigation revealed considerable data regarding hearing-conservation criteria at distances less than 50 m, but little information on the SEL values of typical Army small weapons at distances greater than 300 m. It was necessary, therefore, to extend and supplement the available SEL data base.

Noise measurements were made at existing small-arms ranges at Fort Leonard Wood, MO; Fort McClellan, AL; Fort Knox, KY; and Fort Lewis, WA. Table 1 lists the site each measurement, the weapon measured, the distance at which each measurement was made, and the orientation of the measurement equipment.

Table 1
Summary of Measurement Sites and Distances

Installation	Weapon	Distance	Orientation
Fort Lewis	.45 cal	25 m	Rear and left side of single rifleman
	M16	25 m	0°, 45°, 90°, 135°, 180°; single rifleman
	M14	25 m	Rear of single rifleman
	M60	25 m	Rear of single rifleman
	M16	50 m	45°, 90°; single rifleman
	M16	50 m	Right side of single rifleman
Fort McClellan	M60	90 m	Rear of firing line
	.45 cal	100 m	Rear of firing line
	M16	100 m	Rear of firing line
Fort Knox	.45 cal	120 m	Left side of firing line
		180 m	
Fort Leonard Wood	M16	200 m	Rear of firing line
Fort McClellan	.45 cal	200 m	Right side of firing line
Fort Lewis	M60	200 m	Rear of firing line
Fort McClellan	.45 cal	275 m	
Fort Leonard Wood	M16	300 m	Rear of firing line
	M60	350 m	Rear and right of firing line
Fort McClellan	M16	375 m	Rear of firing line
	M16	400 m	Right side of firing line
		1300 m	Rear and right of firing line
Fort Lewis	M16	1700 m	Rear of night fire range

Two measurement techniques were used: one measured noise levels 25 to 50 m from the weapon to determine the weapon's typical directivity pattern, i.e., whether there was more sound to the left or right than to the rear of the weapon. The second technique measured noise where houses would be normally located, i.e., 100 to 1500 m from the range.

Close-in Measurements

Close-in measurements were made at Fort Lewis at 25 to 50 m and at angles of 0°, 45°, 90°, and 180°, as shown in Figure 1. A single rifleman fired upon command; each round was separated by at least 3 sec from the previous round. Measurements were tape recorded for later analysis. Peak levels recorded in the field were listed by the investigating team on a data sheet.

A B&K 2209 impulse precision sound-level meter with an extension rod connected to a B&K-type 4149 1/2-in. microphone protected by a 1/2-in. windscreen was used at the close-in measurement station. Tape recordings were made from the AC output of the sound-level meter through a QCJA attenuator to the mixer input of a Nagra DJ tape recorder. A calibration tone was placed at the beginning of each reel of tape using a B&K 4220 pistonphone. Calibration was performed at the beginning and end of each measurement period. At the beginning of each measurement period, the prevail-

ing windspeed and direction was noted on the data sheet; windspeed never exceeded 10 mph (11 kmh) during any measurement period. Because previous researchers² reported that different microphone orientations could produce varying values when measuring very close to weapons, three different microphone orientations were used in this investigation. The microphone angle of incidence of the sound wave during measurements was 0°, 45°, and 90°. Subsequent data analysis showed that microphone angle of incidence is not a significant factor at the distances used for these measurements. Figure 2 illustrates a typical measurement setup. Figure 3 is an expanded view of equipment used to make the tape recordings.

Far-Distance Measurements

At each range visited by this investigation, the range safety officer was interviewed to determine the number of rounds fired per exercise, as well as to brief the CERL investigating team on the location of the firing points and the pattern of firing. The total number of rounds fired per visit was determined, as well as the number of rounds fired in each burst by each position. Measurement sites were chosen to the rear or side of

²Garinther, George R., *Transducer Techniques for Measuring the Effect of Small Arms' Noise on Hearing*, TM-11-65/ADA806921L (U.S. Army Human Engineering Labs, 1965).

Figure 1. Close-in measurements.

the ranges at distances ranging from 100 to 1500 m. Peak levels and A-weighted sound levels were tabulated for later analysis and tape recordings were made. The noise monitoring setup was essentially the same as that used for close-in measurements, with the addition of a 10 m microphone extension cable from the sound-level meter to the microphone extension rod, and a CERL Model 270 noise monitor connected to the output of the sound-level meter.³ CERL noise monitor results

³P. D. Schomer et al., *True Integrating Environmental Noise Monitor and Sound Exposure Level Meter, Volume 1: Users Guide*, Technical Report N-41 (U.S. Army Engineer Construction Engineering Research Laboratory [CERL], May 1978).

were printed out on the Model 270's associated printer; these results were later used to verify the tape recordings in the laboratory. Figure 4 illustrates a typical far-distance measurement setup.

All ambient noise levels were at least 10 dB below the measurement data. Wind noise was insignificant because windspeed at all locations was less than 11 kmh.

Appendix A presents the site layout of each range at each installation, raw data sheets listing the number of rounds per burst and number of rounds per exercise, and raw data from the laboratory analysis.

Figure 2. Typical equipment setup.

3 DATA REDUCTION AND RESULTS

Data Reduction

Data collected by the CERL investigating team were reduced to determine the noise level generated (in L_{dn} form) at small-arms ranges measured during this study. Eq 1 is a formal definition of L_{dn} :

$$L_{dn} = 10 \log_{10} \left[\int_{\text{day}} \left(\frac{p(t)}{p_0} \right)^2 dt + 10 \int_{\text{night}} \left(\frac{p(t)}{p_0} \right)^2 dt \right] - 49.4 \quad [\text{Eq 1}]$$

where

$p(t)$ = instantaneous pressure
 p_0 = reference pressure
 $49.4 = 10 \log_{10}$ (number of seconds in a day)
 $= 10 \log_{10}$ (86400)
 t = time

To compute for rifle fire only, the following equation is used:

$$L_{dn} = 10 \log_{10} \left[\sum_{i=1}^{N_d} \int \left(\frac{p(t)}{p_0} \right)^2 dt + 10 \sum_{j=1}^{N_n} \int \left(\frac{p(t)}{p_0} \right)^2 dt \right] - 49.4 \quad [\text{Eq 2}]$$

where

N_d = rounds per day
 N_n = rounds per night

To compute the sound-exposure of a blast the following equation is used:

$$SE = \int p^2(t) dt \quad [\text{Eq 3}]$$

where

SE = sound exposure
 SE' = normalized sound exposure

Let $SE' = SE - 10 \log_{10} p_0^2$; the sound-exposure level of rounds per day and per night can now be computed by using the following equations:

Figure 3. Equipment used during measurements.

$$L_{dn} = 10 \log_{10} (N_d SE' + 10 N_n SE') - 49.4 \quad [\text{Eq 4}]$$

$$= 10 \log_{10} SE' (N_d + 10 N_n) - 49.4$$

$$L_{dn} = SEL_{rd} + 10 \log_{10} (N_d + 10 N_n) - 49.4 \quad [\text{Eq 5}]$$

(Since $SEL_{rd} = 10 \log_{10} SE'$ and
 $\log a \times b = \log a + \log b$.)

where

SEL_{rd} = sound-exposure level per round

For small-arms range fire, Eq 5 reduces to:

$$L_{dn} = SEL_{rd} + 10 \log_{10} (\text{number of rounds per day} \\ + 10 [\text{number of rounds per night}]) - 49.4 \quad [\text{Eq 6}]$$

Similarly, the SEL per round can be determined by using the following equation:

$$SEL_{rd} = SEL_{\text{total number of rounds}} \quad [\text{Eq 7}]$$

$$- 10 \log_{10} (\text{total number of rounds}).$$

SELs for the total number of rounds of a burst of fire were determined from tape recordings or by means of the CERL Model 270 noise monitor. Eq 7 was then applied to these quantities to determine the SEL per round for each noise burst or noise event.

Figure 5 illustrates the analysis setup in the laboratory. The tapes were played back on a Nagra DJ tape recorder and the signal sent into three systems: an audio monitor, a spectrum analyzer, and the CERL

Figure 4. Typical far-distance measurement setup.

Model 270 monitor. The audio monitor (an ordinary amplifier driving a speaker) registered voice commands recorded on the range such as "watch your lane. . ." or "ready with a 5-round magazine. . ."; this provided a record of which firing table was being measured. A Federal Scientific Spectrum Analyzer (UA14A) was used to determine the frequency contribution of the rounds. Two oscilloscopes were used with the analyzer; one showed the blast as it appeared in real time and the other showed the spectral content. A camera recorded spectral-content plots. The vertical scale (dB) and the frequency range were recorded along with the blast sequence number on each photo. The CERL Model 270 noise monitor was used in the single event mode to obtain the SEL of the burst.

Eq 7 was used to calculate the average SEL per round from the SELs for the total number of rounds. Field trip records were surveyed to determine the number of rounds fired for each burst of noise. These noise events had several different meanings:

1. For the pistol noise, there was a definite schedule of rounds (the firing order number). Some had seven rounds per order, some had three, etc.
2. For M16 rifle fire, 10 rounds were typically issued to each rifleman. Firing continued until all rounds were finished. The total number of rounds fired equalled the number of riflemen on the firing line times the number of rounds per magazine.

Figure 5. Spectral content setup.

3. For M60 machine guns, the total number of rounds equals the number of rounds per belt of ammunition times the number of belts used per position per noise event times the number of firing positions.

Table 2 gives the SEL per total number of rounds, the number of rounds for that noise event, and the corresponding SEL per round determined from the data analysis.

Table 2
Summary of Laboratory Data Reduction at Mid and Far Distances

Weapon	Installation	Distance	Total No. Rounds	No. Rounds/ Burst	SEL/ Burst	SEL/ Round
M16	McClellan	100 m	780	156	98.2-100.4	76.2-78.4
M16	McClellan	400 m	468	156	77.8 - 83.7	57.8-61.7
M60	McClellan	90 m	5625	625	101.0-104.0	73.2-76.2
M60	McClellan	350 m	1150	575	93.3 - 94.3	65.7-66.7
M16	McClellan	375 m	1176	147	75.9 - 81.3	54.2-59.6
M16	McClellan	1300 m	147	147	75.5	53.8
.45 cal	McClellan	100 m	2750	varied	N/A	75.4-76.9
.45 cal	McClellan	275 m	2200	varied	N/A	60.2-62.5
.45 cal	McClellan	100 m	2200	varied	N/A	64.9-67.4
.45 cal	Knox	180 m	1200	varied	N/A	69.2-70.2
M16	Wood	200 m	2304	144	82.2 - 85.4	60.6-63.8
M16	Wood	300 m	2160	144	73.8 - 83.1	52.2-61.5
M60	Lewis	200 m	N/A	varied	N/A	59.2-66.2

Frequency Plots

Figure 5 also illustrates how the camera was used to record the spectral content of typical rounds. All records were made at the same frequency range (0 to 10 kHz). These photographic records enabled the CERL investigating team to estimate the typical spectral peaks of each type of weapon, and yielded some indication of the attenuation of the sound with distance. When the photographs were sorted into groups of like shape, it became apparent that the M14 rifle and the M60 machine gun records differed slightly from those of the M16 rifle and the .45 caliber pistol. Figures 6 and 7 are typical of these two groupings. The M60 and M14 show a predominant spectral peak in approximately the 400 Hz range. In contrast, the M16 rifle and the .45 caliber pistol have a spectral peak close to 1000 Hz. Moreover, the M16 and .45 cal have a relatively lower peak amplitude than the others; they also appear to be more "broad banded." The M14 and M60, which had larger rounds in terms of charge weight, have greater total energy per round than the smaller M16 rifle and .45 caliber pistol rounds. However, the A-weighting is such that these larger rounds are attenuated about the same amount as their weight of charge tends to increase their sound level. That is, A-weighting attenuates the 400 Hz peak by about 3 dB in comparison to no attenuation on a 1000 Hz peak. This effect roughly balances the effect of the increased weight of charge in the larger rounds.

Figures 8 and 9 show typical spectral records for an M16 rifle at close (less than 50 m) and far (greater than 300 m) distances, respectively. These figures illustrate the attenuation of the higher frequencies with distance. This high-frequency attenuation causes the A-weighted SEL values per round to decrease at a rate of more than 6 dB per doubling of distance from the noise source.

Results

Table 2 summarizes the data obtained at far distances as described in Appendix A. Table 3 summarizes the data during close-in measurements. Figure 10 plots the data of Tables 2 and 3 to a log-distance scale. The spread of values is caused by weather conditions, with adverse conditions raising the SEL values by as much as 20 dB at 300 m.

The data in top of the "fan" in Figure 10 should be used by Army planners when preparing noise impact predictions since it depicts a "worst case" situation.

The equation to determine SEL per round is:

$$SEL_{Td} = 127.5 - 23 \log_{10} (\text{distance [m]}) \quad [\text{Eq 8}]$$

When the value of SEL_{Td} is inserted into Eq 5:

$$L_{dn} = 78.1 - 23 \log_{10} (\text{distance [m]}) \\ + 10 \log (N_d + 10N_n) \quad [\text{Eq 9}]$$

Figure 6. Typical M14 grouping.

Figure 7. Typical M16 grouping.

Figure 8. Spectral record of M16 rifle (less than 50 m).

Figure 9. Spectral record of M16 rifle (greater than 300 m).

Figure 10. SEL per round vs distance.

Table 3
Summary of Close-in, Single Round Measurements

Distance	Weapon	Orientation	SEL/Round
20 m	.45 cal	Left side	97.0- 98.9
25 m	.45 cal	Rear	91.1- 92.8
	M16	Left side	
		0°	103.8-105.2
		45°	95.2- 96.6
		90°	91.5- 92.6
		135°	92.6- 93.8
		180°	96.9- 97.4
	M14	Rear	86.2- 88.8
	M160	Rear	85.0- 87.8
50 m	M16	Rear (90°)	86.1- 87.0
		Rear (45°)	90.2- 91.0
	M60	Right side	90.9- 93.7

4 NOISE IMPACT PREDICTION METHOD

Figure 10 indicates the range of A-weighted sound-exposure levels vs distance to be expected at any given distance in the vicinity of Army small-arms ranges. Because of the effects of terrain and weather, the possible range of values increases with distance. For planning purposes, it is wise to use the upper limit of this range as given in Eq 8. By means of Eq 8, the Army planner can predict the SEL per round in the vicinity of Army small-arms firing ranges. It is essential, however, that the Army planner take into account that the noise emanating from small-arms ranges is impulsive in nature. Helicopter noise, which also produces impulsive noise, has been assigned a penalty (in dB) by DOD for planning purposes.⁴ The EPA has indicated that a penalty of 5 dB is appropriate for impulsive noise; the International Standards Organization (ISO) also recommends a 5 dB penalty.⁵ Therefore, it is suggested that Army planners add a 5 dB penalty to Eq 8 in order to compensate for the impulsive nature of the sound of small-arms ranges. The following equations give the total planning L_{dn} predicted for any point as

a function of the distance, the number of rounds per day (N_d), and the number of rounds per night (N_n):

$$\begin{aligned}\text{Planning } L_{dn} &= L_{dn} + 5 \\ &= 83.1 - 23 \log_{10} (\text{distance [m]}) \\ &\quad + 10 \log_{10} (N_d + 10N_n) \quad [\text{Eq 10}]\end{aligned}$$

The procedure for implementing Eq 10, using tables and graphs, is given in Appendix B. Appendix B also gives procedures for manually developing L_{dn} contours around a small-arms firing range.

5 CONCLUSIONS AND RECOMMENDATIONS

This report provides SEL vs distance curves for existing Army small-arms ranges. Measured SELs per round at various distances are provided in Figure 10. SEL per round can be calculated at any distance by using Eq 8. Eq 10 is for use by Army planners in calculating the L_{dn} level as a function of distance; this equation includes a 5 dB penalty to account for the impulsive nature of small-arms ranges' noise. For the convenience of planners, Appendix B provides a tabular means of solving for the various quantitative aspects of Eq 10.

It is recommended that procedures provided in Appendix B be used by Army master planners, facility engineers, and environmental officers as guidance in selecting sites for new small-arms ranges or new housing adjacent to existing small-arms ranges.

⁴Environmental Protection: Planning in the Noise Environment, TM 5-803-2 (DOD, 15 Jun 1978); Air Installation Compatible Use Zones (AICUZ) DOD Instruction 4165-57 (30 July 1973) as amended 3 August 1977.

⁵Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, 55019-74 (USEPA, March 1975); Assessment of Noise with Respect to Community Response, International Standards Organization [ISO] Recommendation R1996 (ISO, May 1971).

APPENDIX A: PRESENTATION OF DATA

This appendix presents the results of the laboratory data reduction described in Chapter 3, and includes the layout of each small-arms range measured by this investigation.

Location: Fort McClellan
 Range No.: 22 (Figure A1)
 Weapon fired: M16 rifle
 No. Positions: 52
 No. Rounds/Event: $3 \times 52 = 156 = 22.0$ dB
 Distance to microphone: 100 m

Time (dB)	L_{eq}	SEL	SEL/rd	Comments
18.6	79.6	98.2	76.2	All downwind
16.8	84.2	99.2	77.2	5-7 mph
16.7	82.4	99.1	77.1	
17.0	83.4	100.4	78.4	9 mph
17.0	81.3	98.3	76.3	15 mph gust

Distance to microphone: 400 m

Time (dB)	L_{eq}	SEL	SEL/rd	Comments
15.4	68.3	83.7	61.7	{ Echos, low clouds, crosswind, tornado alert
16.4	67.1	83.5	61.5	
18.9	58.9	77.8	57.8	5-7 mph upwind, echos

Figure A1. Fort McClellan: Range 22.

Location: Fort Leonard Wood
 Range No.: 33 (Figure A2)
 Weapon fired: M16 rifle
 No. Positions: 48
 No. Rounds/Event: $3 \times 48 = 144 = 21.6 \text{ dB}$
 Distance to microphone: 200 m

Time (sec)	L_{eq}	SEL	SEL/rd	Comments
35.1	69.8	85.3	63.7	Crosswind 6-10 mph
32.5	69.5	84.6	63.0	
34.4	68.7	84.1	62.5	
30.6	67.9	82.8	61.2	
33.0	70.2	85.4	63.8	
32.7	68.8	83.9	62.3	
32.7	69.2	84.4	62.8	
33.2	70.2	85.4	63.8	
34.3	68.7	84.1	62.5	
32.0	69.1	84.2	62.6	
31.2	68.0	83.0	61.4	
32.6	68.9	84.0	62.4	
32.8	69.3	84.5	62.9	Afternoon
35.5	67.3	82.9	61.3	
28.8	67.7	82.3	60.7	
26.7	68.0	82.2	60.6	

Location: Fort Leonard Wood
 Range No.: 33 (Figure A2)
 Weapon fired: M16 rifle
 No. Positions: 48
 No. Rounds/Event: $3 \times 48 = 144 = 21.6 \text{ dB}$
 Distance to microphone: 300 m

Time (sec)	L_{eq}	SEL	SEL/rd	Comments
51.0	65.2	82.3	60.7	Crosswind 6-10 mph Morning
47.4	65.6	82.4	60.8	
47.5	64.2	81.0	59.4	
50.1	66.1	83.1	61.5	
38.0	65.3	81.1	59.5	
43.0	64.4	80.7	59.1	
30.3	67.3	82.1	60.5	
33.5	64.8	80.0	58.4	
33.2	64.1	79.3	57.7	
21.9	62.5	75.9	54.3	Afternoon
26.0	64.3	78.4	56.8	
24.5	59.9	73.8	52.2	
26.7	63.4	77.6	56.0	
36.6	61.5	77.2	55.6	
30.4	63.4	78.2	56.6	

Figure A2. Fort Leonard Wood: Range 33.

Location: Fort McClellan

Range No.: 51 (Figure A3)

Weapon fired: M60 machine gun

No. Positions: 25

No. Rounds/Event: $25 \times 25 = 625$ (max) = 28.0 dB

Distance to microphone: 90 m

Time (dB)	L_{eq}	SEL	SEL/rd	Wind	
				Speed	Direction
15.3	88.3	103.6	75.8	12-14	30°
14.8	88.5	103.3	75.7	8	45°
15.1	88.2	103.3	75.7	10-12	0°
15.0	88.5	103.5	76.1	10	45°
18.4	85.6	104.0	76.2		
14.4	89.2	103.6	75.8	10-14	45°
13.6	88.0	101.6	73.8	5	50°
14.8	86.2	101.0	73.2	7	50°
16.8	84.8	101.6	74.0	4	60°

Distance to microphone: 350 m

Time (dB)	L_{eq}	SEL	SEL/rd	Comments
16.8	77.5	94.3	66.7	10 mph crosswind
18.6	74.7	93.3	65.7	

Figure A3. Fort McClellan: Range 51.

Location: Fort McClellan
 Range No.: 13 (Figure A4)
 Weapon fired: .45 cal automatic pistol
 No. Positions: 55
 No. Rounds/Event: See below
 Distance to microphone: 100 m

Time (sec)	L_{eq}	SEL	No. rds	SEL/rd	Comments
104.9	82.6	102.8	550	75.4	Light wind, 30 yd Elevation, Forest cover
104.8	82.9	103.2	550	75.8	
91.7	83.5	103.1	550	75.7	
41.1	85.2	101.3	275	76.9	
80.6	84.3	103.3	550	75.9	
14.4	88.6	100.2	275	75.8	

Distance to microphone: 275 m

Time (sec)	L_{eq}	SEL	No. rds	SEL/rd	Comments
106.7	68.9	89.2	550	61.8	Light wind
91.4	70.3	89.9	550	62.5	
40.9	70.3	86.4	275	62.0	
78.9	68.6	87.6	550	60.2	
16.6	73.0	85.2	275	60.8	

Figure A4. Fort McClellan: Range 13.

Location: Fort McClellan
 Range No.: 25 (Figure A5)
 Weapon fired: M16 rifle
 No. Positions: 49
 No. Rounds/Event: $3 \times 49 = 147 = 21.7 \text{ dB}$
 Distance to microphone: 375 m

Time (dB)	L_{eq}	SEL	SEL/rd	Comments
18.2	62.7	80.9	59.2	12-14 mph crosswind
14.0	61.9	75.9	54.2	
18.0	62.9	80.9	59.2	20 mph, 25 gust
16.1	65.1	81.2	59.5	4-10 mph
18.7	59.8	78.5	56.8	8-12 mph, 25 mph gust
16.5	62.8	79.3	57.6	
18.0	61.0	76.0	57.3	<12 mph
18.4	62.9	81.3	59.6	10-12 mph at 45°

Distance to microphone: 300 m

Time (dB)	L_{eq}	SEL	SEL/rd	Comments
13.3	62.2	75.5	53.8	15 mph downwind

Figure A5. Fort McClellan: Range 25.

Location: Fort McClellan
 Range No.: 19 (Figure A6)
 Weapon fired: .45 cal automatic pistol
 No. Positions: 25
 No. Rounds/Event: see below
 Distance to microphone: 100 m

Time (sec)	L_{eq}	SEL	No. rds	SEL/rd	Comments
111.1	74.4	94.8	550	67.4	3-4 mph
94.1	74.3	94.0	550	66.6	Crosswind
40.1	74.2	90.2	275	65.8	
80.4	73.2	92.3	550	64.9	
14.0	78.1	89.5	275	65.1	

⊙ MEASUREMENT
 POSITION

Figure A6. Fort McClellan: Range 19.

Location: Fort Knox
 Range No.: Record range (Figure A7)
 Weapon fired: .45 cal automatic pistol
 No. Positions: 20
 No. Rounds/Event: see below
 Distance to microphone: 180 m

Time (sec)	L_{eq}	SEL	No. rds	SEL/rd	Comments
41.5	74.5	90.7	140	69.2	7-9 mph
89.3	74.6	94.1	260	70.0	Crosswind
36.6	75.7	91.3	140	69.8	
46.0	75.4	92.0	160	70.0	
29.0	77.1	91.7	140	70.2	
22.0	76.1	89.5	100	69.5	
88.9	74.7	94.2	260	70.1	

Figure A7. Fort Knox: Record range.

Location: Fort Lewis
 Range No.: M60 range (Figure A8)
 Weapon fired: M60 machine gun
 Distance to microphone: 200 m

No. rds	SEL	SEL/rd
3	67.1	62.3
3	70.1	65.3
12	72.6	61.8
11	72.4	62.0
12	72.6	61.8
7	74.1	65.7
6	74.0	66.2
6	73.4	65.6
7	73.9	65.4
10	75.5	65.5
4	66.9	60.8
12	70.0	59.2
11	70.0	59.6
14	72.3	61.2

Figure A8. Fort Lewis: M60 range.

APPENDIX B: TABULAR PREDICTION PROCEDURE

This appendix presents a tabular procedure for determining (1) L_{dn} in the vicinity of an existing or proposed small-arms range, (2) distance to a given L_{dn} zone boundary, and (3) number of rounds required to impact a given noise-sensitive area.

In the first case, L_{dn} can be calculated for a given location by determining the number of rounds fired per day and night, and the distance from the range area to a noise-sensitive land use. In the second case, the distance to a given noise-zone boundary (L_{dn} 65, for instance) can be calculated by determining the L_{dn} and number of rounds fired. In the third case, the number of rounds that could be fired without exceeding a given L_{dn} at a noise-sensitive area can be calculated. From the above, it is apparent that if any two variables are known (L_{dn} , distance to impacted area, or number of rounds fired), the third variable can be determined.

Case 1: Computing L_{dn} from Number of Rounds (Per day and Night) and Distance from Firing Line to Noise-Sensitive Area

The total weighted number of rounds (N_{TOT}) is computed from number of rounds per day and night using equation B1. Table B1 is used to calculate $dB_{N_{TOT}}$ from a determined value for N_{TOT} . Table B2 is used to calculate dB_{dist} from a determined value for distance. The sum of $dB_{N_{TOT}}$ and dB_{dist} produce L_{dn} (see Eq B2).

Eq B1 is used to compute N_{TOT} from the number of rounds fired per day and night. (Since night firing is more annoying to people than day firing, a penalty has been assessed in this equation for rounds fired at night.)

$$N_{TOT} = N_d + 10N_n \quad [\text{Eq B1}]$$

where N_d = number of rounds per day
(0700 to 2200 hr)
 N_n = number of rounds per night
(2200 to 0700 hr)

For example: 5000 rounds fired per day and 500 per night would produce an N_{TOT} of 10,000 rounds.

Table B1 computes $dB_{N_{TOT}}$ from the previously calculated N_{TOT} . For an N_{TOT} of 10,000 rounds, Table B1 yields a $dB_{N_{TOT}}$ of 40. From Table B2,

Table B1
Number of Rounds vs $dB_{N_{TOT}}$ *

N_{TOT}	$dB_{N_{TOT}}$
100	20
200	23
500	27
1,000	30
2,000	33
5,000	37
10,000	40
20,000	43
40,000	46

$$*dB_{N_{TOT}} = 10 \log_{10} (N_{TOT})$$

dB_{dist} is found from the distance from the firing line to the impacted area. For a distance of 600 m, dB_{dist} = 19.2dB. The final result, L_{dn} , is obtained by adding $dB_{N_{TOT}}$ and dB_{dist} . Therefore, for the example cited above, L_{dn} = 59.2 dB.

$$L_{dn} = dB_{N_{TOT}} + dB_{dist} \quad [\text{Eq B2}]$$

where $dB_{N_{TOT}}$ = contribution of rounds
fired per day and night
(from Table B1)

dB_{dist} = contribution of distance
(from Table B2).

Case 2: Computing Distance From Number of Rounds (Per Day and Night) and L_{dn}

The N_{TOT} is calculated from the number of rounds fired per day and night by using Eq B1. Table B1 is used to find $dB_{N_{TOT}}$. The dB_{dist} is found by subtracting $dB_{N_{TOT}}$ from L_{dn} (see Eq B3). Table B3 is used to find distance from dB_{dist} . As Figure B1 shows, a contour has been drawn around the firing line. This contour line signifies constant L_{dn} at the calculated distance from the firing line.

As in Case 1, Eq B1 is used to find N_{TOT} from the number of rounds fired per day and night. For 500 rounds fired in the day and 50 at night, the N_{TOT} is 1000 rounds. Table B1 is used to find $dB_{N_{TOT}}$ knowing N_{TOT} . In this example, N_{TOT} of 1000 gives a $dB_{N_{TOT}}$ of 30. The dB_{dist} may be found by using Eq B3:

$$L_{dn} - dB_{N_{TOT}} = dB_{dist} \quad [\text{Eq B3}]$$

where L_{dn} = level of contour line desired

$dB_{N_{TOT}}$ = contribution of day and night firing
(from Table B1)

Therefore, for an L_{dn} of 65, dB_{dist} would equal 35. Table B3 is used to find distance knowing dB_{dist} . In this case, distance = 120 m.

Case 3: Computing Number of Rounds Fired From Distance (Between Firing Line and Impacted Area) and L_{dn}

Table B2 is used to find dB_{dist} from distance. Eq B4 is used to calculate $dB_{N_{TOT}}$ from L_{dn} and dB_{dist} . Table B1 is entered with $dB_{N_{TOT}}$ to produce N_{TOT} . The optimum mix of rounds per day and night can then be found by using the weighting equation (Eq B1). Distance is used to find dB_{dist} by using Table B2. For a distance of 500 m, dB_{dist} = 21.0 dB.

Equation B4 is then used to calculate $dB_{N_{TOT}}$ knowing L_{dn} and dB_{dist} :

$$dB_{N_{TOT}} = L_{dn} - dB_{dist} \quad [\text{Eq B4}]$$

Table B1 is then used to determine N_{TOT} from $dB_{N_{TOT}}$. The optimum selection of N_d and N_n is made by using Eq B1. (Note: it is important to remember

that one night round has the same impact as 10 rounds per day.)

To find the number of rounds fired (N_{TOT}) to extend a L_{dn} 65 line to 500 m, use Eq B4.

For example:

$$dB_{N_{TOT}} = 65 - 21 = 44$$

which yields N_{TOT} = 20,000 rounds (Table B1). A typical distribution would be N_d = 18,000 rounds; N_n = 200 rounds.

Figure B1 is a graph of planning L_{dn} as a function of N_{TOT} and distance.

Table B3
 dB_{dist} vs Distance*

dB_{dist}	Distance
0	4100 m
1	3700 m
2	3400 m
3	3000 m
4	2700 m
5	2500 m
6	2200 m
7	2000 m
8	1800 m
9	1700 m
10	1500 m
11	1400 m
12	1200 m
13	1100 m
14	1000 m
15	910 m
16	830 m
17	750 m
18	680 m
19	610 m
20	550 m
21	500 m
22	450 m
23	410 m
24	370 m
25	340 m
26	300 m
27	270 m
28	250 m
29	225 m
30	200 m
31	180 m
32	170 m
33	150 m
34	140 m
35	120 m
36	110 m
37	100 m

$$* \text{distance (m)} = 10^{\left(\frac{83.1 - dB_{dist}}{23} \right)}$$

Table B2
Distance vs dB_{dist} *

Distance	dB_{dist}
100 m	37.1
200 m	30.2
300 m	26.1
400 m	23.4
500 m	21.0
600 m	19.2
700 m	17.7
800 m	16.3
900 m	15.2
1,000 m	14.1
1,200 m	12.3
1,400 m	10.7
1,600 m	9.4
1,800 m	8.2
2,000 m	7.2
2,500 m	5.0
3,000 m	3.1
3,500 m	1.6
4,000 m	.3
4,500 m	-.9

$$*dB_{dist} = 83.1 - 23 \log_{10} (\text{distance [m]})$$

Figure B1. Contour of small-arms firing range.

Figure B2. Planning L_{dn} as a function of N_{TOT} and distance.