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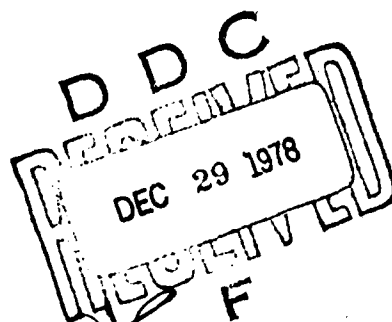
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PREDICTING NOISE IMPACT IN THE VICINITY OF  
SMALL-ARMS RANGES

(9) Interim rept,



by Joseph A. McBryan

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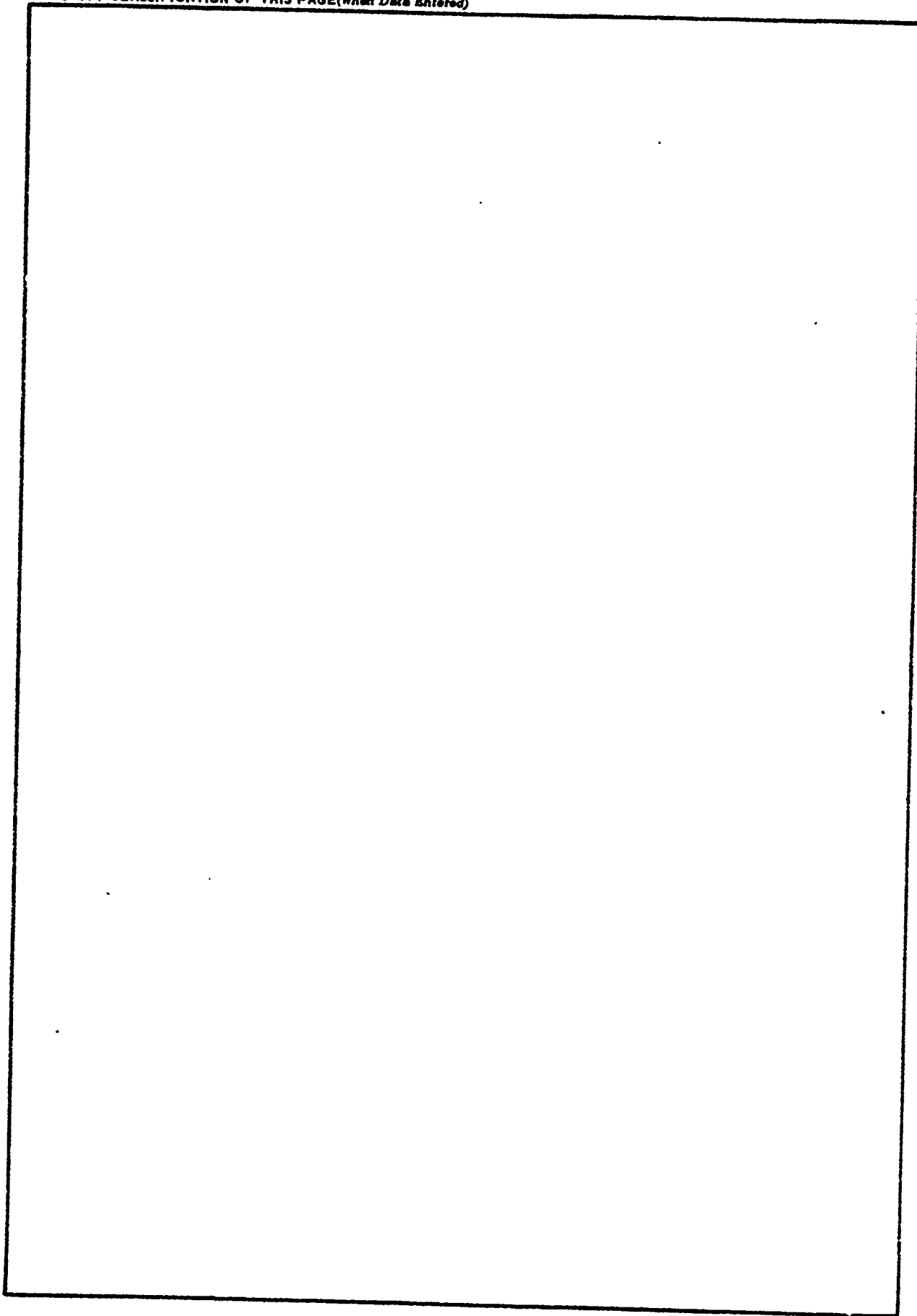
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| 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)<br>day/night average sound level ( $L_{dn}$ )<br>sound-exposure level (SEL)<br>calculation<br>prediction                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                       |                                                                                      |
| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>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. |                       |                                                                                      |

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## 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-MPE-1, 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.

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# 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  $L_{dn}$ .<sup>1</sup>

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 guidance.

<sup>1</sup>Information 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 researchers<sup>2</sup> 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

<sup>2</sup>Garinther, 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).

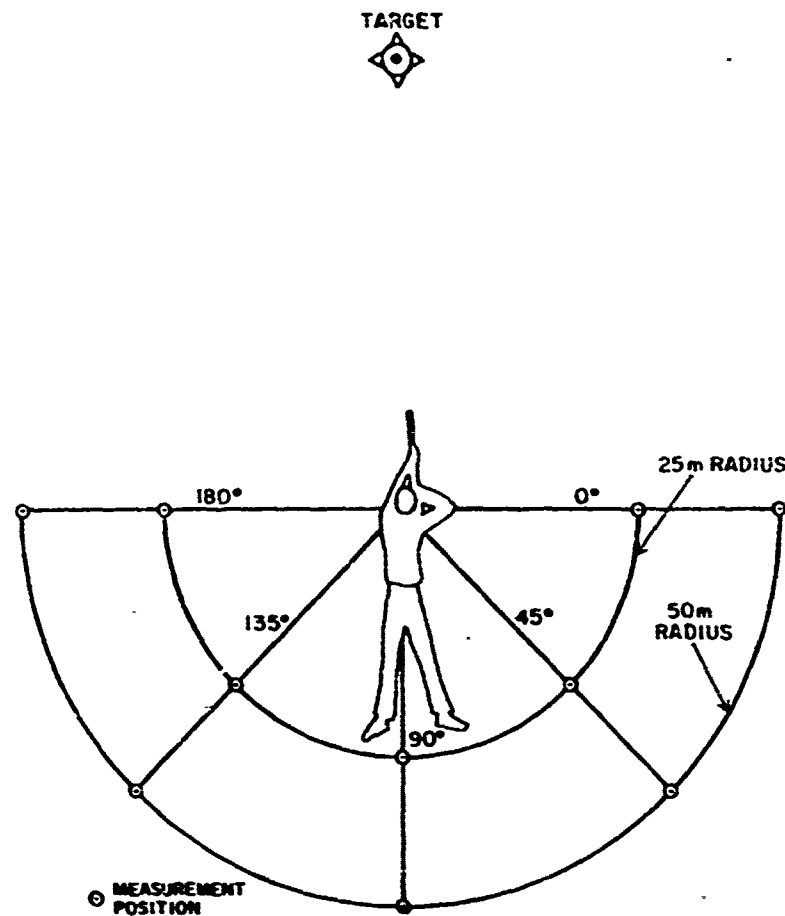


Figure 1. Close-in measurements.

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.<sup>3</sup> CERL noise monitor results

<sup>3</sup>P. 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.

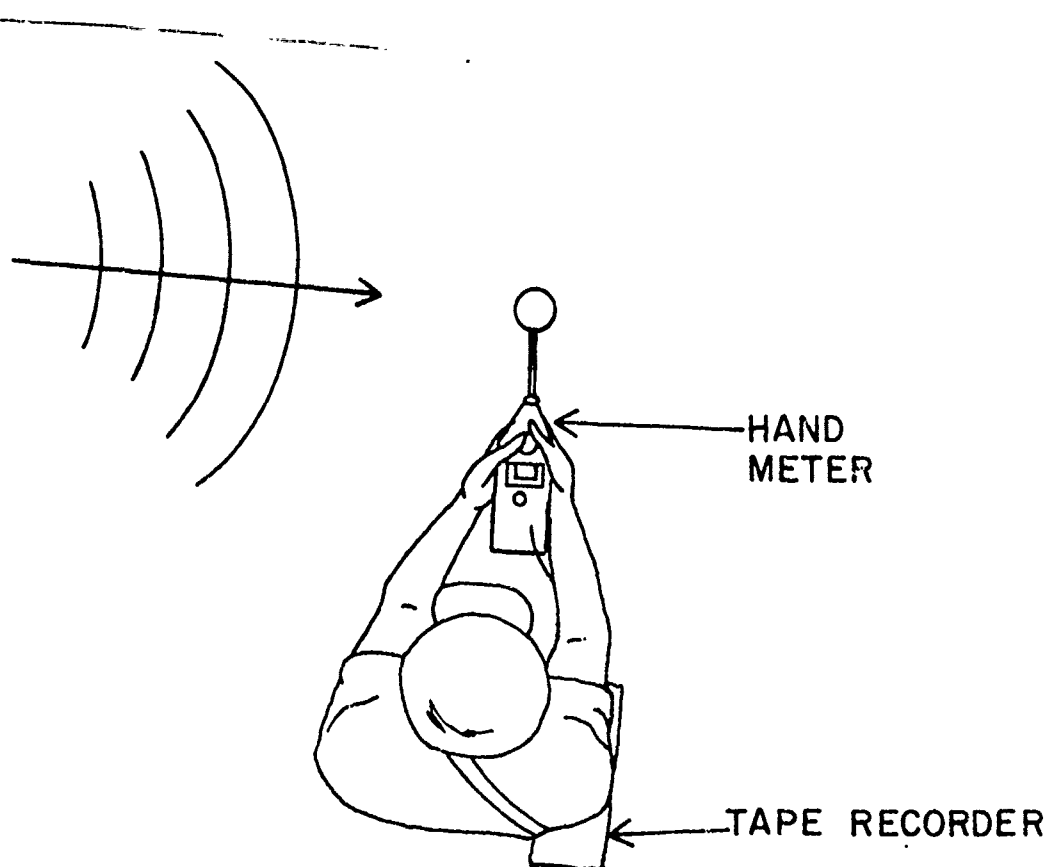


Figure 2. Typical equipment setup.

### 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  $L_{dn}$ :

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

where

$p(t)$  = instantaneous pressure  
 $p_o$  = 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:

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

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

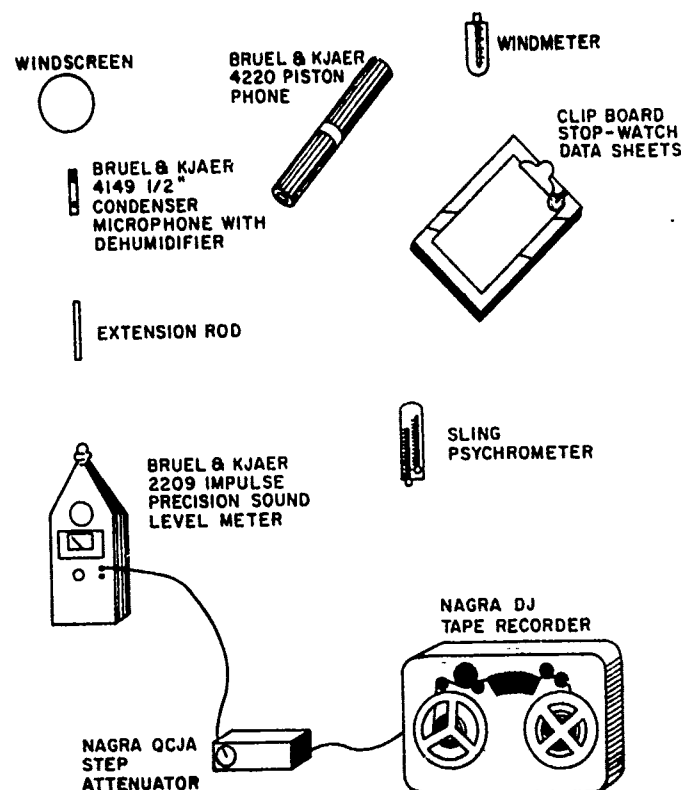


Figure 3. Equipment used during measurements.

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

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

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

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

where

$SEL_{Td}$  = sound-exposure level per round

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

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

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

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

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

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

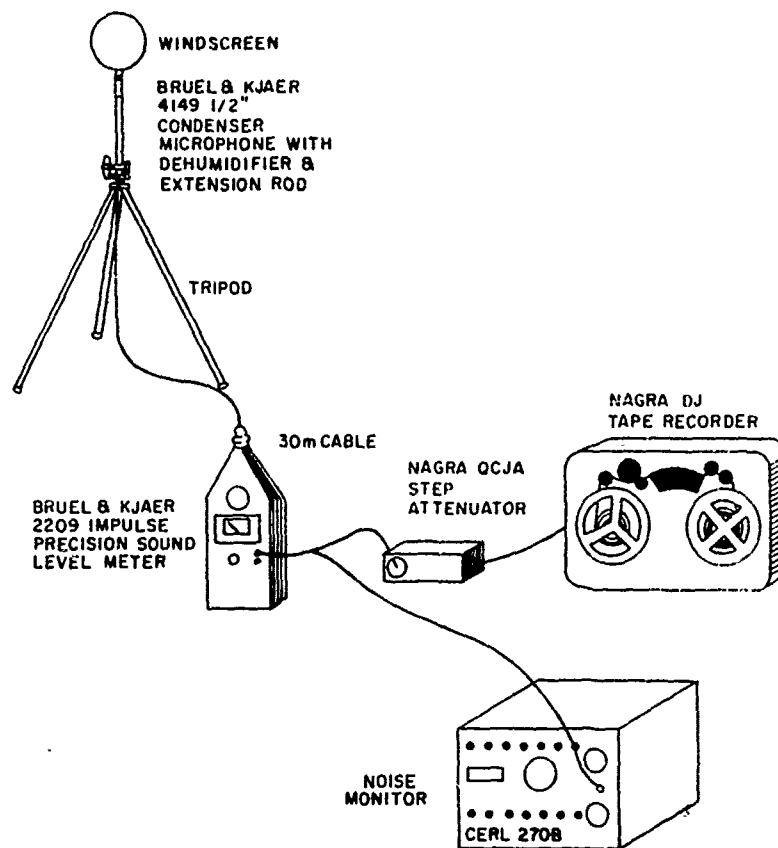


Figure 4. Typical far-distance measurement setup.

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.

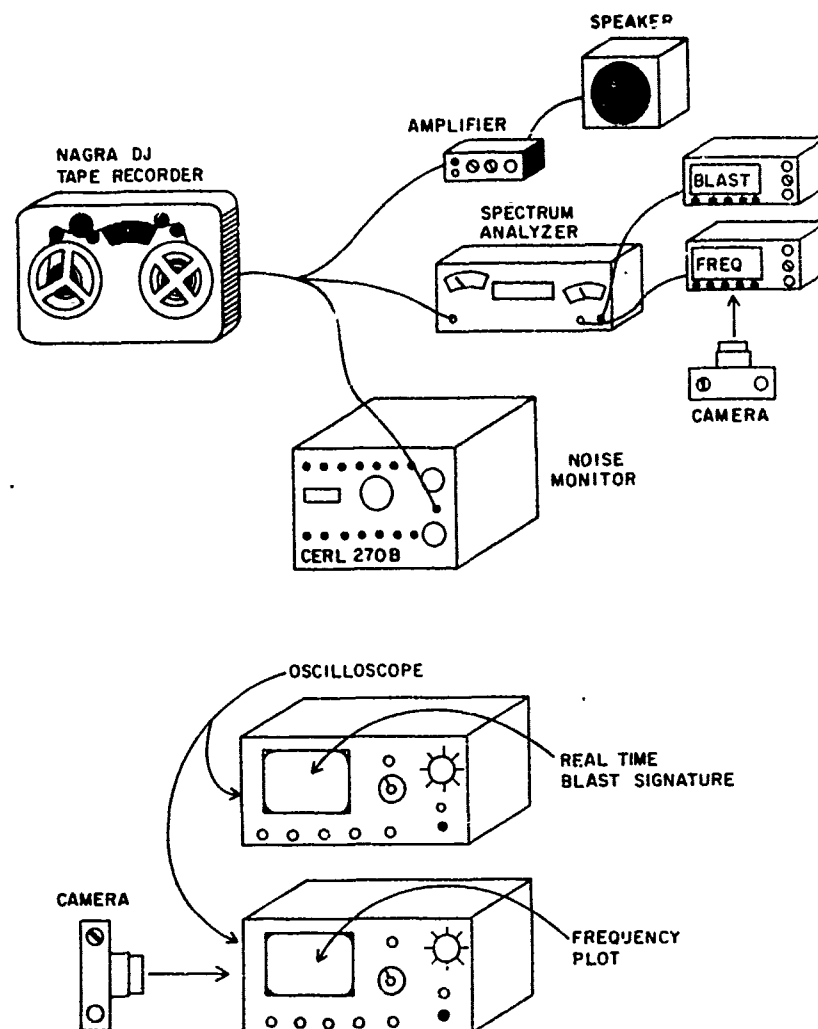


Figure 5. Spectral content setup.

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<br>No. Rounds | No. Rounds/<br>Burst | SEL/<br>Burst | SEL/<br>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:

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

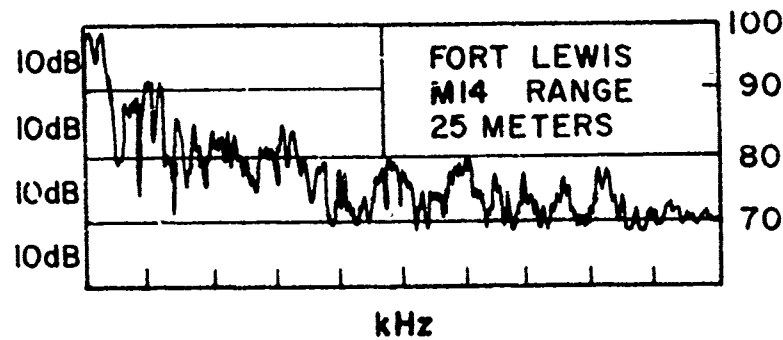


Figure 6. Typical M14 grouping.

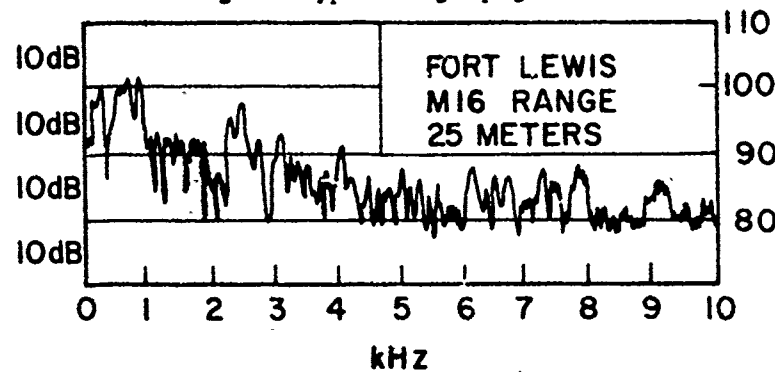


Figure 7. Typical M16 grouping.

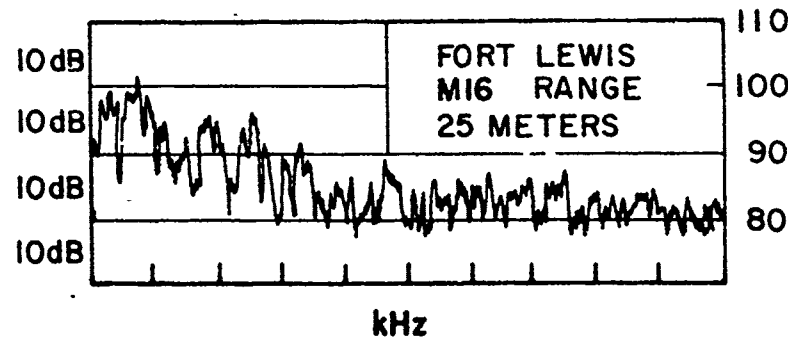


Figure 8. Spectral record of M16 rifle (less than 50 m).

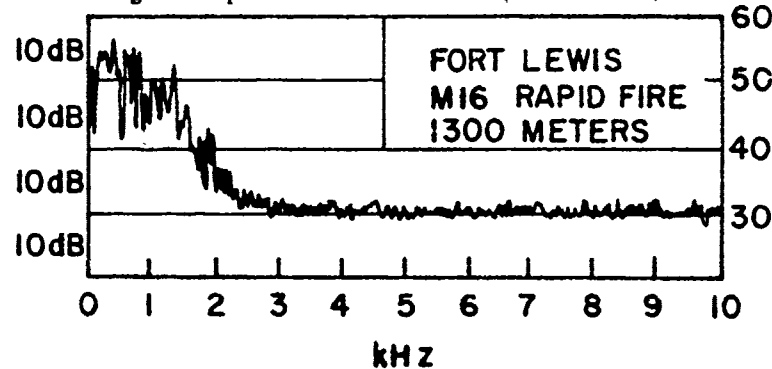


Figure 9. Spectral record of M16 rifle (greater than 300 m).

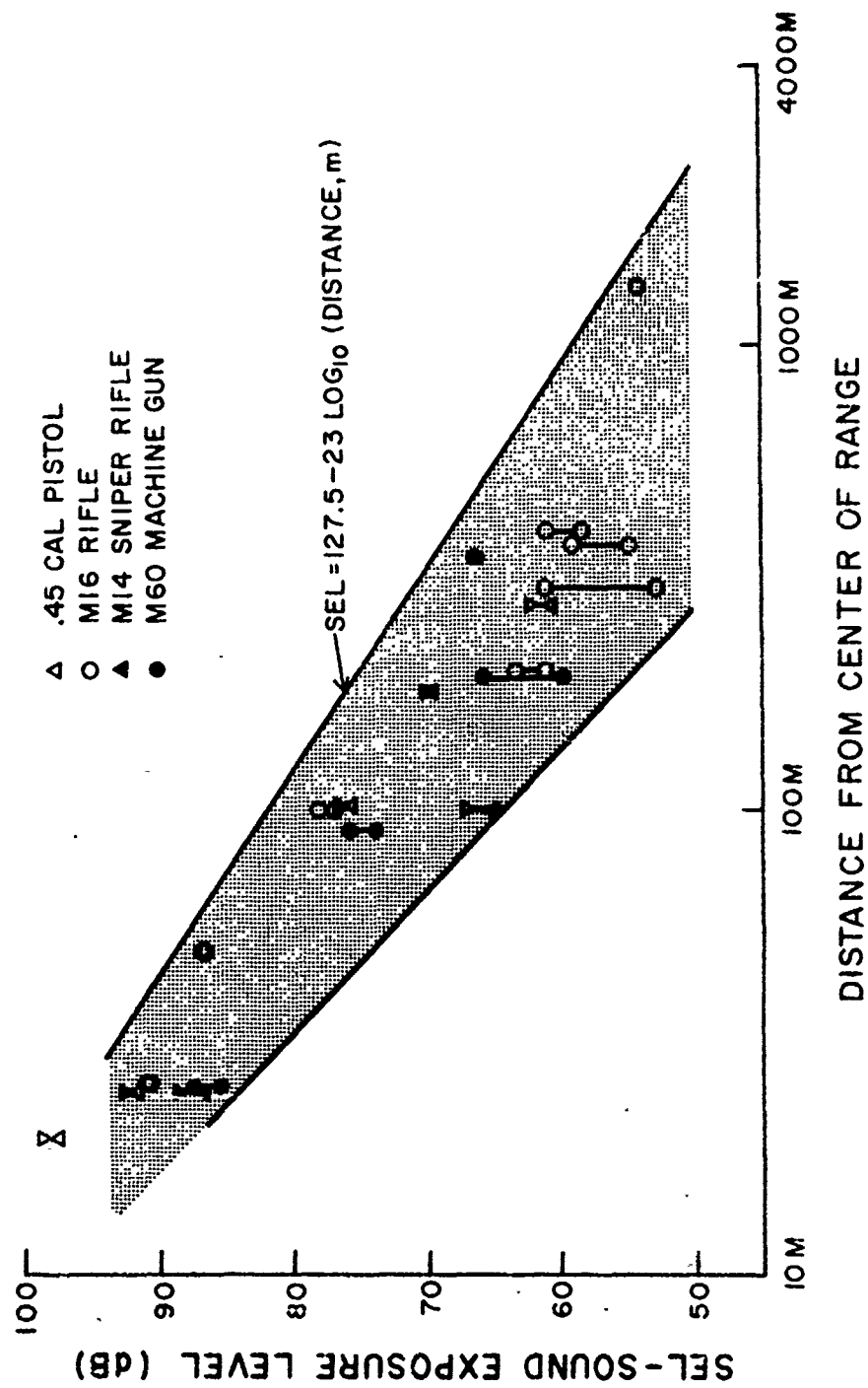


Figure 10. SEL per round vs distance.

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.<sup>4</sup> 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.<sup>5</sup> 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.

<sup>4</sup>Environmental 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.

<sup>5</sup>Information 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,<br>crosswind, tornado alert |
| 16.4      | 67.1     | 83.5 | 61.5   |                                                  |
| 18.9      | 58.9     | 77.8 | 57.8   | 5-7 mph upwind, echos                            |

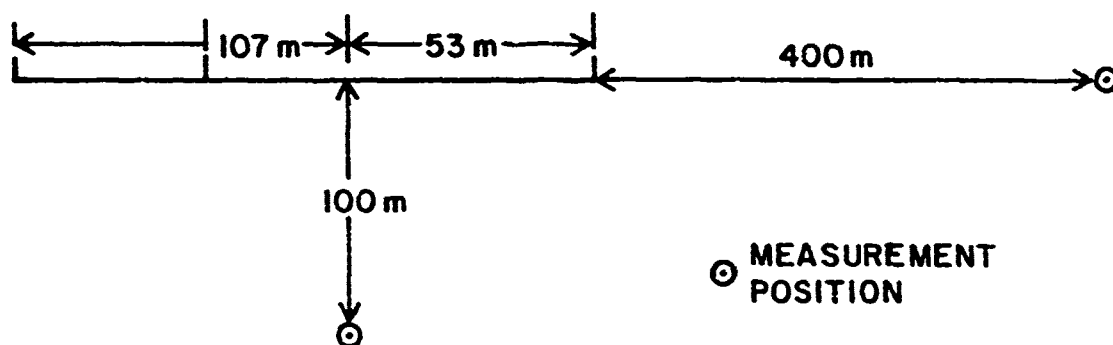


Figure A1. Fort McClellan: Range 22.

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

| Time (sec) | $L_{eq}$ | SEL  | SEL/rd | Comments              |
|------------|----------|------|--------|-----------------------|
| 35.1       | 69.8     | 85.3 | 63.7   | Crosswind<br>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:  $3 \times 48 = 144 = 21.6$  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<br>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   |                               |

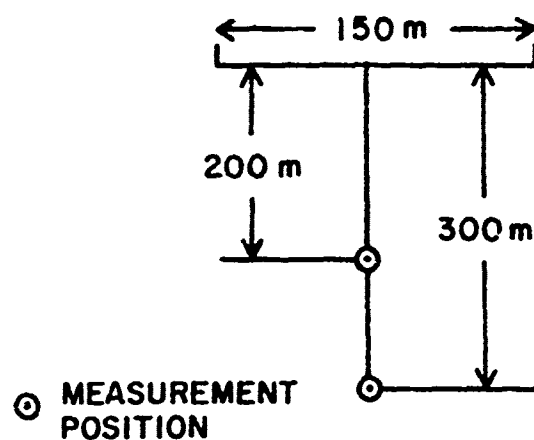


Figure A2. Fort Leonard Wood: Range 33.

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   |                  |

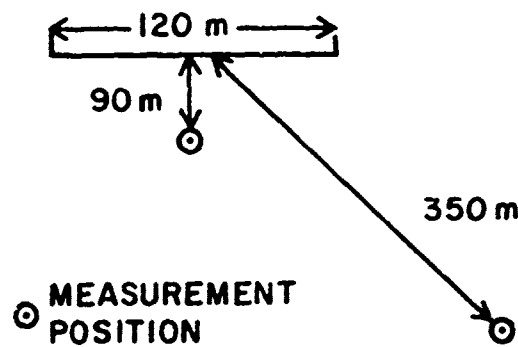


Figure A3. Fort McClellan: Range 51.

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,<br>30 yd<br>Elevation,<br>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   |            |

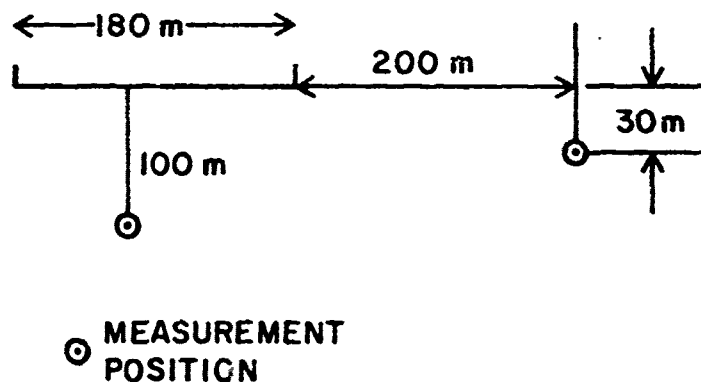


Figure A4. Fort McClellan: Range 13.

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   |                       |
| 18.9      | 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 |

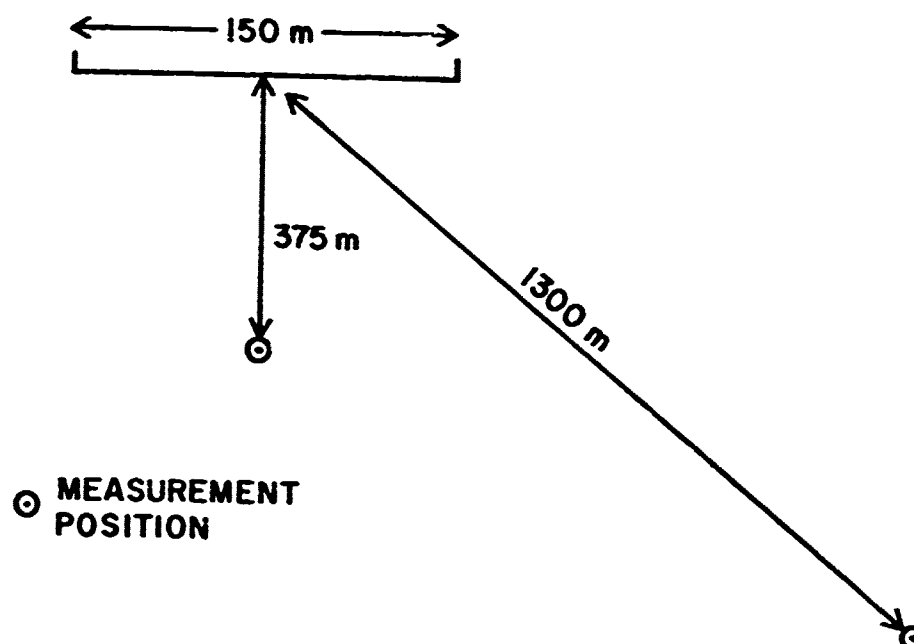
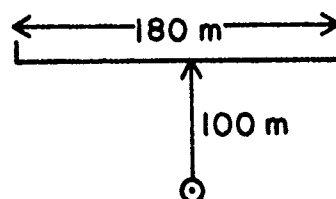


Figure A5. Fort McClellan: Range 25.

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   |           |

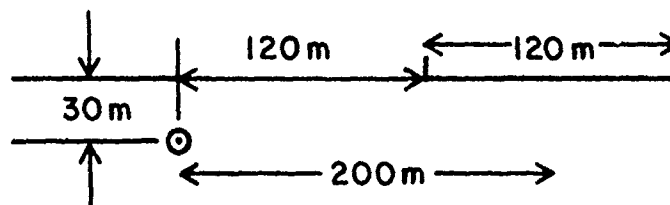


⊙ MEASUREMENT  
 POSITION

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   |           |



⊙ MEASUREMENT  
 POSITION

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   |

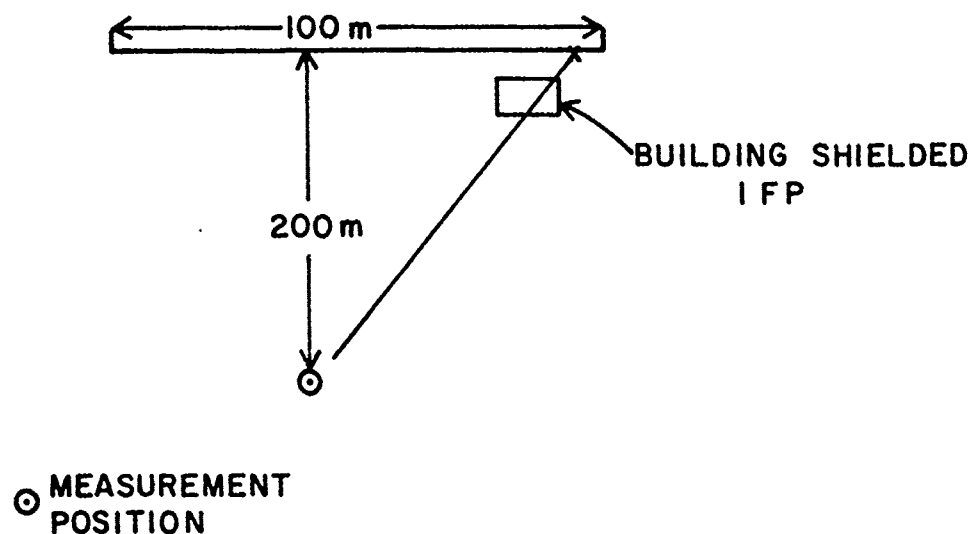


Figure A8. Fort Lewis: M60 range.

## 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,  $dB_{dist} = 19.2\text{dB}$ . The final result,  $L_{dn}$ , is obtained by adding  $dB_{N_{TOT}}$  and  $dB_{dist}$ . Therefore, for the example cited above,  $L_{dn} = 59.2\text{ dB}$ .

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

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:

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

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  $dB_{dist}$ :

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

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    |

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         |

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

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

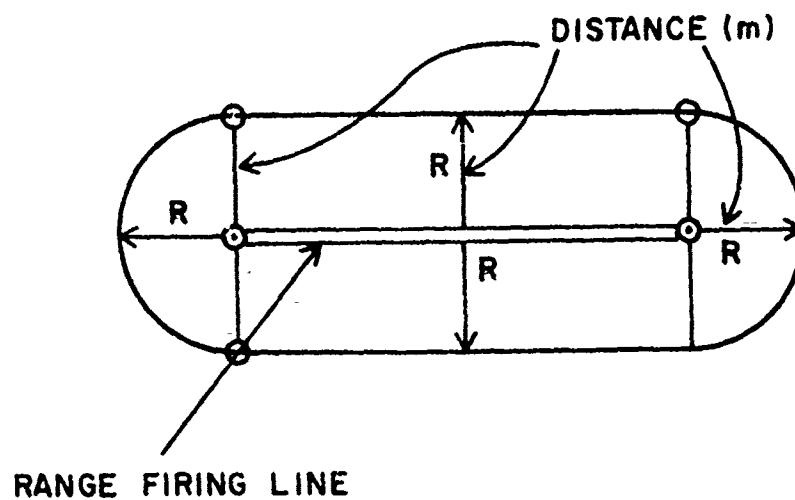


Figure B1. Contour of small-arms firing range.

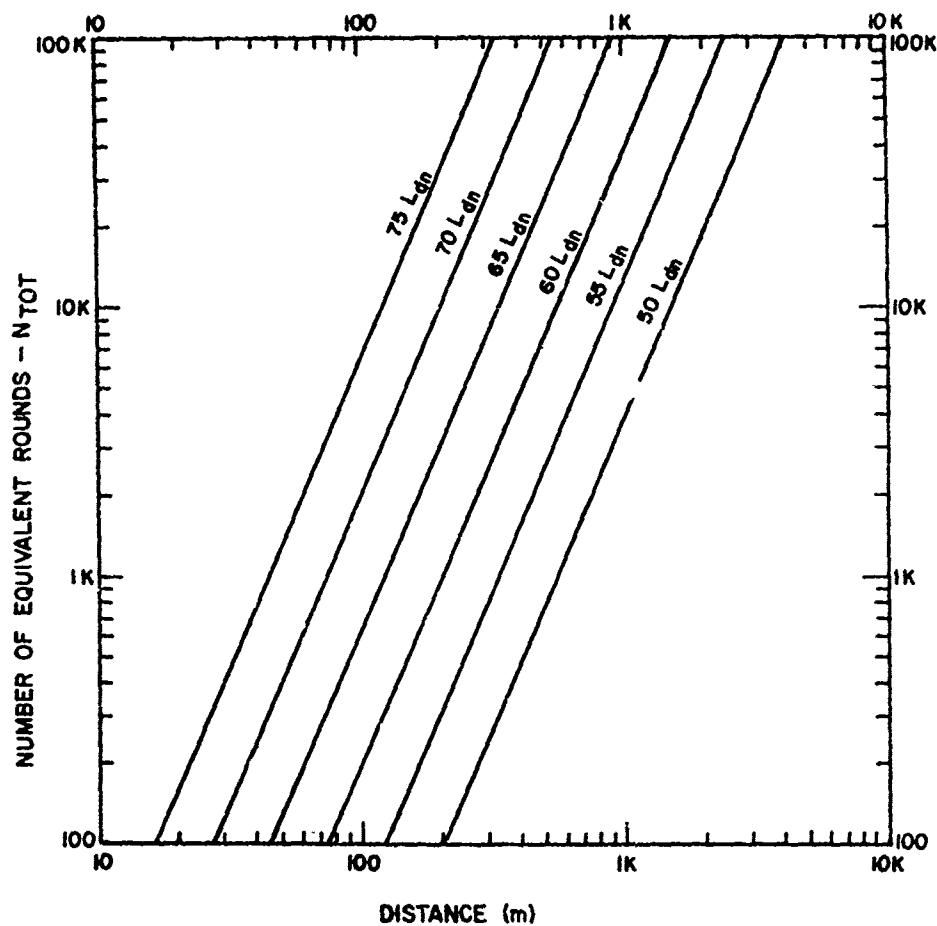


Figure B2. Planning  $L_{dn}$  as a function of  $N_{TOT}$  and distance.

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