Before-and After-Noise Control Treatment Risk Assessment at an Indoor Tactical Multi-lane Army Firing Range

TECHNICAL INFORMATION PAPER NO. 51-006-1112

PURPOSE.

Measurements of the recently acoustically treated, multi-lane, Army indoor tactical firing range (hereafter called “the range”) were taken on 13 December 2011 to establish firing restrictions for range use and to compare against predictions of how well the applied noise controls work. Additional measurements were taken to document the effects of shooting posture on noise exposure, and to measure what happens to the noise levels when silencers are used.

POINTS OF MAJOR INTEREST AND FACTS.

BACKGROUND

Table 1 presents the worst-case, multiple-shooter Allowable Number of Rounds per Day (ANOR) that can be fired at the range, when single or double hearing protection is worn, for the weapons listed. This restriction is per person (not for the total from all shooters). It results from an assessment using the data taken on 13 December, as described below. Worst-case, in this instance, translates to applying the noisiest result from the 5 samples measured for each test condition evaluated and assumes all 14 Soldiers are firing weapons simultaneously. The information from three firing distances (7, 25, and 50 meters(m) from the targets) are included to represent the full range of distances possible at the range.

Results are based on the 85 dBA 8-hour Leq criterion for weapons fire, rather than the more traditional peak level criterion used with weapons fire. The Leq criterion is used here because the firing at the range can be sustained, lasting over long enough periods (more than 1 second), when multiple shooters are involved. The Leq criterion always produces more restrictive results than those based on peak levels.

Presented results should be interpreted as being very conservative to Soldier hearing health, especially because the range is used in many ways, with multiple shooters firing at the same time representing only a fraction of range use. Testing was done with weapons that replicate normal operation at the range.

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For example, not all weapons are fired from all distances. Specifically, the .45 caliber handgun is not normally fired from the 50-m line, and the sniper rifles and machine guns are only fired from the 50-m line. Thus, the .45 cal handguns were not tested at the distant location and the sniper rifles were not tested at the close-in distance. Restrictions in Table 1 apply only to the tested conditions.

As a general rule, small arms weapon fire noise is controlled by the amount and kind of propellant that is in the cartridges that are fired. For this reason, all similarly sized ammunition produces about the same amount of noise. The platform the ammunition is fired from does not make a great deal of difference, as long as it is the same or similar caliber. For example, one would expect all 5.56 millimeter (mm) ammunition to have similar firing restrictions, regardless of which 5.56-mm weapon the ammunition is fired from. It is, therefore, reasonable to apply the results shown below to other weapon systems that use the same ammunition as that tested. It must be cautioned, however, that these extrapolated data have limitations if the weapon being used is fitted with muzzle terminations that reflect noise back towards the shooter (such as muzzle brakes), or if the weapon muzzles are closer to the shooter's ear than in the subject study, as would be the case if a particularly short barrel was used or if the weapon was fired in a different manner than what was studied.

Table 1. Worst-Case MULTIPLE SHOOTER ANOR per Day at the Range based on 8-hour, 85 dBA Leq Criterion

Weapon	Weapon Operation	ANOR with Single Hearing Protection	ANOR with Double Hearing Protection
9mm handgun	Single rounds	1795	5675
.45 cal handgun	Single rounds	1210	3828
M4 normal barrel	Single rounds	639	2021
M4 short barrel	Single rounds	385	1216
M4 silenced	Single rounds	3098	9796
M4	5 round bursts	64 bursts	243 bursts
M17	Single rounds	217	855
M110	Single rounds	474	1499

Weapon	**Weapon Operation**	**ANOR with Single Hearing Protection**	**ANOR with Double Hearing Protection**
M24	Single rounds	960	3035
M249	Single rounds	1214	3840
M249	5 round bursts	242 bursts	768 bursts

Table 2 presents the worst-case SINGLE shooter ANOR that can be fired at the range when single or double hearing protection is worn for the same weapons. These restrictions apply only if there is one shooter firing a weapon at a time. Again, we are considering the information from all three firing distances evaluated, and specifically applying the noisiest result from the five samples measured for each test condition evaluated. The results are, again, also based on the 85-dBA, 8-hour Leq criterion for weapons fire, even though it is unlikely that noise would persist for more than 1 second when only a single shooter was using the range (unless firing a machine gun for a longer than normal period of time). The results should be interpreted as being very conservative of Soldier health.

Table 2. Worst-Case SINGLE SHOOTER ANOR per Day at the Range based on 8-hour 85 dBA Leq Criterion

Weapon	Weapon Operation	ANOR with Single Hearing Protection	ANOR with Double Hearing Protection
9mm handgun	Single rounds	4581	14488
.45 cal handgun	Single rounds	1914	6053
M4 normal barrel	Single rounds	1469	4645
M4 short barrel	Single rounds	776	2455
M4 silenced	Single rounds	18664	59020
M4	5 round bursts	155 bursts	491 bursts
7.62 SCAR	Single rounds	834	2636
M110	Single	875	2767

Weapon	Weapon Operation	ANOR with Single Hearing Protection	ANOR with Double Hearing Protection
	rounds		
M24	Single rounds	2153	6808
M249	Single rounds	2460	7780
M249	5 round bursts	492 bursts	1556 bursts

The firing restrictions listed in Table 1 have been determined by measuring how much noise energy is present at the center of each lane to the side of a shooter, when that shooter is the only one firing a weapon. This enabled construction of a simulated situation where there are 14 shooters firing their weapons, and computation of the total noise energy at any one of their lanes. For example, the shooter in the middle lane receives noise from the shooter's own weapon being fired, from the noise of firing from the two immediately adjacent lanes, the two lanes next over, and so on. What was measured in lane 6 when the shooter was in lane 7 applies in reverse. In other words, the noise a shooter in lane 7 receives from firing in either lane 6 or 8 is the same as the noise measured in the empty lane six from shooting in lane 7. Due to instrumentation limitations, measurements were only made in lanes 7, 6, 5, 3, and 1. The Leq values were estimated as being midway between those measured in adjacent lanes for lanes 2 and 4. The use of estimations for lanes 2 and 4 affects totals by less than a decibel.

The metric involved is the 8-hour, A-weighted Leq, which is, in fact, proportional to the acoustic energy involved. The 8-hour A-weighted Leq has been determined by post-processing the digitized files from the direct measurements, and the totals involved for the shooter in the center lane were then reduced by either an assumed 29 or 34 dB to represent the reduction afforded by single or double hearing protection, respectively. It is a straightforward calculation from that point to identify how many similar such firings it will take to add up to an 8-hour A-weighted Leq criterion of 85 dBA, which is the permissible daily exposure for sounds lasting 1 second or more. Except in rare instances, individual pulses caused by the firing of any of the weapons act independently (do not cancel each other out), enabling this energy-based approach to work.

It is reasonable to challenge the use of this particular criterion for weapons fire from a single shooter, since noise created in that situation normally would last for less than one second. However, the calculations involved for Leq are much simpler than those used for impulse noise lasting less than 1 second, where peak levels and B-durations must be accounted for, and because prior findings indicated the resulting ANORs using the

Leq criterion are acceptable to the range, the simpler method is used to determine Table 2 restrictions. It is stressed that the results are very conservative for this single shooter case. Restrictions can be provided for the alternative assessment, if necessary.

Limitations

The current study is restricted to the evaluation of noise from those weapons which were provided for testing. The collection examined differs in part from what was looked at in 2009, prior to installation of the noise control treatments, and, as a result, a one-to-one comparison of results is not possible. However, this difference did not prevent the main purpose of the study from being accomplished.

There are many technical issues associated with measuring impulse noise in general, and in particular, in the complex environment at this large, tactical range. Field measurements of impulse noise are notoriously challenging. To get repeatable results, especially when doing comparisons, requires everything to be carefully controlled. This was largely accomplished within each set of data taken, where results were generally repeatable to within a decibel. This was not accomplished when microphones were moved to measure new sets of data at different target distances. Hence, the data sets showed variations of a few decibels. This was believed due, in part, to small differences in relative microphone distances (e.g., between the gunner and the microphone located in the adjacent lane), and partly to not controlling for angular position of the gunner position microphone relative to the axis of the weapon, as taken from the muzzle. These kinds of studies are relatively new, and we are still learning. It turns out that this angular position factor is more important than anticipated. There were other differences as well, such as the physical stature of the shooters involved in the two studies, which caused the gunner position microphones to be at different distances from the muzzle. The microphones were found to be 3 to 6 inches farther from the muzzle for each weapon type examined in the subject study due to this factor. All these things taken together detract somewhat from the strength of the observations made below. But, again, these things do not materially affect the findings or recommendations.

Comparison to Untreated Range Results and Estimated Benefit for “Ideal” Range Acoustical Treatment

The 2009 assessment of noise at the range included restrictions determined for several of the same weapons tested during the current study at the same range. The facility did not have acoustical treatment in 2009, but predicted restrictions were made, assuming the range to be “ideally” treated using noise controls like those presently installed. A comparison of all the worst-case restrictions (14 shooters firing simultaneously in the untreated range, and predicted and measured restrictions for an ideally-treated facility) when single hearing protection is used is presented in Table 3, and when double hearing protection is used is in Table 4. Except for the handguns, the treatment was successful in getting restrictions to at least the level that was predicted. Restrictions for the handguns are slightly more severe than predicted.

Table 3 Worst-Case Weapon Firing Restrictions at the Range with Single Hearing Protection Use.

Weapon	Predicted for Ideal Treatment*	As Presented in Table 1 Above
9mm handgun	1982	1795
.45 cal handgun	1349	1210
M4	367	385 to 639
M4	52	64 bursts
7.62mm Sniper rifle	292	474 to 960
M17	**	217
M240B	31 bursts	Not measured
M249	85 bursts	242 bursts

*From 2010 report
**Not measured, but should be similar to 7.62 Sniper rifle that was measured

Effect of Using Silencers

Testing was done at 7 and 25 m using the standard length barrel M4 with and without a silencer attached. As one might expect, the silencer reduced the peak noise substantially. Table 5 shows the 16 to 19-dB reduction of peak levels. The condition of the silencer was not recorded; results with different silencers could be several dB better or worse.

Table 5. Logarithmic Mean Peak Noise Levels at the Shooter Location from Silenced and M4 firings without silencer use, dBP (mean taken from 5 samples of individually fired rounds)

Distance to target, meters	Posture	Level without silencer, dBP	Silenced level, dBP	Difference in dB
7	Standing	163.9	147.0	16.9
25	Standing	165.6	146.9	18.7
25	Kneeling	166.1	147.4	18.7
25	Prone	166.9	150.6	16.3

The effect of a silencer on the shape of the muzzle blast waveform is very dramatic. Figures 1 and 2 show the gunner position time histories for the two conditions. Note the difference in scale. The squiggles at 130 milliseconds (ms) and later have the same intensity in both diagrams but appear different due to the scale. Figure 2 shows the time history of a typical silenced shot at 7 m. Note that the second half of the silenced noise signature starting at about 60 ms resembles that of an "unsilenced" sound. That is because the second half is not due to the muzzle blast, but rather the sound of the bullet striking the bullet trap. At this distance, the bullet sound has about the same peak level as the muzzle blast. This is not true at the 25-m distance, where the added distance subdues the noise coming directly from the bullet strike.

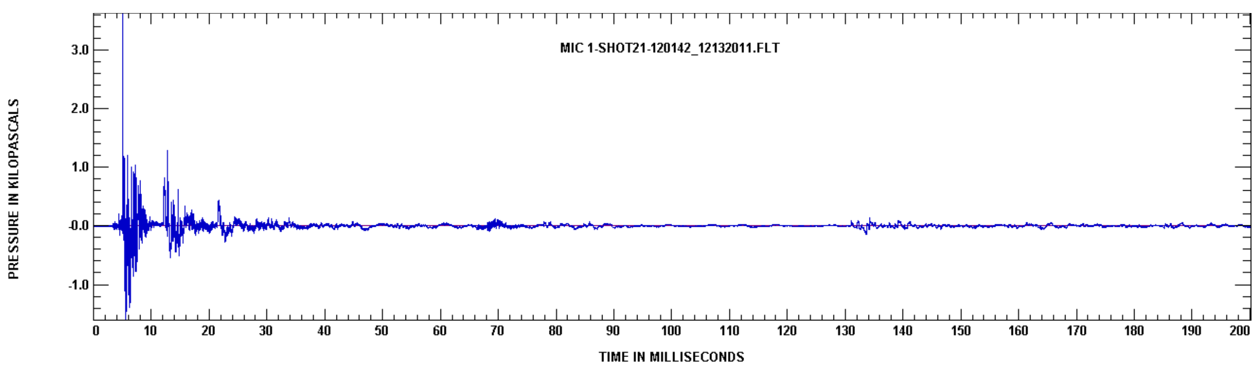

Figure 1. 25-m Waveform for M4 without Silencer

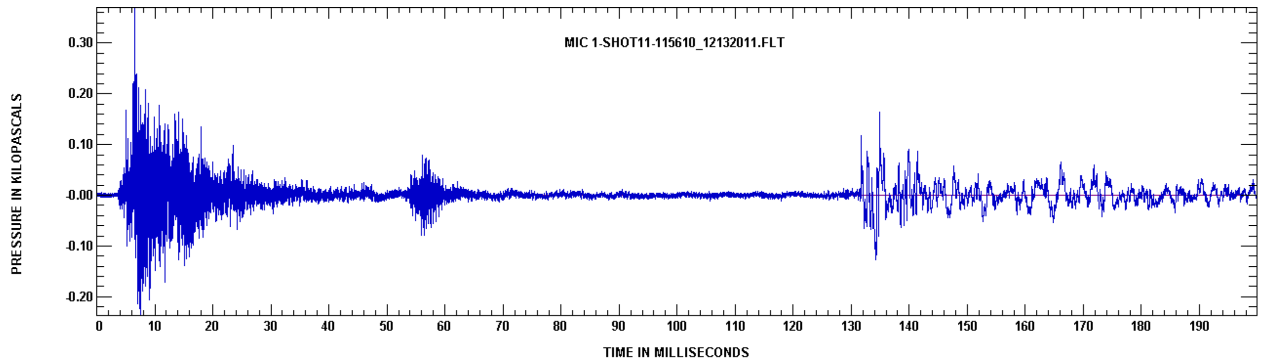

Figure 2. 25-m Waveform for M4 with Silencer

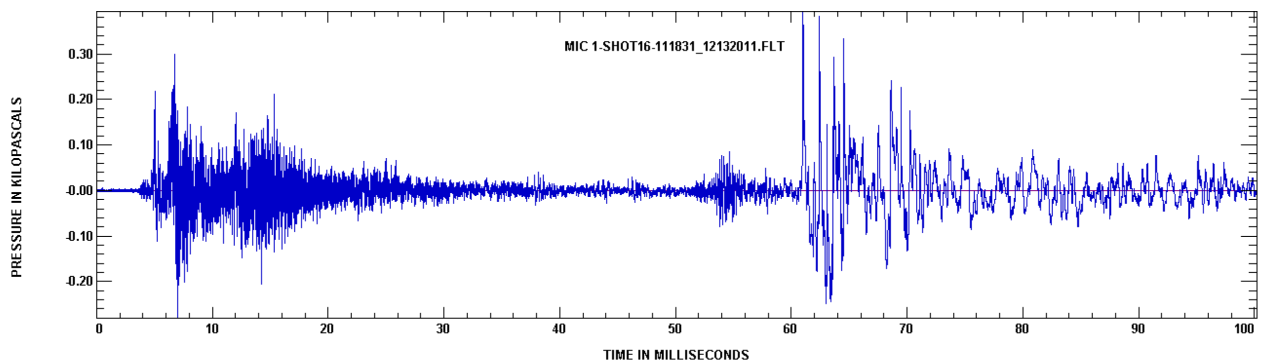

Figure 3. 7-m Waveform for M4 with Silencer

Effect of Posture

The weapons fired at the 25-m distance were all fired in three postures: standing, kneeling, and prone. In each case, the gunner microphone was 15 centimeters (cm) from the shooter's ear closest the muzzle, on a line from the ear to the muzzle, in accordance with the requirements of Military Standard-1474D (MIL-STD-1474D, Military Standard Design Criteria Standard, Noise Limits, 1997). Results are presented in Table 6. There is a tendency for levels to increase slightly as posture is lowered.

Table 6. Logarithmic Mean Peak Levels at the Shooter Location with Different Postures, Firings at 25 Meters from the Targets, dBP (mean taken from 5 samples of individually fired rounds)

Weapon	Peak Level, Standing, dBP	Peak Level, Kneeling, dBP	Peak Level, Prone, dBP
9mm	165.0	164.4	167.0
M4	165.6	166.1	166.9
M4, short	167.7	167.0	167.2
M4, silenced	146.9	147.5	150.5
M17	165.5	166.3	170.6

Interestingly, the peak level identified for the M17 firing was not always due to the direct sound from the muzzle blast. See Figure 4; there are two peaks about 1 ms apart. It is the second peak that is the loudest. This behavior is not present in the other weapon firings, where there is only a single peak. Although it is conjectural, the presence of two peaks spaced this close apart is usually caused by flashing (secondary detonation), and the phenomenon varies in intensity, sometimes making the second peak louder than the first. Flashing would explain why the other weapons do not exhibit this behavior. Without the presumed flashing, the peak levels shown in Table 6 for the SCAR prone would be about 3 dB lower, with smaller differences for the other postures.

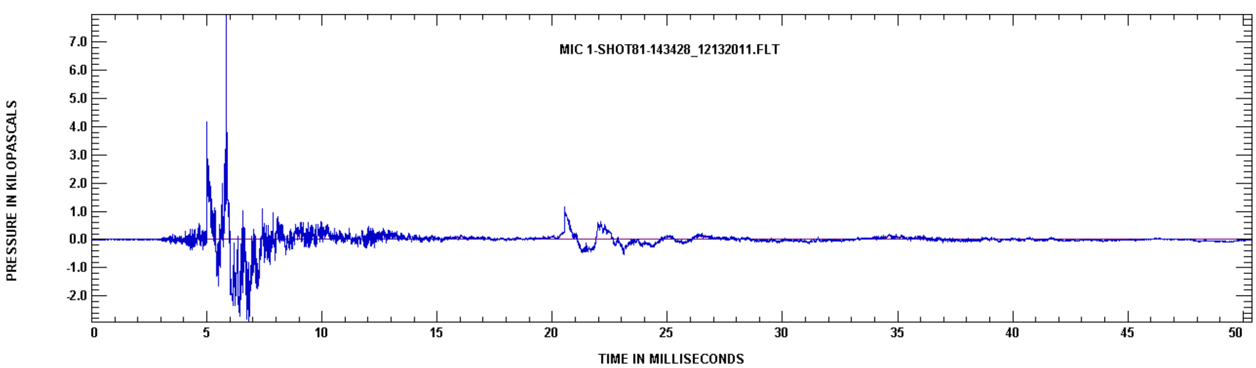

Figure 4. M17 Waveform

Effect of Distance to Target

Several shooting conditions were replicated at the three distances to the targets that were studied. There appears to be an unexpected trend in the results, with levels increasing with distance. See Table 7. This is more likely due to the one microphone involved at the shooter location inadvertently and gradually getting moved laterally away from the gunstock as the distance was increased. As mentioned above, the angle away from the muzzle is known to affect noise (peak levels are always greater the smaller the angle). This factor may not have been well controlled for with these measurements.

Table 7. Peak Standing Shooter Noise Levels, dBP, at Different Distances from the Targets for Various Weapons

Weapon	7 M Peak Level, dBP	25 M Peak Level, dBP	50 M Peak Level, dBP
9 mm	162.4	165.0	166.6
M4	163.9	165.6	167.8
7.62 cal SCAR	164.3	165.5	166
.45 cal	166.4	167.4	Not taken
M4 silenced	147.0	146.9	Not taken
M4 short	166.6	166.7	169.2

General Observations about Noise Control Treatments

It is immediately apparent that the situation is vastly improved by the installation of the noise control surface treatments. The weapon sounds are subjectively different because reflections are significantly reduced. In the untreated space, the sound bounces back and forth from floor to ceiling many times before it dissipates to the point of inaudibility. In the treated space, by the time the sound reflects even once from a treated surface, it is lowered to close to the point of not being hazardous. So the sound does not last for as long as in the untreated space. This has been amply demonstrated by the measurements of reverberation time made by the treatment supplier to demonstrate compliance with contractual requirements (but not reported on herein).

However, this does not mean that there are no reflections. Reflected sound does play a role in overall noise exposure, although that role is materially reduced. Both the floor and the target area remain reflective surfaces. The limiting factor for noise exposure reduction is the sound that comes directly from the weapon, which travels along the shortest path to the receiver and does not strike a treated surface within that time.

Figures 5A and 5B illustrate how the character of the time history changes by comparing the same weapon sound measured in the untreated space with that measured in the treated space. The big spikes are still present; they are the direct sound components. The smaller spikes are diminished.

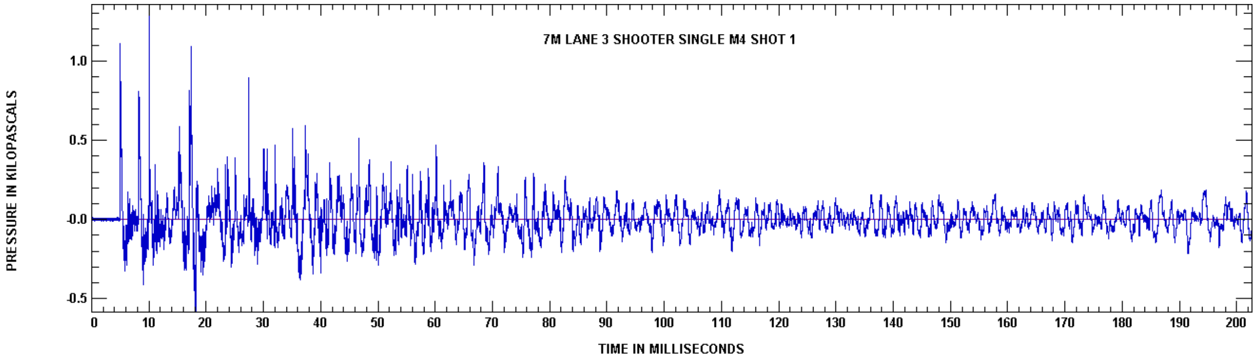

Figure 5. M4 at Unoccupied Lane in Untreated Range

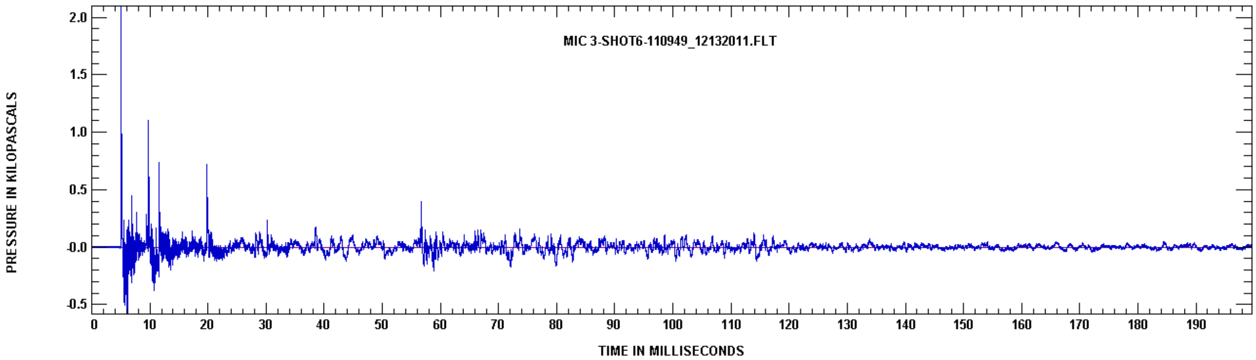

Figure 6. M4 at Unoccupied Lane in Treated Range

One characteristic that affects the hazard of the impulse noise is the B-duration, which is the time it takes for the sound to decay by 20 dB from its peak level. If the smaller spikes are eliminated, the B-duration is reduced. The lower the B-duration, the less hazardous the noise.

Table 8 compares the 7-m shooter before- and after-treatment, worst-case peak levels and B-durations for those weapons that were tested in the two studies, demonstrating the significant reduction in B-duration. Peak levels were expected to be the same, since those levels are controlled by the direct sound to which the shooter is exposed, and that is unaffected by the treatment. However, the lack of perfect control over the many variables involved had an effect in causing peak level variation.

Table 8. Worst Case Peak Levels, dBP, and B-durations, in ms, for the Shooter Firing Different Weapons at 7 m

Weapon	2009 Peak Level, dBP	2011 Peak Level, dBP	2009 B-duration, ms	2011 B-duration, ms
9 mm	164.1	162.8	43.8	8.4
M4	167.6	164.5	54.3	18.1
45 mm	166.0	166.8	38.2	7.6

Figures 7 and 8 illustrate a point related to this subject of minor differences in the waveforms resulting in major effects on calculations. In this case, the minor difference affects B-duration, which is not used in the Leq evaluation discussed above. Nonetheless, it is a point worth illustrating. These figures show two measurements of supposedly identical shots (the firing of the 9-mm handgun from 7 m). The horizontal dashed red lines indicate the B-duration for the two samples. The much longer B-duration in Figure 5A is caused by inconsequential differences in the amplitude of the reflection occurring at about the 45-ms mark.

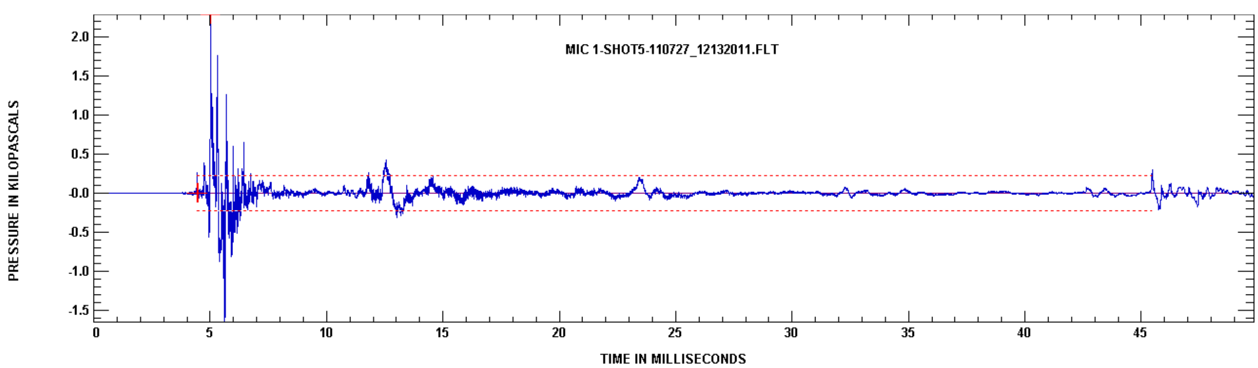

Figure 7. One Sample of 9-mm Handgun Fired at 7 m Showing B-duration Held Up by Minor Peak at 45 ms

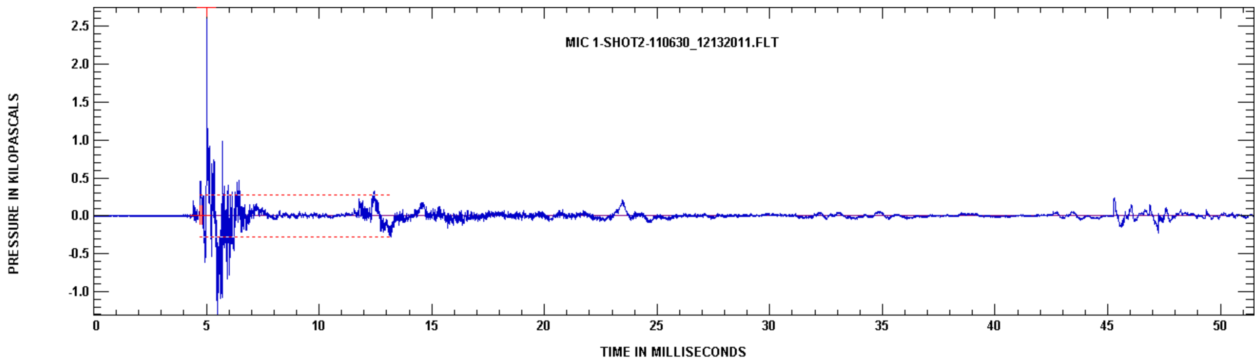

Figure 8. Second Sample of 9-mm Handgun Fired at 7 m Showing Much Briefer B-duration for Slightly Smaller Peak at 45 ms

RECOMMENDATIONS

Follow the firing restrictions shown in Tables 1A and 1B for multiple or single shooters active on the range, respectively, according to whether single or double hearing protection is used. Apply the firing restrictions to all the similarly sized ranges that have been acoustically treated with the same treatment as the subject range.

Apply the firing restrictions to other similarly-sized weapons that have not been specifically measured, subject to the caveats listed in the text immediately above Table 1.

Continue to provide single hearing protection for personnel in the control room, and require that this hearing protection be worn during automatic weapon fire.

As mission permits, shooters should be spread out to lower their noise exposure hazard and use flash and noise suppressors when firing weapons.

Table 4. Worst-Case Weapon Firing Restrictions at the Range with Double Hearing Protection Use

Weapon	Untreated Range*	Predicted for Ideal Treatment*	As Presented in Table 1 Above
9mm handgun	2201	6266	5675
.45 cal handgun	1622	4265	3828
M4	704	1162	1216 to 2021
M4	94 bursts	164	243 bursts
Sniper rifle	689	924	1499 to 3035
M17	**	**	855
M240B	48 bursts	97 bursts	Not measured
M249	58 bursts	277 bursts	768 bursts

*From 2010 report
**Not measured, but should be similar to 7.62 Sniper rifle that was measure