McDavitt Ryan C MR

From: Jokel, Charles R Mr CIV USA MEDCOM CHPPM [charles.jokel@us.army.mil]
Sent: Monday, March 29, 2010 3:02 PM
To: McDavitt Ryan C MR; Tyron Joseph D LTC
Subject: firing range study (UNCLASSIFIED)
Attachments: study results.docx

Classification: UNCLASSIFIED
Caveats: NONE

Attached is a memo describing firing limitations for Special Forces indoor firing ranges now under construction, when built with and without different degrees of sound attenuation incorporated in the final implementation.
The author of the report is Charles Jokel, noise control engineer for PHC, contact information below. The memo documents results of measurements made at the Special Forces range at Ft Campbell, KY (Dec
2009) and the Navy Seal range at Little Creek, VA (Jan 2010).

Chuck Jokel
US Army Public Health Command (Provisional) [formerly US Army Center for Health Promotion and Preventive Medicine (CHPPM)] MCHB-TS-MHC
5158 Blackhawk Road
Building E4435 room 107-5
APG, MD 21010
charles.jokel@us.army.mil
410-436-1058, DSN 584-1058
FAX: 410-436-4117

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USASFC(A)
Indoor Baffle Range
Noise Abatement Brief

18MAR10

Purpose

To provide USASOC(A) Command and staff the USASFC(A) acceptable corrective action to mitigate the noise levels within the Indoor Baffle Ranges at all SFG(A) locations.

Problem Set

- Noise Abatement
  - Current condition violates OSHA and Army noise safety standards
  - Both total sound pressure level and reverberation must be addressed
- Ballistics (Ricochet & Back Splatter)
- Capital Investment & Life Cycle Cost
- Weight (added load to the structure)
- USASFC(A) soldiers shoot more rounds per day than a typical indoor range, this increases the risk

Current Status

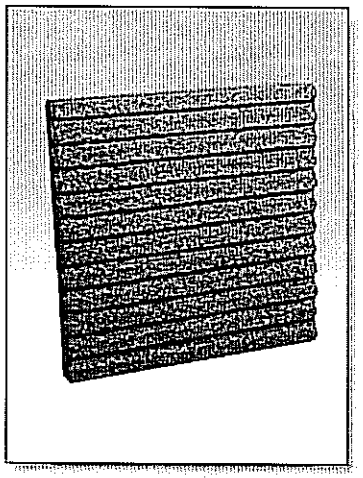
Location	Status
FLWA 1 SFG(A)	Construction on-going Structural
FBNC 3 SFG(A)	Construction on-going
FCKY 5 SFG(A)	Complete
EAFB 7th SFG(A)	Awarded
FCCO 10th SFG(A)	Complete

Testing

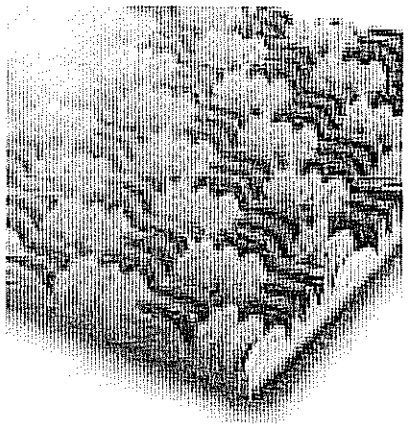
- Live fire testing conducted at FCKY on 15DEC09 by Mr. Jokel of USAPHC
  - Existing USASFC(A) range as constructed with no noise abatement
- Live fire testing utilizing the same methodology conducted at Little Creek Naval Base, Virginia on 24JAN10
  - Similar range treated with noise abatement foam on ceiling and above 7 foot above floor

Possible Solutions

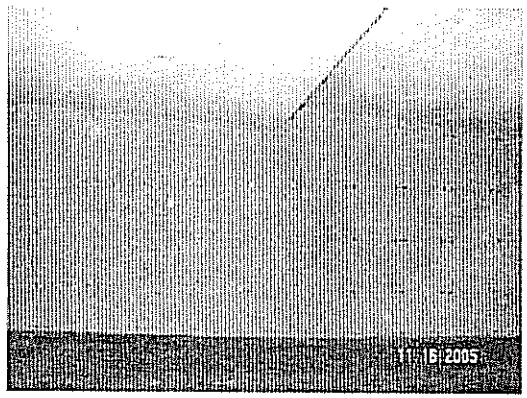
- Acoustical Dura Bloc Panel



- Noise Abatement Foam (Sonex)



- Troy Acoustics System



Product Comparison

System	NRC => 0.8	Material Cost	Install Cost	LBS/SF	Life Cycle
A-Dura Bloc	**0.65**	$11.25	$7.00	7.00	5 year or 2,200 Rounds
Foam (Sonex)	0.85	$6.33	$7.00	2.75	TBD
Troy Acoustics	0.95	$10.59	$700	3.50	5 year guarantee

Note: NRC => 0.80 is the minimum requirement, Dura Bloc is still needed for ballistic mitigation

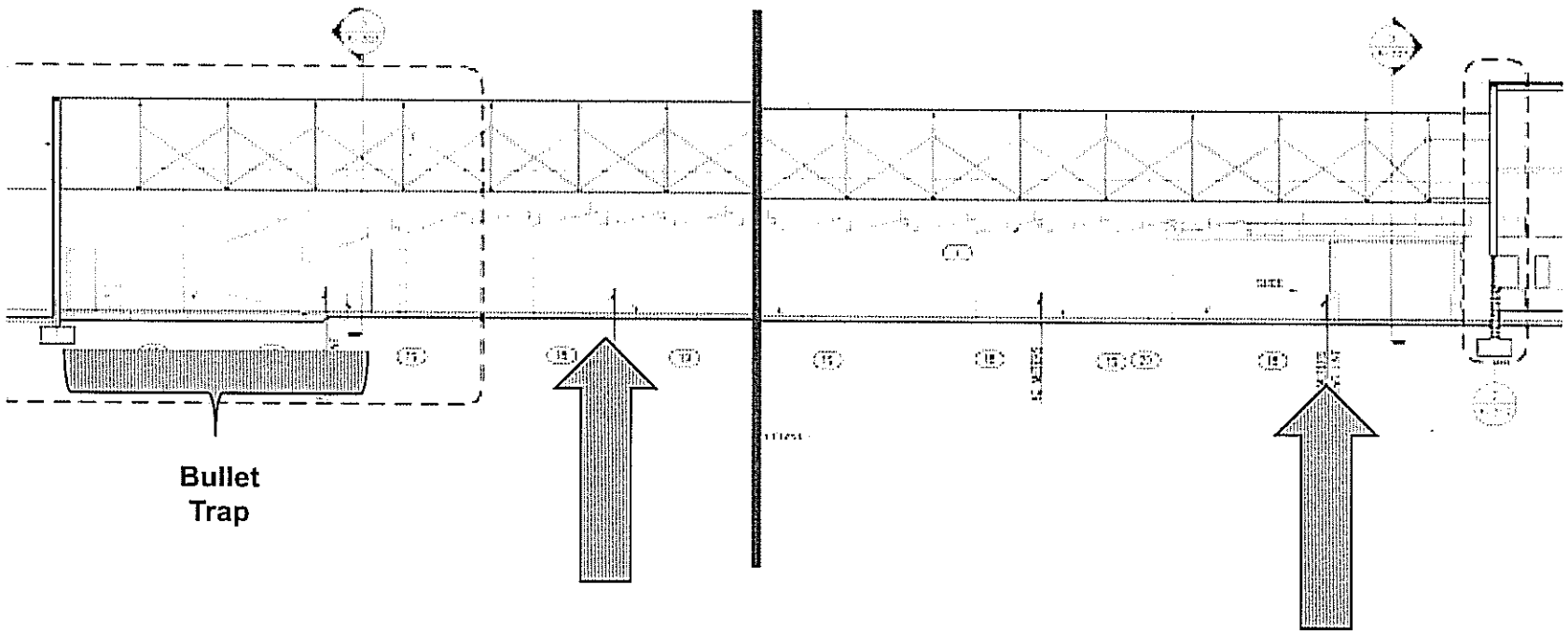
Performance Comparison

System	Noise	Ballistics	Cost
A-Dura Bloc	**Does not meet minimum standard**	Excellent	Highest
Foam (Sonex)	Good	None	Lowest
Troy Acoustics	Excellent	Good	High

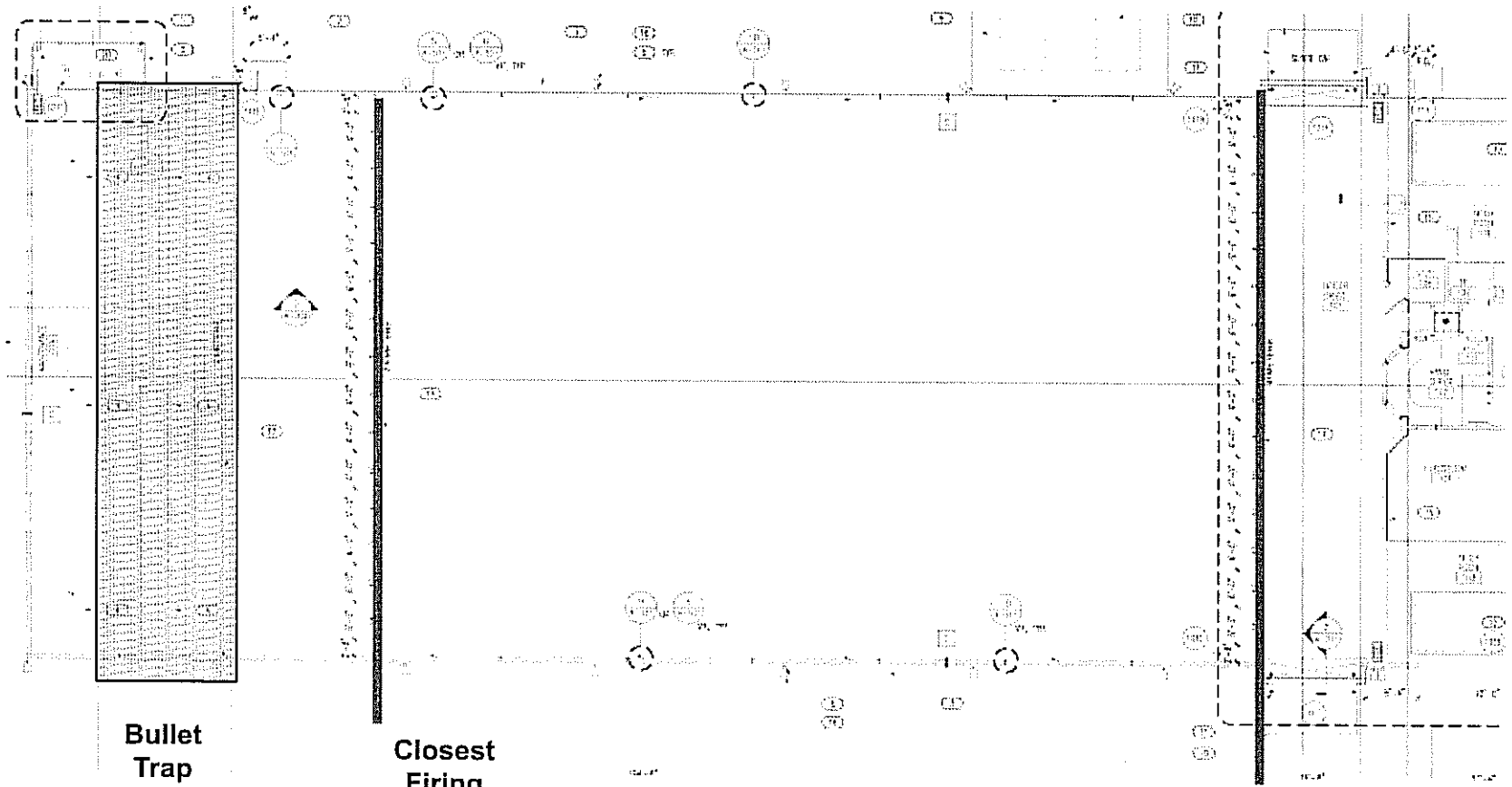
USASFC(A) Recommendation

- USASOC to address this issue for all five locations across & all five USACE Districts involved
- Potential for USACE (Huntsville or other) to manage all five IOT gain better economy of scale
- Implement corrective action NLT 120 days to the constructed ranges

Range Orientation (Section)



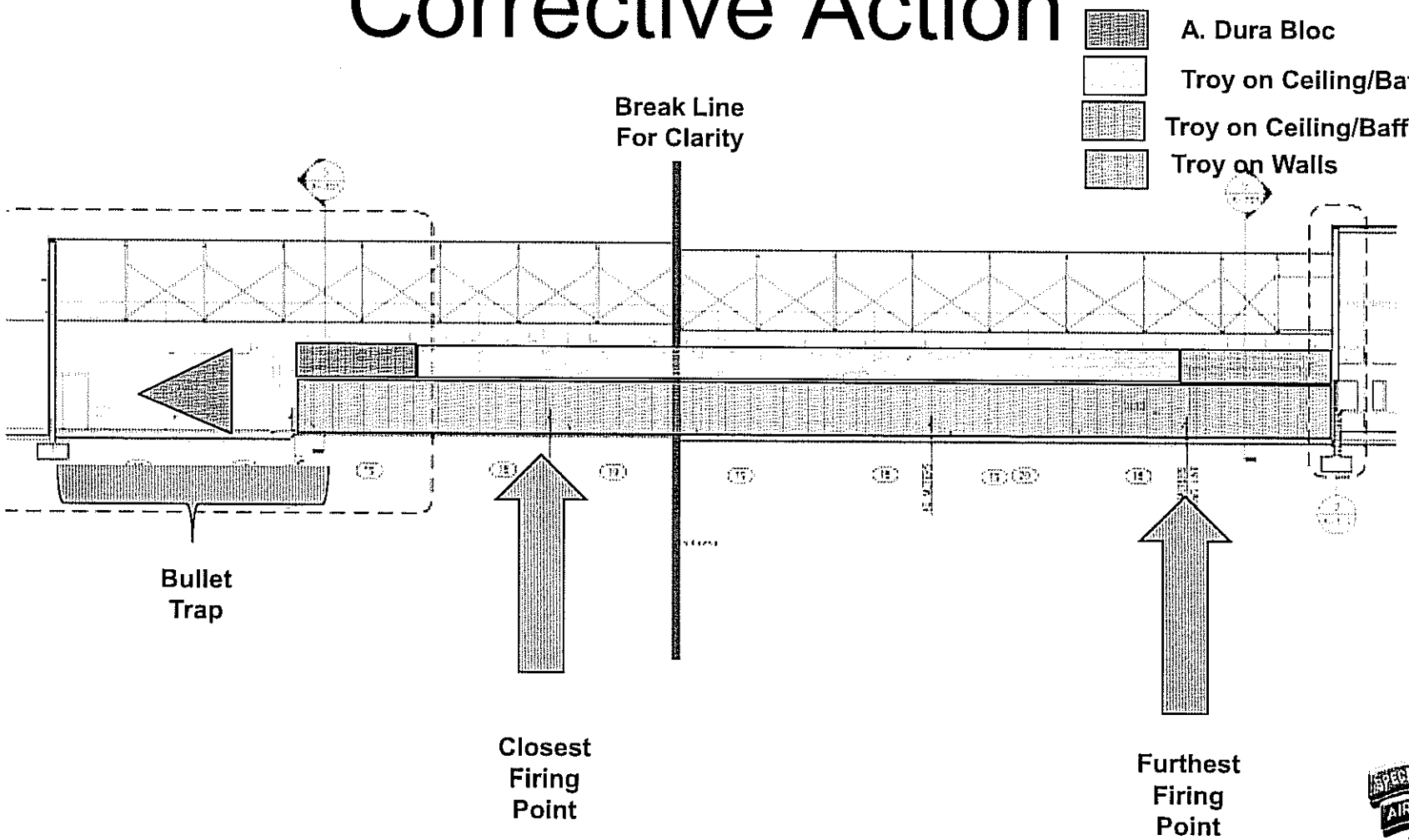
Range Orientation (Plan View)



USASFC(A) Acceptable Corrective Action

- Troy Acoustics floor to ceiling on three walls (not within bullet trap)
- Troy Acoustics on 18 of 20 baffles
- Acoustic Dura Bloc panel on 2 baffles closest to bullet trap (for ballistic mitigation)
- Acoustic Dura Bloc panel on the triangle portion of both walls within the bullet trap (for ballistic mitigation)
- Acoustic Dura Bloc panel on ricochet protection areas (outlet & door protectors)

USASFC(A) Acceptable Corrective Action



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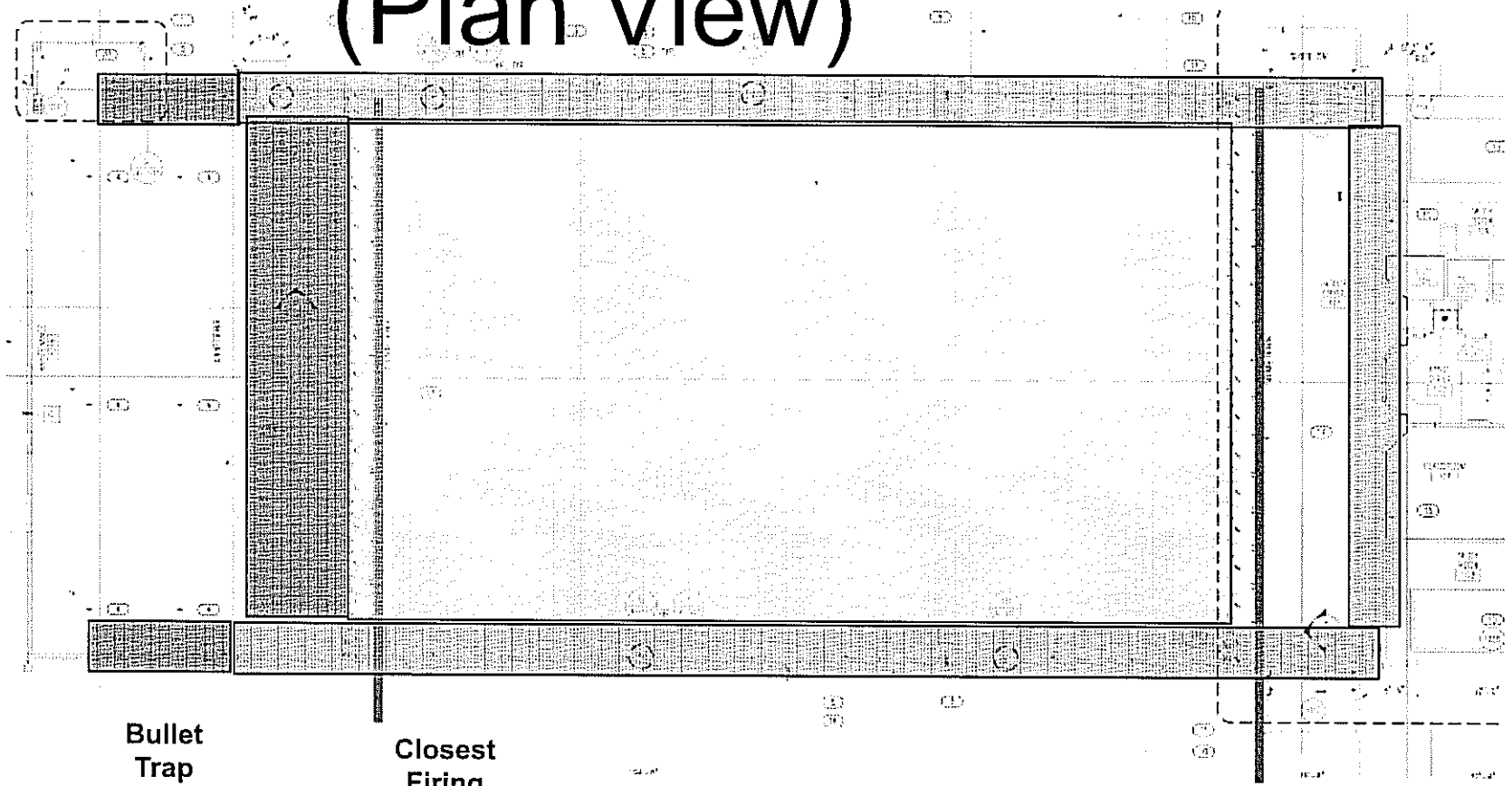
Corrective Action (Plan View)

A. Dura Bloc

Troy on Ceiling/Baffles

Troy on Walls



Bullet Trap

Closest Firing Point

Furthest Firing Point

Corrective Action

- Benefits
  - Best acoustic performance
  - Dura Bloc provides best ballistic performance
  - Long term, low maintenance
  - High quality installation with warranties

ROM IGE Per Range:	
Contractor	$350,000
Oversight (6%)	$ 21,000
Contingency (10%)	$ 37,100
Total	$408,100

$2.04M for all five ranges

Note: ~$400K contingency is available on the EAFB project.

Synopsis

Firing restrictions for a variety of small arms used in indoor firing ranges has been determined based on studies conducted at two similar ranges (Ft Campbell and Little Creek), differing mainly in acoustical treatment (Ft Campbell has none, Little Creek some). Restrictions have also been estimated for a range like the present Ft Campbell range, but fitted with "ideal" acoustical treatment, defined as material that optimally deals with sound absorption of small arms fire noise. The restrictions are summarized below for a range with shooters firing from each lane (simulating maximum noise production) and are based on a combination of direct measurement and modeling, using the most severe damage risk criteria that might apply to the situation. The numbers stipulate the number of rounds that each Soldier can fire in any 24 hour period. The caveat is that the shooters are to wear well fitted double hearing protection.

For purposes of decision making as to what to do about the noise, the restrictions may be thought of as falling into three categories: unacceptable (the present case at Ft Campbell), possibly acceptable for some applications (the present case at Little Creek), and best obtainable for already built facilities (note that different facility building designs might yield further improvements, but are beyond the scope of this study).

The numbers presented result from choosing the most medically conservative of two available Damage Risk Criteria for noise, neither of which perfectly deals with the kinds of noise exposure that result with small arms fired indoors but which are the best DRCs available. The restrictions are significant, but do reflect that the noise involved is intense and that the way the range is used is mainly with multiple shooters rather than individual shooters.

Allowed Number of Rounds per Day (or Bursts for Automatic Weapon Fire) when using Double Hearing Protection, for Indoor Ranges with Three Degrees of Acoustic Treatment

Degree of Treatment	Weapon						
	Sniper Rifle	M4	M4 (burst mode)	45 cal	9 mm	M240B (burst mode)	M249 (burst mode)
Bare walls (Ft Campbell)	689	704	94	1622	2201	48	58
Some treatment (Little Creek; 1-inch acoustic foam covering plywood)	825	997	139	3757	5308	85	225
Ideal Treatment (Like Little Creek but with 2-inch acoustic foam covering plywood or Troy System)	924	1162	164	4265	6266	97	269

I. Introduction

A. Background.

This study is intended to accomplish two things: (1) to describe firing limitations for the weapons that the Special Forces will be using at their indoor ranges now under construction, and (2) to evaluate the potential benefit of applying surface acoustical treatments to the currently untreated walls and baffles at the Special Forces ranges. Weapon fire was first measured at the brand new indoor range at Ft Campbell to address the first mission. Identical measurements were then done at the Navy Seal Little Creek range. An A to B comparison between the two facilities provided information about how much hazard is reduced with treatment. Some physical differences between the two ranges and issues with getting the same complement of weapons tested at Little Creek range complicated the assessment. Nonetheless, the comparison study does provide useful information and enables a prediction of the effect on firing restrictions of "ideal" treatment to be developed.

Noise assessment of indoor firing ranges is complicated, particularly for tactical ranges where the sounds involved can originate anywhere in the space, at any time, and can originate at many locations simultaneously. A major complication is that no hazard assessment criterion applies directly to the situation; interpretation of how to apply existing criteria is required. Obviously, there is impulsive noise present, and there are criteria that apply to impulsive noise. But the kind of noise environment that is created in the ranges can and often is one where the impulses occur spaced out in regular or irregular ways over extended periods of time, and existing impulse noise criteria apply to more defined situations. Conversely, the criteria available to assess noise that is present over extended periods of time...what are called steady state noise criteria...may not work well with exposures consisting almost entirely of individual impulses. As a consequence the assessment approach examines the environment from both perspectives, separately treating the exposures involved as both impulsive and steady-state. Comments are offered below as to how to best interpret the results.

B. Summary of Firing Limitations

Table 1 summarizes the results of the analysis for the Ft Campbell firing range shooters, as that facility currently exists (without any acoustical surface treatments). Limitations based on the impulse and steady-state criteria are presented. The key number is the Allowed Number of Rounds (ANR) which refers to how many rounds are permitted during a 24-hour period. Whichever criterion governs the single shooter situation is highlighted in red for the single

shooter case and in blue for the multi-shooter case. The ANR for the impulse criterion are multiplied by 20 if double hearing protection is worn; the increase for wearing double protection with the steady state criterion is level-dependent but roughly triples the ANR compared with the single protection number.

Table 1. Daily Allowed Number of Rounds or Bursts by Weapon and Criterion for Single and Multiple Shooters at the Ft Campbell Range as a Function of Criterion and Hearing Protection Usage.

Criterion	Condition	Weapon						
		Sniper Rifle	M4	M4 (burst mode)	45 cal	9 mm	M240B (burst mode)	M249 (burst mode)
Impulse criterion with single hearing protection	single shooter	1443	429	79	1428	2857	105	525
	multiple shooters	662	385	71	690	1389	40	183
Impulse criterion with double hearing protection	single shooter	28860	8580	1580	28560	57140	2100	10500
	multiple shooters	13245	7692	1415	13790	27772	809	3657
steady state criterion with single hearing protection	single shooter	741	851	100	2187	2754	89	147
	multiple shooters	218	222	30	513	696	15	18
steady state criterion with double hearing protection	single shooter	2137	2691	316	6918	8709	281	467
	multiple shooters	689	704	94	1622	2201	48	58

Table 2 summarizes the Little Creek range firing limitations against identical criteria for the two rifles and one handgun that could be evaluated.

Table 2. Daily Allowed Number of Rounds by Weapon and Criterion for Single and Multiple Shooters at the Little Creek Range When Firing From the 10 Yard Line as a Function of Criterion and Hearing Protection Usage.

Criterion	Condition	Weapon		
		Sniper Rifle	M4	9 mm
Impulse criterion with single hearing protection	single shooter	8556	817	5935
	multiple shooters	1408	621	4762
Impulse criterion with double hearing protection	single shooter	171320	16340	113280
	multiple shooters	28160	12420	95238
steady state criterion with single hearing protection	single shooter	3019	2137	1380
	multiple shooters	261	315	1678
steady state criterion with double hearing protection	single shooter	9549	6760	4365
	multiple shooters	825	997	5308

C. Conclusions

Some of the conclusions that can be drawn from the analysis are:

1. With some weapons, the steady state noise governs the situation for the single shooter case (dBA levels control over dBP levels), with others impulse noise governs. The steady state noise governs in all multishooter cases.
2. Single shooter limitations are reasonable, even with only single hearing protection being worn, but the range is designed for multiple shooter use.
3. Multiple shooter limitations are restrictive, particularly for weapons fired in bursts.
4. Direct sound, which is a significant contributor to exposures, will always be present, regardless of whether or not surface treatment (the only practical means of noise control) is applied. Fortunately, the surface treatment will have an indirect effect of lowering the B-duration of each impulse, lessening the effect of both direct and reflected sounds.
5. Surface treatment will also reduce reverberation time significantly and thus alter (improve) the "character" of the sound heard, but different metrics of the acoustical nature of the range, besides reverberation time, may be needed to estimate changes in ANR. Reliance on a performance metric such as reverberation time to indicate potential health effects is risky.
6. In a tactical range, such as the ones used by Special Forces, the more surfaces covered by acoustic treatment, the better. Priority should be directed at covering ceiling baffle surfaces, but covering side and rear wall surfaces will provide further benefit.
7. With fixed line ranges, most benefit is obtained by surface treatment near the shooting line. It is not necessary to cover distant baffles with acoustic treatment. Other kinds of noise control, specifically acoustically lined barriers between lanes, would be of greater benefit and would aid in ventilation control.
8. Single hearing protection should be provided to control room personnel, but their use may not have to be made mandatory depending on the amount of automatic weapon fire that takes place.
9. If ceiling surface treatment in a tactical range does not completely cover the ceiling area, firing restrictions will depend on exact firing positions relative to the areas that are covered.

D. Summary of Recommendations

1. Limit exposures in the range to the most rigorous restrictions given in Table 1 that are appropriate for using single or double hearing protection (whichever is determined as policy) until the range can be acoustically treated.
2. Apply surface treatment like the foam covered plywood treatment at Little Creek to the ranges, and once accomplished limit exposures to the most rigorous restrictions given in Table 2 for the appropriate use scenario.

3. If the Troy system or a 2 inch foam treatment over plywood is implemented, firing restrictions can be further relaxed, and predicted restrictions are presented below (Tables 20-23).
4. Reevaluate the situation after a treatment is implemented.
5. Provide hearing protection for personnel in the control room and require the protection be worn during automatic weapon fire if such weapon fire is more than occasional.
6. If opportunity permits, shooters should be spread out to lower hazard. There is also a small benefit that will accrue by grouping shooters in central lanes, rather than end lanes, when possible.

I. Impulsive criteria

A. General

The hazard assessment of impulsive Army weapon noise typically begins by examining the peak level of the sound produced by the weapon, and a characteristic of the time-history of the noise signature (the waveform) called the B-duration. The peak level is the maximum instantaneous pressure recorded, expressed either as a pressure term (pascal or kilopascal) or more commonly, as a peak decibel level, dBP. The B-duration is the time it takes for the peak to decay by 20 decibels, thus providing an indication of its persistence. It is expressed in milliseconds (msec). These two characteristics are used in a formula contained in MIL-STD 1474D which determines the allowable number of rounds per day that may safely be fired, assuming the person exposed is wearing hearing protection. The hazard associated with noise exposure is inversely proportional to the ANR. The higher the ANR, the less hazardous is the noise.

This methodology for assessing impulse noise associates the noise coming from a single weapon to the person or crew using that weapon and to personnel who may be nearby. In a firing range, impulsive noise exposure generally originates from multiple sources. For shooters, there is the noise of the shooter's own weapon to contend with, as well as the noise coming from weapons in adjacent firing lanes and from reflections. Such exposure is going to be dependent on the amount of time the shooter is going to spend in the range and on the level of activity around him, as well as the particulars of the weaponry being fired and the acoustical characteristics of the range. For this analysis, a methodology that has been developed for exposure to mixes of impulses with different levels of weaponry used outdoors is applied to the more complex indoor situation.

The DTC group responsible for taking the measurements evaluated here provided a list of the specific measurement equipment used in the study, and that list is presented in Appendix A.

Each digitized sample obtained was manually post processed at PHC to permit examination of the individual time histories of the shots and to quantify key noise characteristics.

To keep the measurement program manageable, all shooting was done with the shooter in the standing position. Since a shooter was present (as opposed to firing remotely with the weapon mounted in a jig), microphones were placed at a standard height of 1.6 m, 15 cm from the ear of the shooter, on a line between the shooter's ear closest the muzzle and the end of the muzzle. This resulted in the microphones positioned at the distances listed in Table 3 from the muzzle of the weapon used by the shooter. Additional microphones were placed at a 1.6 m height at the center position of two other lanes. When firing was done at lane 1 (the one closest the right-hand wall facing downrange), the two other instrumented positions were lanes 3 and 7. When the firing was done at lane 7 (the center lane), the two other instrumented positions were lanes 1 and 3. Additional Data was taken at two positions in the reverberant sound field.

Table 3. Distances From Microphone to Gun Muzzle.

Weapon	Distance in inches
7.62 sniper rifle	28
5.56 M4 rifle	19.5
45 cal handgun	17.5
9 mm handgun	17.5
M240B Machine Gun	23
M249 Machine Gun	22

The following figures illustrate some key aspects about the sounds investigated.

Figure 1A illustrates a typical waveform for the shooter position, in this case the sound caused by firing a shot from the sniper rifle. All the other single shot shooter position waveforms are similar in nature, varying only in detail. The first 1.5 seconds of the sound are displayed (the sound continues to echo beyond this time in a space with hard surfaces, such as at Ft Campbell). In this case, the peak level very near the beginning of the waveform reaches about 3.4 KPa, which is equivalent to almost 165 dBP. That peak is due to the muzzle blast reaching the microphone. Reflections of that blast are seen as gradually decaying spikes in the trace.

Figure 1A. Example of Single Shooter Noise Exposure.

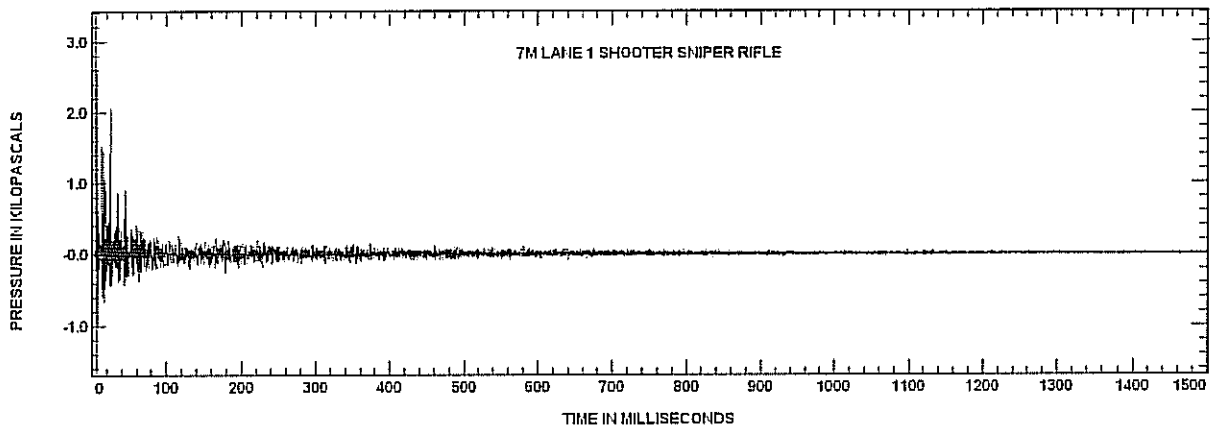


Figure 1B zooms in on the first 200 msec of the signal to illustrate two things: the dominance of nearby reflections, and the B-duration. The most significant reflections all occur within the first 50 msec in this case; the energy in this waveform is hardly affected by the "tail" after this period. The sharp spikes in the waveform are each a reflection that originates off of the floor, ceiling, wall, or bullet trap. It is possible to label the reflective surface of each spike because the reflective surfaces are at a known distance from the shooter, and the speed of sound is also known (sound travels about 1 foot per msec). Reflections from the back wall and side wall farthest from the shooter, are going to have a lot of time to decay before getting back to the shooter. These distant reflections are thus immaterial to the overall exposure. The dashed lines represent the extent of the B-duration for this shot.

Figure 1B. Expanded View of Single Shooter Noise Exposure.

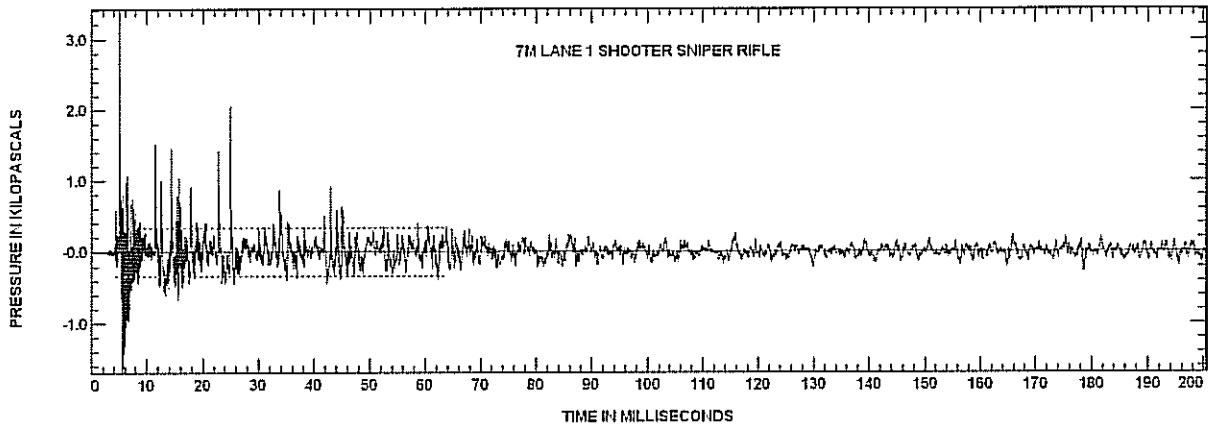


Figure 2 shows the waveform at the lane 1 shooter position when similar weapons are fired near simultaneously at lanes 1 through 7. The main spike at about 40 msec is due to the muzzle blast associated with the lane 1 weapon firing. The direct sounds from muzzle blast originating in nearby lanes are much lower in amplitude because of normal sound decay with distance. In this case, the B-duration is going to depend on the exact sequence of weapon fire. If the lane 1 weapon fires first, the B-duration would be longer than if it is fired last. The variability of

possible B-duration certainly complicates the analysis to follow because the available criteria for hazard of impulse noise exposure consider the B-duration to be a weapon-related characteristic and here it is a characteristic affected by the operation. In a sense, this issue is moot because most of the firing limitations turn out to depend on measures of the noise that relate to the average level, and not to impulsive character such as the B-duration. But for purposes of assessing the noise against impulse criteria it does need to be noted that a single B-duration is assumed for each weapon, and that B-duration is established at the shooter position when the shooter is the only one firing the weapon; in other words the influence of firing sequence for multishooters is ignored.

Figure 2. Example of Multiple Weapons Being Fired Near Simultaneously at the Lane 1 Shooter Position at Ft Campbell.

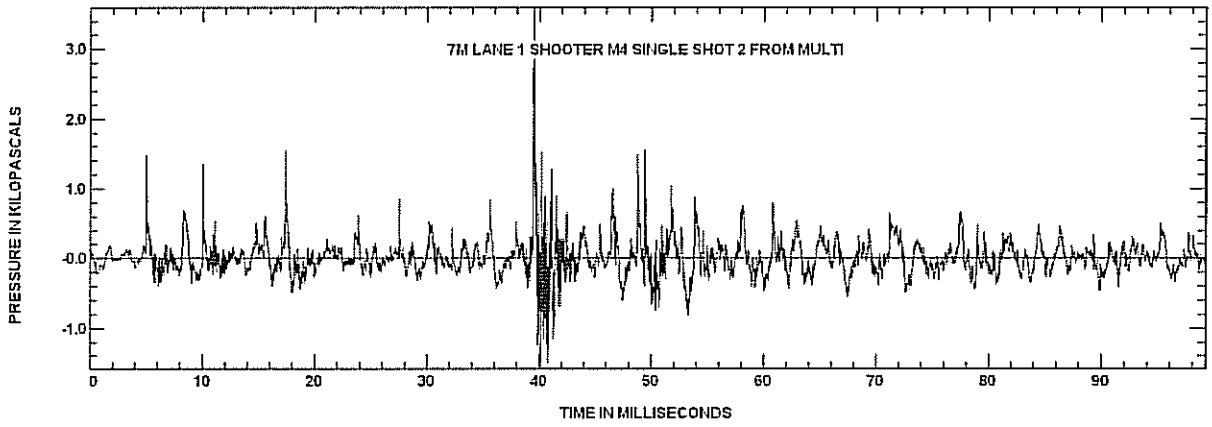


Figure 3 shows the waveform at the lane 1 shooter position when that shooter is the only one firing a weapon, and he is firing the M4 in automatic mode, producing a 7 round burst. There is some variability in the pressure levels for each shot within the burst, but when the pressure levels are converted to decibels, the differences are small. In any case, the differences are probably due to slight changes in position of the muzzle relative to the microphone as much as with normal (very small) round to round variation in noise. In this case, the B-duration is defined according to MIL-STD 1474D as the B-duration for a single shot multiplied by the number of rounds shot per 200 msec interval.

Figure 3. Example of Automatic Fire From a Single Weapon at the Lane 1 Shooter Position at Ft Campbell.

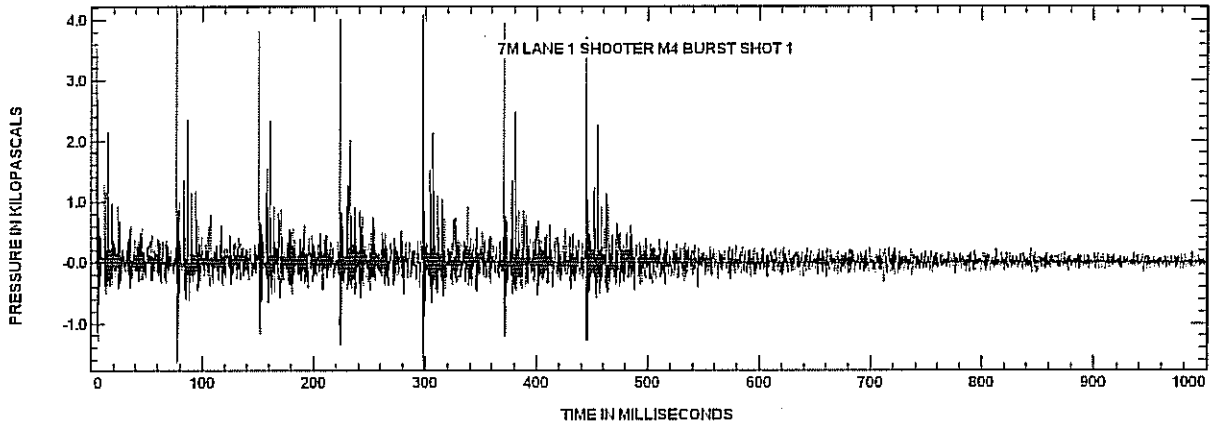


Figure 4A and 4B show what the waveform typically looks like at an "instructor" position, 10 feet directly behind the Lane 1 shooter firing a single shot from an M4. The level of the muzzle blast is much reduced and closer to the background levels, so the details of the tail part of the waveform are more apparent in this illustration. Were a B-duration for this waveform to be established, it would reach the 200 msec worst case value used in MIL STD 1474D because reflections keep noise levels high compared with background for quite some time.

Figure 4B (the first 100 msec of the waveform shown in Figure 4A) illustrates that the reflected sounds at the instructor position from the ceiling can register higher than the directly received sound, even though they travel further and thus had more chance to decay. The directly received sound is the very first spike at 5 msec. All the other spikes are due to reflections. The reason the reflected sounds a few msec after the direct sound can be higher is that the peak levels become exaggerated if striking the microphone surface perpendicularly. Such is the case with the ceiling reflection impinging on the vertically oriented microphone. Peak levels are accurately determined only when the sound approaches the microphone from the side (or comes from below).

Figure 4A. Example of Instructor Noise Exposure from the Firing of an M4 in Lane 1 at Ft Campbell.

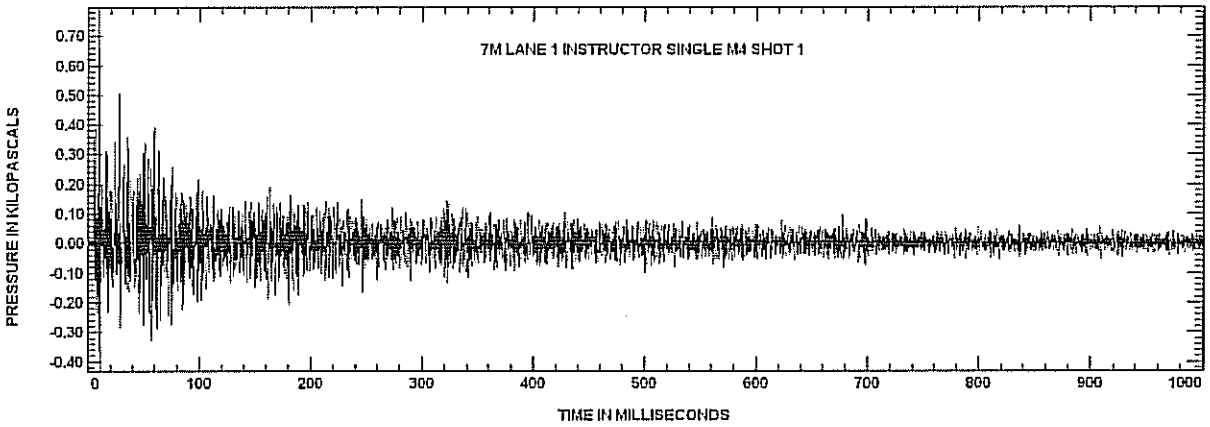
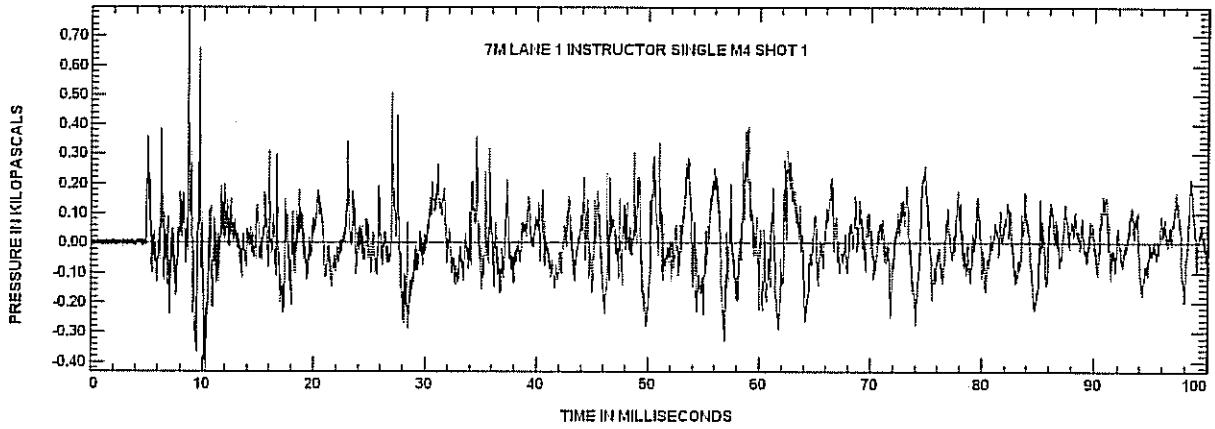


Figure 4B. First 100 Msec of Time History of Waveform Shown in Figure 4A.



B. Impulse Analysis of the Untreated Range at Ft Campbell

1. Shooters; The Simplest Case for an Untreated Range

Assume there is one shooter on the range firing his weapon. Assuming the noise signature is always the same, doing this gives us an upper bound on what number of rounds can be safely fired in the range; there is no additional noise to consider from other weapons being fired.

In the case for an untreated range (one without any sound absorbing materials on range surfaces), it does not matter where the shooter is firing from, because the peak levels and B-durations are not going to change. This would not be the case for a partially treated range, as discussed later.

The firing limitations for the single shooter case are presented in Table 4. The M4 firing in automatic mode and the machine gun ANR are expressed in terms of bursts, not rounds. The term "effective" in the B-duration column means that the B-duration has been calculated based on the MIL-STD 1474D standard, as required for such fire. The "+" symbol indicates the actual B-duration calculates to a higher number, but is truncated to 200 once that level is reached because firing limitations do not change beyond that number.

The ANR values for the untreated range presented in Table 4 are obtained by plugging the worst case peak level and B-duration 7 meter Ft Campbell results into the MIL-STD 1474D equation. The actual amount of data that was recorded and the information extracted from the raw data is very extensive. An example of the kinds of details that were obtained (for the M4 rifle in this case) is given in Appendix B. The results were hand initially hand tabulated from the raw data,

so not all the details are available in as neat a form as in Appendix B for all the weapons. However, the additional detail can be furnished if requested. Data for the 50 m firing line there have not yet been reduced, and will be provided separately.

Table 4. Single Shooter Firing Restrictions For an Untreated Indoor Range, Based on Measurements At the 7 Meter Firing Line (Worst Case) and on the Impulsive Noise Criterion.

Weapon	Peak Level, dBP	B-duration, ms	ANR*
7.62 sniper rifle	164.7	59.5	1443
5.56 M4 rifle	167.6	54.3	429
5.56 M4 rifle auto	167.5	200+ effective	79 bursts
45 cal handgun	166.0	38.2	1428
9mm handgun	164.1	43.8	2857
M240B machine gun	166.9	200+ effective	105 bursts
M249 machine gun	163.4	200+ effective	525 bursts

*Allowable Number of Rounds; multiply by 20 if double hearing protection is worn

2. Shooters; The More Complex Case for an Untreated Range

Assessing the more complex case of there being multiple shooters involves accounting for additional noise exposure due to sounds directly from other weapons being fired and the reflections associated with those shots, as well as from the noise from the shooters own weapon. Because all these impulses arriving at the shooter's ears have their own levels, there is no single equation that can be used to establish an ANR.

Experience with dealing with mixed noise exposures from firing howitzers with different charge levels during the course of a day of training provides a means to integrate the various shots into a single exposure to evaluate hazard. The method treats each impulse as contributing a "dose" of noise to a combined total. Each dose is proportional to the ANR for that impulse, if taken as the only kind of sound involved in the exposure. In this process, louder impulses get weighted proportionally more due to the logarithmic nature of the criteria used to calculate the ANR. The individual doses then are summed according to whatever firing scenario is considered. The ANR that falls out when the total of all the doses is 100% yields the sought after final number.

Admittedly, this method is a bit simplistic in that it implies the hazard associated with each impulse is independent. In reality, the hazard is probably influenced by the exact timing of the impulse, such that complete independence for two shots heard very close to one another is going to be different than if spaced out in time. However, given the likely distribution of weapon firings during the course of the day, the adopted method seems a reasonable way to tackle the problem.

In summation, the dose per round fired is going to consist of:

1. Noise directly from the shooter's own weapon. This has been measured (for example, it was 0.069% for the shooter in lane 1 when the sniper rifle is fired from lane 1). The values come from calculations using ANR values determined from worst case peak levels for weapon noise drawn from data such as is shown in Appendix B. The inverse of the ANR, multiplied by 100 is the dose per shot; those values have been used to populate the dose contribution in the column headed "Directly from Shooter's Own Weapon" in Table 5 which follows.
2. Noise directly from each of the weapons in each other lane. This refers to propagation of the original muzzle blast coming directly from the weapon, without reflection. This was measured in lane 3 for each firing, and in either lane 1 or 7 when the weapon was fired in lanes 7 or 1 respectively. The values for the noise coming from each of the other lanes can be estimated based on the laws governing how point sources of sound decay with distance (sound decays at 6 dB per doubling of distance). This means that the noise from lane 2 based on the measurement in lane 3 would be 6 dB higher (It is half the distance to the muzzle), and the noise from each more distant lane (to either side) would be proportionately lower. An example of the calculation is given in Appendix C. Measurements agree reasonably with the model described here. The weapon-specific sums due to this contribution are used to populate the next row in Table 5.
3. Noise from closest reflections. A model predicting levels and consequent doses from reflections off of the ceiling, floor, walls and bullet trap has been developed and an example of the calculations involved (for the Sniper Rifle) is given in Appendix D. It starts with measurements of the direct noise in lane 3, with reflected wave levels calculated based on how much further the reflected wave travels than the direct wave. Calculations were made for weapons fired from all lanes, but it turns out that reflected noise from only the closest two lanes on both sides of the shooter matters. The model predicts noise from closest reflections for the most impacted lane, which is the one in the middle of the range (lane 7). The total from these closest reflections is provided in the row headed "From Nearest Reflections" in Table 5.

Table 5 compiles the doses received for each weapon, and presents the corresponding ANRs. Note these ANR values are all lower than for a shooter firing alone.

Table 5. Multiple shooter Doses and Daily ANR for the Untreated Range (All Lanes Occupied), Based on Impulse Noise Criterion (and Worst Case Measured Levels).

NOISE	WEAPON						
	Sniper Rifle	M4 Rifle	M4 burst	45 cal	9 mm	M240B	M249
Directly From Shooter's Own Weapon	0.069	0.233	1.259	0.070	0.035	0.955	0.191
Directly From All Other Weapons	0.069	0.023	0.130	0.074	0.037	1.428	0.281
From Nearest Reflections	0.013	0.004	0.024	0.001	0.000	0.088	0.075
Total dose/round	0.151	0.260	1.413	0.145	0.072	2.471	0.547
Resultant ANR for single hearing protection	662	385	71	690	1389	40	183
Resultant ANR for double hearing protection	13245	7692	1415	13790	27772	809	3657

3. Instructors or Other Personnel On The Untreated Range During Weapon Fire

For personnel who are in the range near the shooters (as opposed to being in the control room) as part of their job, they will be exposed to less noise than the shooters per unit time.

A crude estimate of the exposure of these other personnel can be gotten by using the above analytical approach, but dropping the contribution of noise coming directly from the shooters' own weapon. It will be crude because Table 5 is based on sound that travels sideways, and anyone else in the range will stand behind the shooters thus receiving weapon noise that is considerably quieter due the directionality of the sounds and to the extra distance. Table 6 compiles the same information provided in Table 5 after dropping the contribution from the shooters own weapon. Again, this is a crude estimate and actual restrictions should be much more relaxed.

It is understood that the personnel who do the "instructing" in the Special Forces do not do the instructing as a regular job. Accordingly, it is assumed the Special Forces instructor will not be exposed to any more weapon fire than the personnel actually doing the shooting. Since these estimated exposures already yield more relaxed firing restrictions for the instructor, a more

refined modeling has not been attempted. A more detailed and accurate assessment of this situation can be prepared in lieu of the estimate if the firing restrictions for the instructors presented here are considered too restrictive.

Table 6. Estimated Doses and Daily ANR for Instructors on the Untreated Range during Weapon Fire.

NOISE	WEAPON						
	Sniper Rifle	M4 Rifle	M4 burst	45 cal	9 mm	M240B	M249
Directly From All Other Weapons	0.069	0.023	0.130	0.074	0.037	1.428	0.281
From Nearest Reflections	0.013	0.004	0.024	0.001	0.000	0.088	0.075
Total dose/round	0.082	0.027	0.154	0.075	0.037	1.516	0.356
Resultant ANR for single hearing protection	1220	3704	649	1333	2703	66	281
Resultant ANR for double hearing protection	24390	74074	12987	26667	54054	1319	5618

4. Control Room personnel

Peak levels, maximum slow response A-weighted sound levels, and Leq measured over 10 second intervals were measured for all the weapon shots at Ft. Campbell using a hand held Larson Davis 831 sound level meter equipped with a ¼ inch microphone. The worst case sound level results are summarized in Table 7. Sound levels exceed 85 dBA only when weapons are fired in the burst mode. Normally, hearing protection is required to be worn when sound levels exceed 85 dBA, but facilities may waive that requirement if the above-85 dBA noise is very infrequent. No overall daily exposure in the control would be expected to exceed an 8-hour 85 dBA steady state value, or a 140 dBP value. No control room data was obtained at Little Creek.

Table 7 Range of Worst Case Noise (Across Weapon Types) in the Ft Campbell Control Room

Condition	Firing Position	A-Weighted Sound Level, slow response, dBA	Peak Sound Pressure Level, dBP
Single shot	7 m line	62.6-81.9	91.9-104.7
Bursts	7 m line	87.4-87.9	106.9-108.4
Single shot	50 m line	66.6-84.8	91.6-105.9
Bursts	50 m line	86.2-95.5	103.5-116.8

C. Impulsive Noise in a Treated Range

1. 10 Yard Firing Line Results

The data for the treated range presented in Table 8 are worst case values extracted from the 10 yard firing line results obtained at Little Creek. The firing limitations in this table would apply if there were only a single shooter on the range; these figures are directly comparable to the figures given in Table 3 for the untreated range. Again, the reduced data are extensive and are currently available only in hand tabulated format. The data can be tabulated and provided if requested.

The 10 yard line is midway beneath 3 downrange spans of acoustic foam lined ceiling baffles. At this location the ceiling is covered with sound absorbing foam material (believed to be 1-inch thick Sonex) for 21 feet in front of the firing line and 21 feet behind it. The foam covers 17/32 fire rated plywood applied to the flat sides of 2x4s mounted to the AS-500 steel. The sidewall is uncovered to a height of 9 feet. Above that, the wall is covered with the 1-inch thick acoustic foam applied directly to the wall. The rear wall, which is 12 feet behind the 100 yard firing line, is uncovered. The microphone and shooter positions used at Ft Campbell were replicated for this part of the study. Not all weapons could be evaluated, so the results given in Table 8 represent only a portion of the situations studied at Ft Campbell.

Table 8. Shooter Firing restrictions in a treated indoor range based on weapon type, based on worst case measurement from the 10 yard firing line and on impulsive noise criteria.

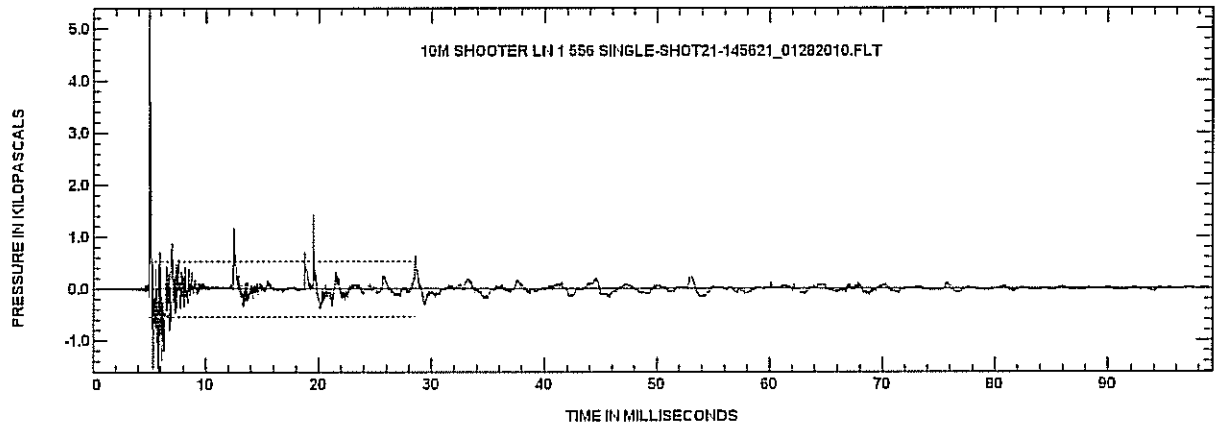
Weapon	Peak Level, dBP	B-duration, ms	ANR*
7.62 sniper rifle	163.1	27.1	8566
5.56 M4 rifle	168.6	23.6	817
9mm handgun	165.7	14.5	5935

*Daily Allowable Number of Rounds; multiply by 20 if double hearing protection is worn

The peak levels measured at Little Creek are within a dB of those measured at Ft Campbell. The differences in B-duration of all results are, however, more substantial, and are real. They are due to the effect of the surface treatment on reflections. The net result is that many more rounds are permitted in the treated facility.

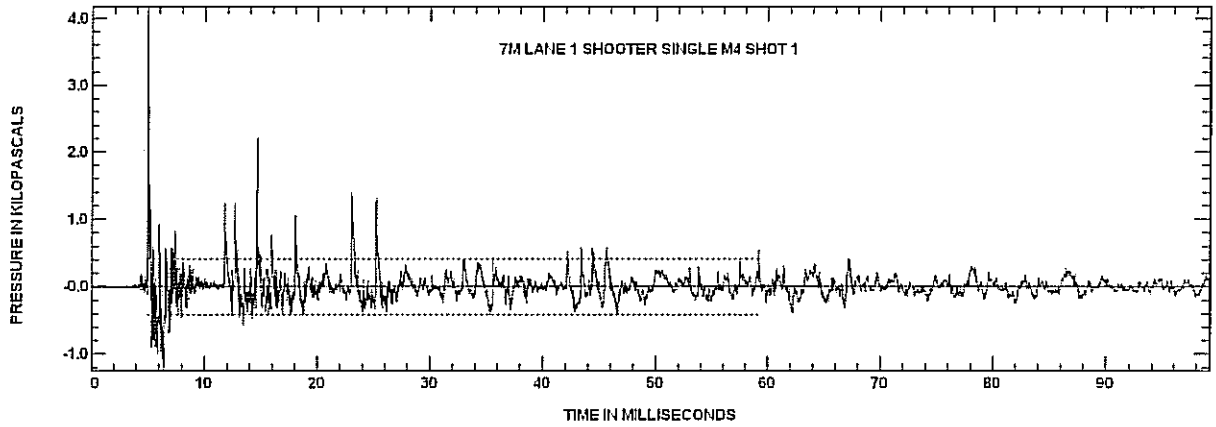
Figure 5 shows a typical time history of one of the shots measured at and originating at the lane 1 shooter position (it happens to be one of the M4 shots). It is a "cleaner" looking waverform because there are fewer reflections. The highest spike at 5 msec is due to the muzzle blast. The spike at 13 msec is the reflection from the floor. The small spike at 19 msec is the reflection from the wall (it is not present at the tracings from shots measured at the lane 7 shooter position when the weapon is fired from lane 7), and the spike at 20 msec is the reflection from the ceiling. Subsequent spikes are irrelevant. The dashed horizontal lines represent the B-duration.

Figure 5. Typical Waveform for a Single Shooter at Little Creek Firing From Lane 1.



It is clear that the B-duration is shortened as a benefit of ceiling absorption compared with what was measured at Ft Campbell. Compare the B-duration in Figure 5 with that shown in Figure 6 which represents the sound measured for a similar situation at Ft Campbell. (The timing of the different reflections between the two sites is different because the dimensions of the two facilities differ). It is equally clear that better performing sound absorptive materials would further shorten the B-duration, lessening the calculated hazard associated with this shot.

Figure 6. Single Shooter at Ft Campbell Firing the Same Weapon at the Same Position as Shown in Figure 5.



The 20 msec spike in Figure 5 suggests there is still some energy being from reflected from the ceiling, but it is worth pointing out again that the spike magnitude is exaggerated. A surface treatment with better sound absorbing capability would be better in reducing the level of this spike.

The situation involving multiple shooters is presented in Table 9. The same kind of analysis used in developing Table 5 was used here, but the model for Little Creek assumes reflections from the ceiling are reduced by 80% (about 5 dB), and adjusts the travel distance for the reflected impulses to account for dimensional differences between Ft Campbell and Little Creek. This adjustment affected only the values in the row titled "From Nearest Reflections".

Table 9. Multiple Shooter Doses and Daily ANR For the Treated Range (All Lanes Occupied).

NOISE	WEAPON		
	Sniper Rifle	M4 Rifle	9 mm
Directly From Shooter's Own Weapon	0.012	0.122	0.017
Directly From All Other Weapons	0.050	0.035	0.002
From Nearest Reflections	0.009	0.004	0.002
Total per rnd	0.071	0.161	0.021
Resultant ANR for single hearing protection	1408	621	4762

The situation for other personnel on the range is presented in Table 10, which is created by eliminating the contribution given in the first row of Table 9 from the exposures. As before, the Table 10 values are extremely conservative due to the simplistic assumptions used, and if the values presented are too restrictive, further calculations can be provided.

Table 10. Estimated Doses and ANR for Instructors For the Treated Range During Weapon Fire

NOISE	WEAPON		
	Sniper Rifle	M4 Rifle	9 mm
Directly From All Other Weapons	0.050	0.035	0.002
From Nearest Reflections	0.009	0.004	0.002
Total per rnd	0.059	0.039	0.004
Resultant ANR for single hearing protection	1695	2564	25000

2. 80 Yard Firing Line Results

The values for the peak levels at the 80 yard firing line at Little Creek are presented in Table 11. The 80 yard firing line is midway between 8 rows of baffles that are covered with the plywood

treatment described above. There is no foam material covering these baffles. No data were obtained for the 9 mm firearm at this firing position.

Table 11. Single Shooter Firing restrictions For a Treated Indoor Range Based on Measurements From the 80 Yard Firing Line and on Impulsive Noise Criterion.

Weapon	Peak Level, dBP	B-duration, ms	ANR*
7.62 sniper rifle	164.7	57.4	1513
5.56 M4 rifle	167.7	49.5	462

*Daily Allowable Number of Rounds; multiply by 20 if double hearing protection is worn

Clearly, the foam does a better job than the plywood with regard to reducing the B-duration (compare Table 11 with Table 8; the plywood barely makes an improvement over bare steel in that regard (Table 11 vs Table 3). However, as expected, peak levels are similar under either type of baffle. Note that the firing restrictions at this range are significantly different for two firing line cases investigated at Little Creek (Tables 8 vs Table 11). There is no single set of firing restrictions for this range because the acoustics of the interior space are position dependent.

II. Steady State Noise Criteria

A. General

Because the sounds in the firing range consist of impulses that are, or certainly can, occur more than twice per second on a regular basis, it is appropriate to consider the noise steady state and to compare the range noise against steady state noise criteria. The steady state criterion is that such sound is hazardous if it equals or exceeds 85 dBA at the ear, on average, when measured over an 8 hour period. Of course, the actual exposures that happen in a firing range consist of relatively brief elements that do not go on continuously over the course of the day. However, the elements can be converted in whole or in part into 8 hour averages. In effect, whatever energy is in the impulses is spread out over time. If one uses a time-intensity trading relationship of 3 dB per doubling or halving of exposure time (which appropriately reflects the physics of the situation), the math involved is equivalent to saying the 8-hour A-weighted Leq ("El-e-q," which stands for equivalent level) for the at-ear exposure should be less than 85 dBA. Furthermore, such an exposure equates to an Leq of 114 dBA as measured outside the ear of a person wearing single hearing protection that provides 29 dB of protection (114 minus 25 dB = 85 dBA inside the protector, at the ear). ANR computations for protectors used in the following assessment assume that this 29 dB of protection occurs for single protectors, and that use of double protectors provides an additional 5 dB of protection. Unless otherwise noted, use of the term Leq in the remainder of this report should be taken as meaning 8-hour A-weighted Leq.

B. Steady State Noise Analysis of the Untreated Range at Ft Campbell

Everything in the steady state analysis begins with the Leq of a single shot. The relevant worst-case values for this metric for the different weapons, assuming only shooters firing their own weapon are present in the range, are given in Table 12. The Leq of any number of similar gunshots can be determined by adding 10 times the log of the number of shots in an 8 hour period to the Leq of a single one of those gunshots. Similarly, the Leq of any combination of different gunshots can be determined by logarithmically adding the 8-hour Leq levels of all the individual gunshots in that period.

All Leq values in Table 12 are all based on the A-weighted Leq values measured over the first one second of sound after the weapon is fired. The one second value accounts for essentially all the acoustic energy generated by the shooting that is present in the time history, even though the sound remains audible beyond that period .

Table 12. Single Shooter Firing Restrictions For an Untreated Indoor Range Based on Worst Case steady state noise criteria.

Weapon	8-Hr A-weighted Leq, dBA	ANR for single hearing protection*	ANR for double hearing protection**
Sniper	85.3	741	2137
5.56 M4 rifle	84.7	851	2691
5/56 M4 rifle (auto)	94	100 bursts	316 bursts
45 cal handgun	80.6	2187	6918
9mm handgun	79.6	2754	8709
M240B machine gun	94.5	89 bursts	281 bursts
M249 machine gun	92.3	147 bursts	467 bursts

*assumes 29 dB of protection ** assumes 34 dB of protection

Like the case for impulse noise, the effect of direct and reflected sound from other shooters in the area can be calculated from modeling. The results of that work are given in Table 13 for shooters and in Table 14 for other personnel who may be behind the shooter.

Table 13. Multishooter A-Weighted Leq and ANR for Worst-Case Shooter On the Untreated Range (All Lanes Occupied)

NOISE	WEAPON						
	Sniper Rifle	M4 Rifle	M4 burst	45 cal	9 mm	M240B	M249
Directly From Shooter's Own Weapon	85.3	84.7	94.0	80.6	79.6	94.5	92.3
Directly From All Other Weapons	84.8	84.9	93.4	83.2	81.9	98.3	94.7
From Nearest Reflections	87.1	87.2	95.7	82.2	80.6	98.5	99.6
Total	90.6	90.5	99.3	86.9	85.6	102.2	101.4
Resultant ANR for single hearing protection	218	222	30	513	696	15	18
reduced total for double protection	86	86	94	82	81	97	96
Resultant ANR for double hearing protection	689	704	94	1622	2201	48	58

Table 14. Multishooter A-Weighted Leq and ANR for Instructors On the Untreated Range During Weapon Fire

NOISE	WEAPON						
	Sniper Rifle	M4 Rifle	M4 burst	45 cal	9 mm	M240B	M249
Directly From All Other Weapons	84.8	84.9	93.4	83.2	81.9	98.3	94.7
From Nearest Reflections	87.1	87.2	95.7	82.2	80.6	98.5	99.6
Total	89.1	89.2	97.7	85.7	84.3	101.4	100.8
Resultant ANR for single hearing protection	308	301	43	670	931	18	21
reduced total for double protection	84	84	93	81	79	96	96
Resultant ANR for double hearing protection	975	953	135	2119	2945	57	66

C. Steady State Noise Analysis for the Treated Range at Little Creek

1. The Single Shooter Case For the Treated Range

The data obtained at Little Creek, where some ceiling and some wall surfaces are acoustically treated, have also been evaluated against the steady state criterion. The 10 yard shooter position Leq of each of the shots fired from three different weapons at Little Creek are provided in Table 15 and these are all based on the same types of data used for the Ft Campbell analysis. The 80 yard steady state firing restrictions would be similar because the Leq values are similar.

Table 15. Single Shooter Firing Restrictions For the Little Creek 10 Yard Firing Line Based On Steady State Noise Criterion.

Weapon	8-Hr A-weighted Leq, dBA	ANR for single hearing protection*	ANR for double hearing protection**
Sniper rifle	80.7	3019	9549
5.56 M4 rifle	82.6	2137	6760
9mm handgun	79.2	1380	4365

*assumes 29 dB of protection ** assumes 34 dB of protection

Table 16 presents the range of results for the 10 yard firing line, Table 17 for the 80 yard firing line. As described previously, the 10 yard firing line is directly under foam-lined baffles, and the 80 yard firing line is directly under plywood-lined baffles.

Table 16. Range of Leq Values Measured at the 10 Yard Firing Line at Little Creek

Weapon	Leq Measured at Shooter Position for Lane 1 When Fired From Lane 1	Leq Measured at Shooter Position for Lane 7 When Fired From Lane 7
Sniper rifle	80.2-80.7	79.8-80.3
M4	82.4-82.6	81.1-81.2
9 mm	78.8-79.2	77.7-78.1

Table 17. Range of Leq Values Measured at the 80 Yard Firing Line at Little Creek

Weapon	Leq Measured at Shooter Position for Lane 1 When Fired From Lane 1	Leq Measured at Shooter Position for Lane 7 When Fired From Lane 7
Sniper rifle	81.9-82.3	80.6-81.0
M4	81.5-82.8	80.3-80.7

The last two tables suggest that the wall adjacent to Lane 1 has a minor effect, slightly raising the Leq values for shooters next to it.

Although the Leq figures in Tables 16 and 17 are both lower than those obtained at the untreated Ft Campbell range (Table 12), a striking aspect is that the foam surface only lessens the Leq values by about a dB more than the plywood. This is a somewhat surprising turn of events, in that plywood is not generally considered an acoustically absorbent material. It suggests the foam is performing poorly or the plywood better than expected.

In fact, it is probably due to the fact that the 1 inch thick foam is a poor acoustical absorber below 500 Hz, and the gunshot spectra, were they broken down by frequency, have maximum energy content at about 500 Hz, with substantial contributions of energy below that frequency. It is also known that the plywood acts as what is called a panel absorber. The latter suggests that specific plywood thicknesses and mounting patterns may actually enable the plywood absorption characteristics to be optimized. However, it needs to be kept in mind that the foam, as described previously, is more effective at reducing B-durations. A better approach than either the present foam treatment or the plywood might be to use thicker foam or some other broadband sound absorbing material, either of which could provide superior noise reduction to that for the surface treatments at Little Creek.

2. The Multi-Shooter Case For the Treated Range

Tables 18 and 19 provide results of the analysis for the multishooter case for both the shooter and for other personnel present on the range. The analysis parallels that done for Ft Campbell, using identical assumptions about reflections as for the single shooter case presented above. The figures for the weapons in the last four columns of both tables are based on estimates, not actual data

Table 18. Multishooter A-Weighted Leq and ANR For the Treated Range (All Lanes Occupied).

NOISE	WEAPON						
	Sniper Rifle	M4 Rifle	9 mm	45 cal	m240b	m249	m4bursts
From Shooter's Own Weapon	80.7	82.6	74.2	75.2	92.5	90.3	92
Directly From All Other Weapons	86.5	85.1	78.0	79.6	95.9	91	93.4
From Nearest Reflections	86.0	84.6	77.8	79.4	95.7	90.8	92.9
Total Leq per rnd	89.8	89.0	81.8	83.3	99.7	95.5	97.6
Resultant ANR for single protection	261	315	1678	1188	27	71	44
Resultant ANR for double protection	825	997	5308	3757	85	225	139

Table 19. Instructor A-Weighted Leq and ANR For the Treated Range During Weapon Fire

NOISE	WEAPON						
	Sniper Rifle	M4 Rifle	9 mm	45 cal	m240b	m249	m4bursts
Directly From All Other Weapons	86.5	85.1	78.0	79.6	95.9	91.0	93.4
From Nearest Reflections	86.0	84.6	77.8	79.4	95.7	90.8	92.9
Total Leq per rnd	89.3	87.9	80.9	82.5	98.8	93.9	96.2
Resultant ANR for single protection	297	409	2036	1409	33	102	61
Resultant ANR for double protection	940	1292	6440	4455	104	323	192

III. Comments and Observations

A. Comments

Although firing limitations for the untreated Ft Campbell range may be within acceptable limits for Soldiers who use the range as an individual, the range is obviously designed to be used by many Soldiers at the same time, and the firing limitations for that situation are very severe and no doubt unacceptable. The situation with firing automatic weapons is clearly too restrictive.

Firing limitations for a range treated like the one at Little Creek will relax a bit in comparison. Were Ft Campbell treated like Little Creek the results would be very similar, although not quite as good because the baffle height at Ft Campbell is slightly lower. The restrictions will remain significant for multiple shooters, and particularly so for weapons fired in automatic mode.

Application of better surface treatments can further relax firing restrictions and reduce hazards. Better surface treatment would consist of either using one of the two commercially viable options here: (1) acoustic foam with better sound absorbing properties than the 1-inch thick Sonex material applied over similar plywood treatment, or (2) the Troy system. These could be considered "ideal" solutions, providing the maximum reduction in hazard and increase in ANR possible through noise control other than silencing the weapons themselves and through use of

personal protection. Estimates have been prepared below to examine what such an implementation would produce in terms of increased ANR for the Special Forces indoor ranges.

The estimates are summarized in Tables 20 and 21 for comparison with Tables 4 and 5 respectively with regard to the impulse criterion. In Tables 20 and 21 peak levels from Ft Campbell are used, but the B-durations are estimated. The reflections from the ceiling are considered gone, leaving just the first reflection from the floor as the remaining significant noise. The presented ANR would be different if Little Creek peak level data were used to determine the numbers.

Table 20. Single Shooter Firing Restrictions For an "Ideally" Treated Indoor Range Based on Weapon Type and Impulsive Noise Criterion.

Weapon	Peak Level, dBP	B-duration, ms	ANR*
7.62 sniper rifle	164.7	20	6137
5.56 M4 rifle	167.6	20	1614
5.56 M4 rifle auto	167.5	60 effective	393 bursts
45 cal handgun	166.0	10	8467
9mm handgun	164.1	10	20312
M240B machine gun	166.9	150 effective	153 bursts
M249 machine gun	163.4	150 effective	769 bursts

*Allowable Number of Rounds; multiply by 20 if double hearing protection is worn

Table 21. Multishooter Doses and ANR For an "Ideally" Treated Indoor Range (All Lanes Occupied) Based on Impulse Noise Criterion.

NOISE	WEAPON						
	Sniper Rifle	M4 Rifle	M4 burst	45 cal	9 mm	M240B	M249
Directly From Shooter's Own Weapon	0.016	0.062	0.254	0.012	0.005	0.652	0.130
Directly From All Other Weapons	0.016	0.006	0.026	0.001	0.000	0.323	0.062
From Nearest Reflections	0.002	0.001	0.003	0.000	0.000	0.037	0.007
Total	0.034	0.069	0.283	0.013	0.005	1.012	0.199
Resultant ANR for single hearing protection	2941	1449	353	7692	20000	99	503
Resultant ANR for double hearing protection	58824	28986	7067	153846	400000	1976	10050

The estimates are summarized in Tables 22 and 23 for comparisons with Tables 12 and 13 with regard to the steady state criterion (for single and multiple shooters). Leq levels were found to decrease at Little Creek compared with Ft Campbell, and would be expected to decrease even further with ideal treatment. The decrease in Leq levels for sounds from a single shooter's own weapon was found to range from 2 to 5 dB at Little Creek. A conservative 2 dB reduction was applied to levels for such sounds for Little Creek-like treatment for weapons that were not directly measured at Little Creek. A further decrease of 2 dB is applied to all weapons for the ideal treatment in creating Tables 22 and 23.

Table 22. Single Shooter Firing Restrictions for an "Ideally" Treated Indoor Range Based on Steady State Noise Criterion.

Weapon	8-Hr A-weighted Leq, dBA	ANR for single hearing protection*	ANR for double hearing protection**
Sniper	78.7	3388	10715
5.56 M4 rifle	80.6	2187	6918
5/56 M4 rifle (auto)	90	251 bursts	794 bursts
45 cal handgun	73.2	12022	38018
9mm handgun	72.2	15135	47863
M240B machine gun	90.5	223 bursts	707 bursts
M249 machine gun	88.3	371 bursts	1862 bursts

*assumes 29 dB of protection ** assumes 34 dB of protection

Table 23. Multishooter A-Weighted Leq and ANR for an "Ideally" Treated Range (All Lanes Occupied), Based on Steady State Criterion.

NOISE	WEAPON						
	Sniper Rifle	M4 Rifle	M4 burst	45 cal	9 mm	M240B	M249
From Shooter's Own Weapon	78.7	80.6	90.0	73.2	72.2	90.5	88.3
Directly From All Other Weapons	86.5	85.1	93.4	79.6	77.7	95.9	91.0
From Nearest Reflections	85.3	83.9	92.2	78.7	77.1	95.0	90.1
Total, dBA	89.3	88.3	96.9	82.7	81.0	99.1	94.7
Resultant ANR for single hearing protection	292	367	52	1349	1982	31	85
reduced total for single hearing protection, dBA	84	83	92	78	76	94	90
Resultant ANR for double hearing protection	924	1162	164	4265	6266	97	269

B. Observations

1. Repeatability of measurements.

The peak level of each shot is remarkably similar to each of the other ones in the same grouping, regardless of whether the data was taken at Ft Campbell or at Little Creek, or where at those locations the data was measured.. This is a known characteristic of small arms noise. Most variation obtained with peak level is due to small deviations in shooter position relative to the location of the microphone. The same cannot be said about variations in B-duration, values of which depend on physical surroundings at the measurement location (although the variation at a particular location is small for each group at a specific location. These findings should be useful for future studies.

2. Comparisons to Older Small Arms Data

The levels measured in this study are generally a few dB higher than published for corresponding weapons. This is because MIL-STD 1474D specifies a slightly different microphone locations for measuring weapon noise, depending on whether or not a person is pulling the trigger or if the weapon ins mounted on a jig and fired remotely. The latter position is farther from the muzzle and hence slightly quieter. It is the one typically used for weapons qualification. The standard measurements are all made outdoors, and thus B-durations are shorter than measured in the subject study.

The levels measured in the subject study are consistent with (within a dB or two) several prior studies done from the 1970's to the 1990's for indoor or semi-enclosed firing ranges used in the Army.

Appendix A. Instrumentation for Range Measurements

ITEM	MANUFACTURER	NUMBER		CALIBRATION DUE DATE, 2010
		MODEL	SERIAL	
Microphone, 1/4 in.	G.R.A.S.	46BH	53797	07 June
Microphone, 1/4 in.	G.R.A.S.	46BH	87143	12 July
Microphone, 1/4 in.	G.R.A.S.	46BH	87142	12 July
Microphone, 1/4 in.	G.R.A.S.	46BH	87144	07 June
Microphone, 1/4 in.	G.R.A.S.	46BH	51522	07 June
Microphone, 1/4 in.	G.R.A.S.	46BH	87141	10 June
Microphone, 1/4 in.	B&K	4938	2411464	28 May
Microphone, 1/4 in.	B&K	4938	2411003	28 May
Microphone, 1/4 in.	B&K	4938	2411001	28 May
Preamplifier	G.R.A.S.	46BH	85184	07 June
Preamplifier	G.R.A.S.	46BH	85189	12 July
Preamplifier	G.R.A.S.	46BH	85177	12 July
Preamplifier	G.R.A.S.	46BH	85180	07 June
Preamplifier	G.R.A.S.	46BH	85158	07 June
Preamplifier	G.R.A.S.	46BH	85186	10 June
Preamplifier	B&K	2670	2479328	28 May
Preamplifier	B&K	2670	2479352	28 May
Preamplifier	B&K	2670	2479318	28 May
Power supply	B&K	NEXUS 2690	2236689	9 November
Digital acquisition system	National Instruments	NI PXI-1031DC	779050-01	16 November
Pistonphone	B&K	4220	1164880	17 July

Appendix B. Example of 7 Meter Firing Line Results for Ft Campbell (for the M4 Rifle)

The following is for the M4 Rifle fired from lane 1

measure-ment position	lane num.	Raw Pk,dBP	actual peak for direct sound, dBP*	B-duration, msec	8-hour Aweighted Leq based on the first part of the waveform with a duration of			
					1 second	500 msec	200 msec	50 msec
shooter	1	166.4		54	84.4	84.3	83.8	82.8
		167.6		54.3	84.7	84.6	84.2	83.2
		167		54.4	84.6	84.4	84	83.1
instructor	1	152	145.7		80.7	80.3	79	74.4
		151.1	146.5		80.7	80.3	79	74.1
		151.2	145.4		80.4	80	78.7	74.1
shooter	3	156.7	154.9		82.6	82.4	81.6	79.2
		156.2	154.9		82.6	82.4	81.6	79.2
		156.3	154.9		82.6	82.4	81.6	79.2
instructor	3	149.5	143.3		79.7	79.2	77.8	73.6
		148.9	147.4		79.6	79.1	77.7	73.2
		150	144.6		79.5	79.1	77.6	73.6
shooter	7	146.8	144.6		79.5	79.1	77.6	73.6
		147.3	144.6		80.7	80.3	79	76
		149.4	144.6		80.7	80.3	79	76
instructor	7	144.1	136.8		79.3	78.8	77.1	71.6
		144.8	135.9		79.4	78.9	77.4	72
		143.2	134.6		79	78.5	76.9	71.7

the following is for the M4 Rifle fired from lane 7

shooter	7	overload						
instructor	7	150.7	144.4		80.1	79.5	77.8	71.6
		150.7	144.4		80.1	79.5	77.8	71.6
		150.4	144.4		80.1	79.5	77.7	71.2
shooter	3	149.9	147		81.3	80.9	79.6	75.2
		149.6	149.6		81.4	81.1	79.8	75.5
		149.5	149.3		81.4	81	79.7	75.3
instructor	3	146.3	142.1		79.7	79.2	77.7	71.6
		146.5	142.1		79.9	79.4	77.8	71.7
		147	139		79.9	79.4	77.9	71.9
shooter	1	148.3	145.2		80.2	79.8	78.5	75.1
		147.9	145.2		80.2	79.8	78.5	75.1
		147.6	145.4		80.4	80	78.7	75.3
instructor	1	146.4	142		79.9	79.4	77.7	72.4
		146.4	140.8		80	79.4	77.8	72.1
		146.4	139.3		79.8	79.2	77.6	72.4

the following is for the M4 Rifle fired from lanes 1-7

shooter	1	166			89.6			
		165.1			88.3			
		165.1			89.2			
		164			89.2			
		163.4			89.3			
instructor	1	154.2			88.1			
		152.6			88			
		150.7			87.8			
		153.4			88.2			
		152			88.1			
shooter	7	overload						
instructor	7	150.2			86.9			
		150			87.2			
		151.8			87			
		149.9			87.1			
		149.5			87.1			

the following is for the M4 Rifle fired in bursts from lane 1 (worst case peak of burst)

shooter	1	166.5			92.8			
		167.5			93.9			
		166.7			943			
instructor	1	154			88.7			
		156.4			89.9			
		154.2			90			
shooter	3	158.6			90.7			
		157.4			91.7			
		157.9			91.4			
instructor	3	151.4			88			
		150.3			88.6			
		150.8			88.5			
shooter	7	150.7			88.9			
		150.9			89.9			
		150.6			89.9			
instructor	7	147.8			87.6			
		149.2			88.5			
		147.8			88.6			

*The actual peak attributed to the direct sound is usually less than the reflected sound due to exaggerations caused by orientation of the microphone (see text); the raw data simply picked out the highest peak level in the sample.

Appendix C. Examples of Direct Sound Calculations for Sniper Rifle and M4 Rifle

lane number	distance to center of lane 1, ft	20log ratio lane number to lane 2	Peak level for direct sound in lane after subtracting distance correction from lane 2 direct sound,dBP	B-duration, msec	ANR	dose per round, %	ACTUAL PEAK
SNIPER RIFLE							
1	0		164.7	59.5	1443	0.069	164.7
2	6.4		163.0	59.5	3157	0.063	
3	12.8	6.0206	157.0	59.5	50028	0.004	157
4	19.2	9.542425	153.5	59.5	255679	0.001	
5	25.6	12.0412	151.0	59.5	808071	0.000	
6	32	13.9794	149.0	59.5	1972828	0.000	
7	38.4	15.56303	147.4	59.5	4090857	0.000	145.6
8	44.8	16.90196	146.1	59.5	7578818	0.000	
9	51.2	18.0618	144.9	59.5	12929128	0.000	
10	57.6	19.08485	143.9	59.5	20709964	0.000	
11	64	20	143.0	59.5	31565255	0.000	
12	70.4	20.82785	142.2	59.5	46214690	0.000	
13	76.8	21.58362	141.4	59.5	65453713	0.000	
14	83.2	22.27887	140.7	59.5	90153525	0.000	
15	89.6	22.92256	140.1	59.5	121261084	0.000	
16	96	23.52183	139.5	59.5	159799104	0.000	
17	102.4	24.0824	138.9	59.5	206866056	0.000	
						0.069	

M4 RIFLE							
1	0		167.6	54.3	429	0.233	167.6
2	6.4		160.9	54.3	9375	0.021	
3	12.8	6.0206	154.9	54.3	148578	0.001	154.9
4	19.2	9.542425	151.4	54.3	759344	0.000	
5	25.6	12.0412	148.9	54.3	2399903	0.000	
6	32	13.9794	146.9	54.3	5859137	0.000	
7	38.4	15.56303	145.3	54.3	12149507	0.000	144.6
8	44.8	16.90196	144.0	54.3	22508462	0.000	
9	51.2	18.0618	142.8	54.3	38398442	0.000	
10	57.6	19.08485	141.8	54.3	61506880	0.000	
11	64	20	140.9	54.3	93746197	0.000	
12	70.4	20.82785	140.1	54.3	137253808	0.000	
13	76.8	21.58362	139.3	54.3	194392115	0.000	
14	83.2	22.27887	138.6	54.3	267748514	0.000	
15	89.6	22.92256	138.0	54.3	360135392	0.000	
16	96	23.52183	137.4	54.3	474590124	0.000	
17	102.4	24.0824	136.8	54.3	614375079	0.000	
						0.023	

Appendix D. Example of Calculations for Reflections for Sniper Rifle

condition	distance for reflection to travel vs starting level, ft	dB decay		B-duration	ANR	twice dose per round times 100
weapon:			sniper rifle			
direct level at 6.4 ft from lane 1 (lane 3 level + 6 dB)			163.0			
first reflection off of floor to adjacent lane	11.87	-5.4	157.6	59.5	37384	0.005
first reflection off of ceiling to adjacent lane	13.60	-6.5	156.5	59.5	64364	0.003
second off of floor	22.92	-11.1	151.9	59.5	519113	0.000
second off of ceiling	22.92	-11.1	151.9	59.5	519113	0.000
third off of floor	44.47	-16.8	146.2	59.5	7355835	0.000
third off of ceiling	44.47	-16.8	146.2	59.5	7355835	0.000
off of wall	42.60	-16.5	146.5	59.5	6196234	0.000
off of other wall	42.60	-16.5	146.5	59.5	6196234	0.000
off of bullet trap	43.28	-16.6	146.4	59.5	6598910	0.000
fourth off of floor	66.27	-20.3	142.7	59.5	36297182	0.000
fourth off of ceiling	66.27	-20.3	142.7	59.5	36297182	0.000

first reflection off of floor to next lane over	16.24	-8.1	154.9	59.5	130970	0.002
first reflection off of ceiling to next lane over	17.55	-8.8	154.2	59.5	178295	0.001
second off of floor	25.47	-12.0	151.0	59.5	792112	0.000
second off of ceiling	25.47	-12.0	151.0	59.5	792112	0.000
third off of floor	45.84	-17.1	145.9	59.5	8305805	0.000
third off of ceiling	45.84	-17.1	145.9	59.5	8305805	0.000
off of wall	36.20	-15.1	147.9	59.5	3230901	0.000
off of other wall	36.20	-15.1	147.9	59.5	3230901	0.000
off of bullet trap	44.67	-16.9	146.1	59.5	7493267	0.000
fourth off of floor	67.22	-20.4	142.6	59.5	38423141	0.000
fourth off of ceiling	67.22	-20.4	142.6	59.5	38423141	0.000
						0.013

INFORMATION PAPER

AOSO-EN
21 March 2010

SUBJECT: Special Forces Indoor Baffle Range Noise Mitigation

1. **Purpose:** To provide USASFC(A) recommended way-a-head to mitigate unsafe sound levels within the SF indoor baffle ranges.

2. **Facts:** The SF indoor baffle ranges create an unsafe condition for operators due to the level of noise exposure during reasonably predictable use by SF soldiers. USASFC(A) in conjunction with US Army Public Health Command has conducted live fire testing at both a constructed SF baffle range, a similar Navy indoor range treated with acoustical foam, and examined data from an Air Force indoor range treated with a composite acoustical system. The five ranges being constructed for the USASFC(A) are all P2 funded Army projects.

3. Conclusion: USASFC(A) recommends the use of the Troy Acoustic, or a similar system with equal performance.

Mr. Ryan McDavitt, CCM/910-643-8437
ryan.c.mcdavitt@soc.mil

Enclosures
1. Memo from Mr. Chuck Jokel, USAPHC, 29MAR10
2. Power Point Presentation, AOSO-EN, USASFC(A) recommendations
3. Troy Acoustic product data

28358 Constellation Road,
Suite 640
Santa Clarita, CA 91355

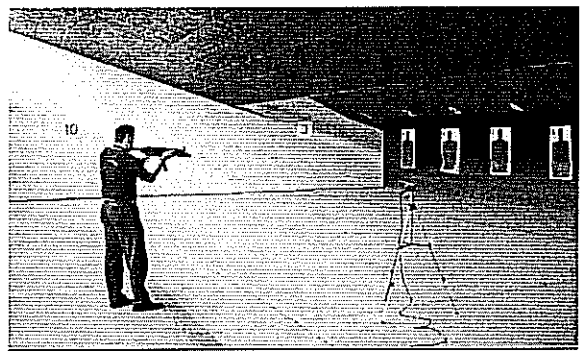
[p] 800.987.3306
[p] 818.376.8490

[w] troyacoustics.com

Troy Acoustics Corporation

Technical Data:

Patented Troy™ Acoustic System



APPLICABLE STANDARDS

- ASTM C423 Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method
- ASTM E84 Standard Test Method for Surface Burning Characteristic of Building Materials
- ASTM E90 Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements
- ASTM E413 Classification for Rating Sound Insulation

PHYSICAL PROPERTIES

- Waterproof, cementitious wood fiber board to ASTM C612 Type 1A or 1B
- Reverberation time - 1.25 seconds or less, ASTM RT-60
- Sound absorption coefficients – NRC .95 Type B and A mountings, to ASTM C423
- Troy Wool thermal 4.8R per inch

FIRE PERFORMANCE

- The system is UL classified as noncombustible per ASTM C136 and complies with ASTM C665 Type 1 Surface burn characteristics
- Flame spread - 5 or less, ASTM E84
- Smoke developed - 0, ASTM E84
- Troy System is comprised of 2 primary components that absorb, trap and muffle sound energy:
    - Troy Board™ : a composite wood fiber cement matrix board composed of dimensionally stable, unfaced rigid cement wood fiber board containing only natural materials.
    - Troy Wool™, a high density mineral wool is 2.5 lbs./cubic foot. Troy Board is Board density is 3.5 psf minimum per 1" (25.4 mm) section.
- Troy Board and Troy Wool contain no asbestos, urea- formaldehyde or CFC blown agents.
- Troy Board structural acoustical boards are rugged, strong and waterproof. The natural components that make up Troy Board material are impregnable to the elements, thus enabling the system's use for both interior and exterior applications.

INDOOR FIRING RANGE LOAD WEIGHTS

- Load weight of 3.5 psf for 1" (25.4 mm) Troy Board with Troy Wool typically used on safety ceiling and baffle
- Load weight of 6.5 psf for typical 2" (51 mm) Troy Board with Troy Wool typically used on sidewall treatment

OTHER INFORMATION

- The Troy System is comprised of Troy Board and Troy Wool; thicknesses vary based on noise reduction criteria
- Installation shall comply with the requirements of all applicable local, state and federal code jurisdictions
- Pricing typically includes a pre-site visit, onsite visit by noise attenuation manufacturer and sound testing to confirm that there is a 1.25 second reverb time
- Troy Acoustics has over 5 years of shooting range experience with guaranteed acoustic performance
- Troy Acoustics guarantees that the system will perform acoustically for a period of 5 years
- Troy shall provide replacement board for those boards which are damaged 50% by errant rounds. (excludes shipping and installation) for a period of NTE 5 years.
- The system is not intended for intentional fire.
- Installation shop drawings are typically included in pricing.
- Troy System is site specific design for compliance with OSHA noise exposure limits and the ETL (Engineering Technical Letter)
- Certified by USAF for antirichochet properties.
- US Patent number 5661273

The world's highest acoustical rating.
The industry's only guaranteed solution.

Troy Acoustics Corporation

There Is ONE and ONLY One Acoustical Sound Absorption And Noise Abatement System That Meets The Needs Of Military, Government, And Law Enforcement Ranges...

The Troy System is the ONE and ONLY acoustical sound absorption and noise abatement system that:

- Meets OSHA guidelines for noise exposure limits under CFR Section 29 and the Air Force ETL
- Guarantees a 1.25 reverberation time (RT60)
- Certified by United States Air Force for anti-ricochet properties
- Inch for inch, dollar for dollar the highest NRC and STC ratings in the industry
- Absorbs 95% of all muzzle blast energy, at all frequencies
- Reduces overall peak loudness by at least 5 dB
- Offers up to a 5-year free replacement warranty
- Acoustic properties guaranteed for the life of the range
- Tested and proven since 1997 in over 60 military, government, and civilian indoor and outdoor installations including: U.S. Secret Service(2 Ranges), U.S. Customs and Border Protection (5 ranges), Wright Patterson AFB (2 Ranges)

The ONE and ONLY One System proven, tested, and guaranteed ... Troy

28358 Constellation Road Suite 640 Santa Clarita, CA 91355-5039 800-987-3306 www.troyacoustics.com

The Worlds Highest Acoustical Rating .... The Industry's Only Guaranteed Solution

Troy Acoustics Corporation

Case Study:

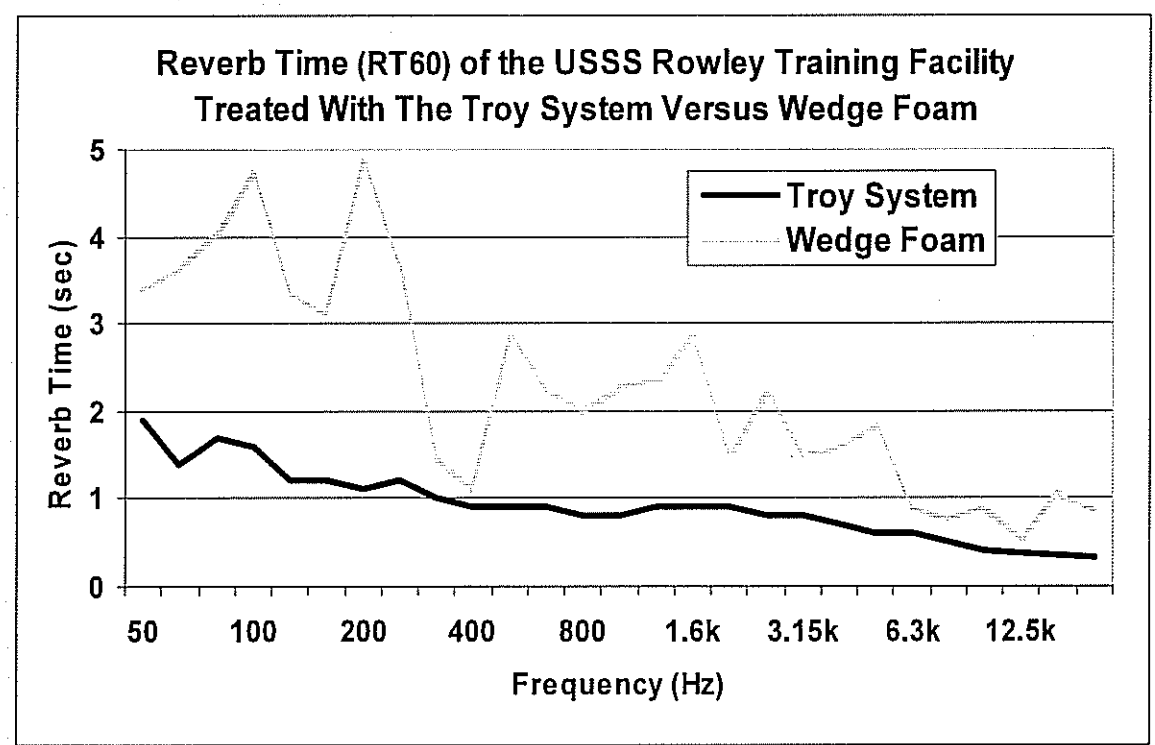
United States Secret Service, James J Rowley Training Center, Beltsville, MD

In 2007 Troy Acoustics Corporation was contacted by the United States Secret Service, their training facility in Beltsville, MD had been cited by OSHA for high noise exposure limits in the range, and control booth, and was ordered to reduce range instruction time. The two 12 lane indoor ranges were at that time fully treated with an acoustical wedge foam product (such as Sonex).

Troy Acoustics Corporation supplied the acoustic design, removal of the acoustical wedge foam, installation of the Troy System, and before and after sound testing. After the installation of the Troy System the ranges met all standards and were approved for full operation.

Chart 1 below shows a comparison of the ACTUAL before and after ASTM RT60 results for one of the 12 lane small arms ranges at United States Secret Service, Beltsville, MD

Chart 1



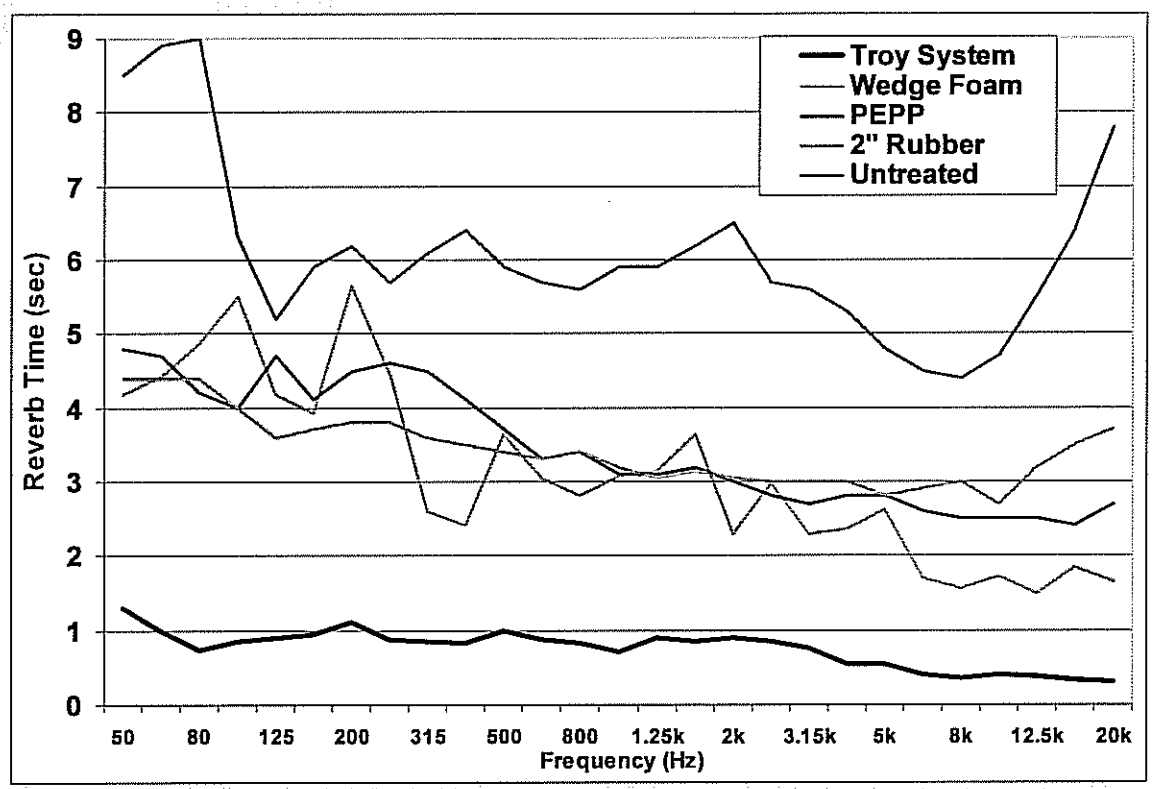
Troy Acoustics Corporation

Comparative Data

Troy Acoustics has the only "guaranteed" acoustical noise reduction solution for indoor and outdoor shooting ranges. Other products may claim similar, noise reduction coefficients (NRC) but only Troy's patented technology delivers the highest level of sound absorption and noise abatement in the industry, at all frequencies.

Chart 2 shows a generic comparison of the reverb time (RT60) in an indoor small arms range that is; untreated, treated with wedge foam, PEPP, 2" Rubber, and the Troy System. It can be seen that effectiveness of the PEPP, and 2" Rubber is moderate at mid and high frequencies and almost non existent at low frequencies. The acoustic foam effectiveness is totally uneven showing a reverb time of 2.4 at 400 Hz and 5.64 at 200 Hz. On the other hand the Troy System displays an almost flat reverb time with an overall RT60 less than 1.25 seconds.

Chart 2



Troy Acoustics Corporation

Troy's Comprehensive Testing Methodology

In November of 2009 Stephen Katz, Troy Acoustics Corporation's VP, Applied Research and Technology instituted a comprehensive testing methodology for small and large arms ranges. The testing utilizes over 16 instrumentation microphones and body sensors recorded as audio files on a 192k/24 bit recording system so that the data can be post analyzed.

The body testing, which is unique was instituted by Troy Acoustics Corporation to better understand the influence on the body of high pressure waves. Although, the effect of impulse noise on hearing is widely studied and understood there is very little data on the physiological effects on shooters and instructors that train and work in these ranges.

Wright Patterson AFB First Facility Comprehensively Tested

The first facility to be comprehensively tested was the small and large indoor ranges at Wright Patterson Air Force Base, Dayton OH, prior and after the installation of the Troy System. A full report is forthcoming.

Chart 3 below shows the comparative RT60 for the large range (21 lanes) at Wright Patterson Air Force Base, Dayton OH, before and after treatment with the Troy System. The range was built with acoustic tile on the baffles, the side and rear wall were smooth concrete. It can be seen the Troy System reduced the RT60 in the large range from 3.51 seconds measured in the bay to 1.21, and from 3.02 in the shooters stall (lane 11) to 1.16 seconds.

Chart 3

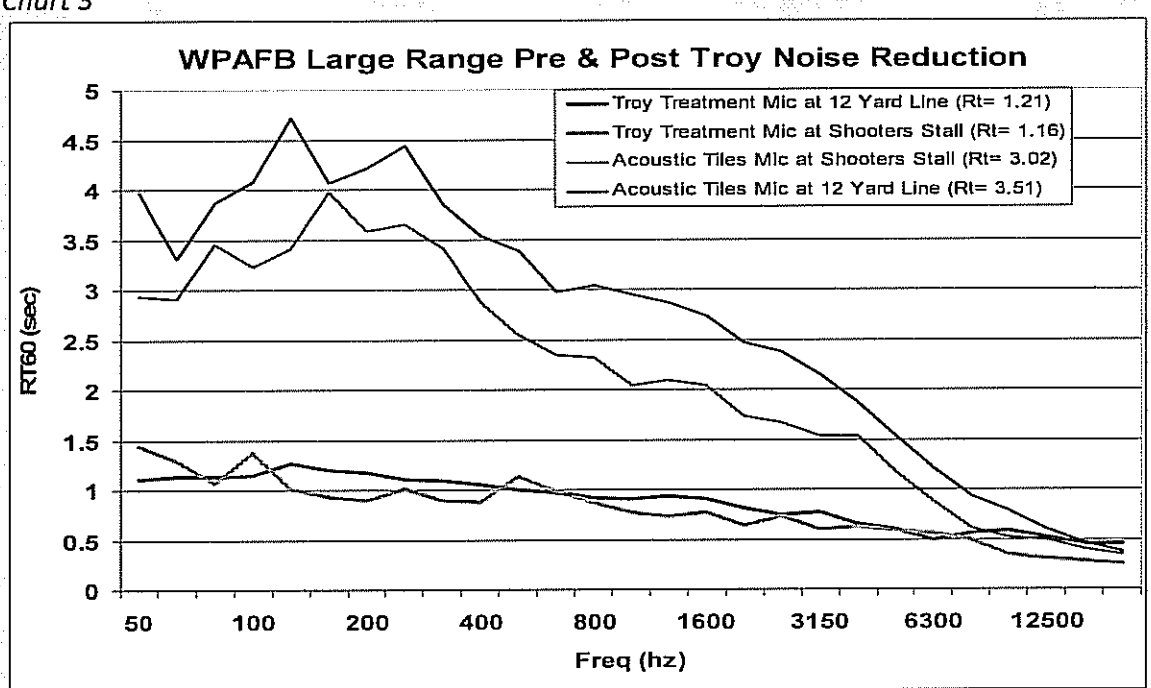
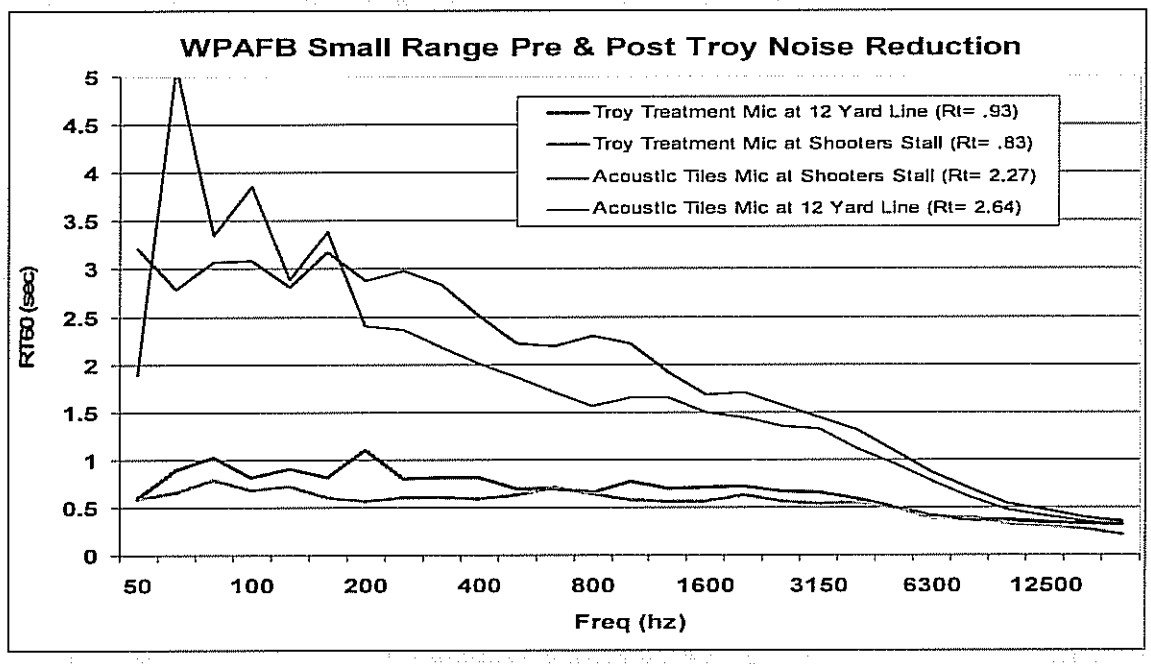


Chart 4 shows the shows the comparative RT60 for the small range (2 lanes) at Wright Patterson Air Force Base, Dayton OH, before and after treatment with the Troy System. The range was built with acoustic tile on the baffles, the side and rear wall were smooth concrete. It can be seen the Troy System reduced the RT60 in the small range from 2.64 seconds in the bay to .93 seconds, and from 2.27 in the shooters stall (lane 2) to .83 seconds.

Chart 4



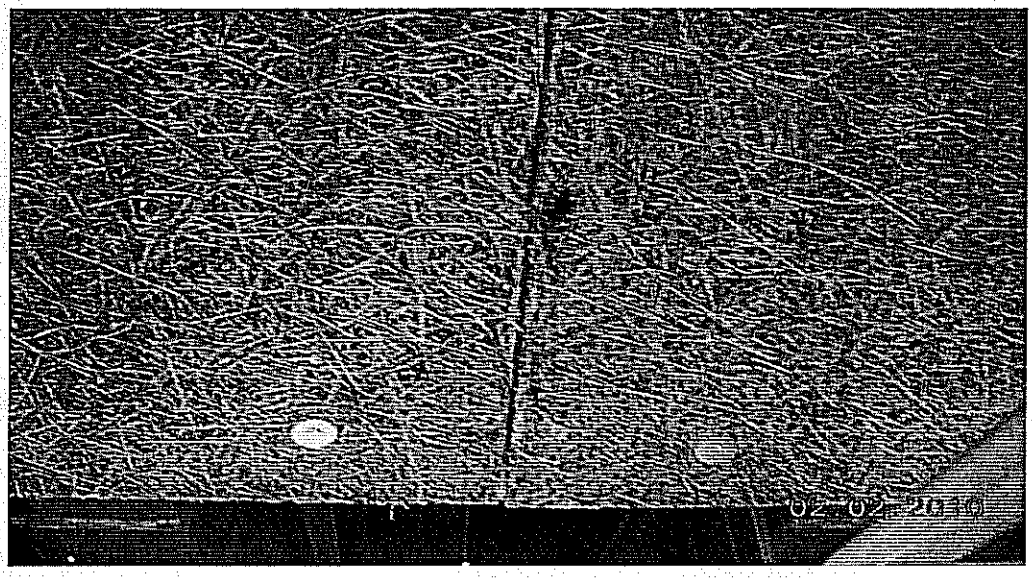
For a presentation of more data from the Wright Patterson Air Force Base testing please contact Joan Drucker at Troy Acoustics Corporation, 800-987-3306 Ext. 400

Ballistics

Under the auspices of the United States Air Force a test was designed, and witnessed by Mr. Rolland Roth, HQ AFSFC/SFXW, and Mr. Jeffrey Nielsen, HQ AFCESA/CEOA to evaluate the performance of the Troy System in retaining bullet splash-back and mitigating ricochets, as compared to standard plywood covering (United States Air Force Engineering Technical Letter ETL 08-11: Small Arms Range Design and Construction, Section 7.5 Ballistic Safety Structures for shooting ranges). The test resulted in a formal approval to allow the Troy System in lieu of 2 layers of plywood. Troy Acoustics has been advised, in writing, that this test procedure will be published in the summer 2010 edition of the ETL. (For a copy of the test procedure visit www.troyacoustics.com/download.htm.) Troy is the only acoustical sound absorption and noise abatement system to receive such an endorsement.

Troy Acoustics Corporation

The picture below shows a round fired at Wright Patterson AFB, taken after the comprehensive acoustical testing, where a round errantly struck a baffle.



The picture below shows the Santa Ana Police, Santa Ana, CA training facility with wedge foam (Sonex) acoustical wall and baffle treatment after one year of use. Troy Acoustics was called in because the wedge foam was offering almost no acoustical benefit.

Troy Acoustics Corporation

Who Are We: Troy Acoustics Corporation

Bill Bergiadis, CEO

- Inventor and patent holder of the Troy System™ sound wall design
- Has provided acoustical consulting and design/engineering services for: City of Los Angeles, LAPD, NYPD, Santa Monica Police Department, City of Pasadena, Pasadena Police Department, Chula Vista Police Department, FBI, NASA Ames, US Navy, US Secret Service, Lawrence Livermore National Laboratory, Lawrence Berkeley Nation, City of Manhattan Beach Fire Department, the City of West Hollywood, City of Thousand Oaks and many various private Fortune 500 Companies.
- Established more sophisticated criteria for shooting range acoustic performance

Joan Terry Drucker, Vice President, Marketing and Business Development

- Over 25 years business management experience in environmental products and services
- Former Vice President, General Manager, Savage Range Systems: manufacturer and developer of shooting range equipment
- Former President, founder of Environmental Visions, Inc.
- Former senior management of division of United Technologies Corporation
- Over 15 years experience in firearms related industry
- Developed a series of Architectural Seminars: Design and Development of Shooting Ranges
- Chairperson NRA Range Development and Operations Conference, Vendor Night

Stephen Katz, VP, Applied Research and Technology

- Over 40 years acoustical and sound engineering experience
- Won an ***Academy Award*** for the co-development of Dolby Stereo
- Has over thirty feature film credits including, *Star Wars, Close Encounters of the Third Kind*
- Recording engineer for Jimi Hendrix, Chuck Berry, Ike and Tina Turner, Barry Manilow, and the St. Louis Symphony
- Designed and built recording studios for Dolly Parton and Porter Wagner, the original Cherokee Ranch (Steely Dan, *aja*), and Grand Funk Railroad
- Founding partner Eventide Electronics, one of the first manufacturers of professional digital audio equipment including digital delay lines, auto-locators, and pitch changers