Crucible Spotsylvania

Acoustical Assessment

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Executive Summary

An acoustical study was performed to assess the potential consequences of noise that may be produced by Crucible's proposed facilities and operations at their new location in Spotsylvania, Virginia. This report will describe the study's goals, methodology, relevant noise criteria, technical assumptions, noise modeling and measurements, findings, conclusions and recommendations.

Crucible, currently located and operating in Stafford County, Virginia since 1998, is proposing to build and operate a new facility in Spotsylvania County, Virginia. Continuing to provide their original services, the new facility would feature personal defense training, firearms classes and live-fire exercises, evasive driving techniques, bodyguard and protective services training, and para-military training. Crucible's typical client base is comprised of employees of the U.S. Government, Non-governmental organizations (NGOs), and multi-national corporations whose employees live and work in dangerous and austere locations worldwide.

In brief summary, the findings of this acoustical study indicate that future full build-out noise produced from Crucible's use of firearms, vehicles, and simulated IEDs would comply with guidelines and criteria limits contained in the Spotsylvania County Noise Ordinance (Chapter 14, Article II) at all noise-sensitive receptors within the communities proximal to Crucible's new facility. If its proposed project is approved, it is understood that Crucible, being a commercial establishment from which noise due to the above activities is customarily emitted, would be exempt, during certain times of each day, from the legal requirement to comply with the noise ordinance.

Notwithstanding the exemption, Crucible will attempt to reduce potential noise emissions to specifically address noise concerns raised by their immediate neighbors by voluntarily implementing a variety of noise mitigation measures into their new facility design; the more significant ones of which include:

- A willingness to take all reasonable and feasible steps necessary to voluntarily comply with the noise limits contained in the Spotsylvania County noise ordinance.
- Retain the services of an acoustical expert with specific expertise in evaluating firing range noise emissions to perform a comprehensive noise study.
- Construct 20-foot-tall range-side berms and backstops for noise control.
- Erect 12-foot-tall noise barriers to reduce noise affecting nearby receptors.
- Limit themselves to using only buried, simulated Improvised Explosive Devices (IED).
- Construct 10-foot-tall ballistic (and noise reducing) walls dividing the ranges.
- Orienting the entire facility so that the downrange direction points towards the west.
- Construct a substantially enclosed "shoot house".
- Prohibit the use of high explosives and rifle calibers larger than .338 Lapua Magnum due to community concerns over noise and safety.
- Willingly limit their live fire operations from 8:00 AM to 10:00 PM, Monday through Friday; and 9:00 AM to 5:00 PM on Saturday; and 10:00 AM to 4:00 PM on Sunday, where all firing range training will be limited to occur no later than two (2) hours after astronomical twilight as recorded by the United States Naval Observatory (USNO).

Based on the acoustical findings of this study and its proactive commitments to noise control, it is *concluded that the new Crucible facility would be a noise-compatible land-use within its proposed location in Spotsylvania, Virginia.*

The following report contains more detailed information supporting this conclusion and recommendation. A summary of acoustical terms and definitions is contained in **Appendix A**, and evidence of the principle investigator's and peer reviewer's professional acoustical qualifications may be found in **Appendix B**.

Project Description

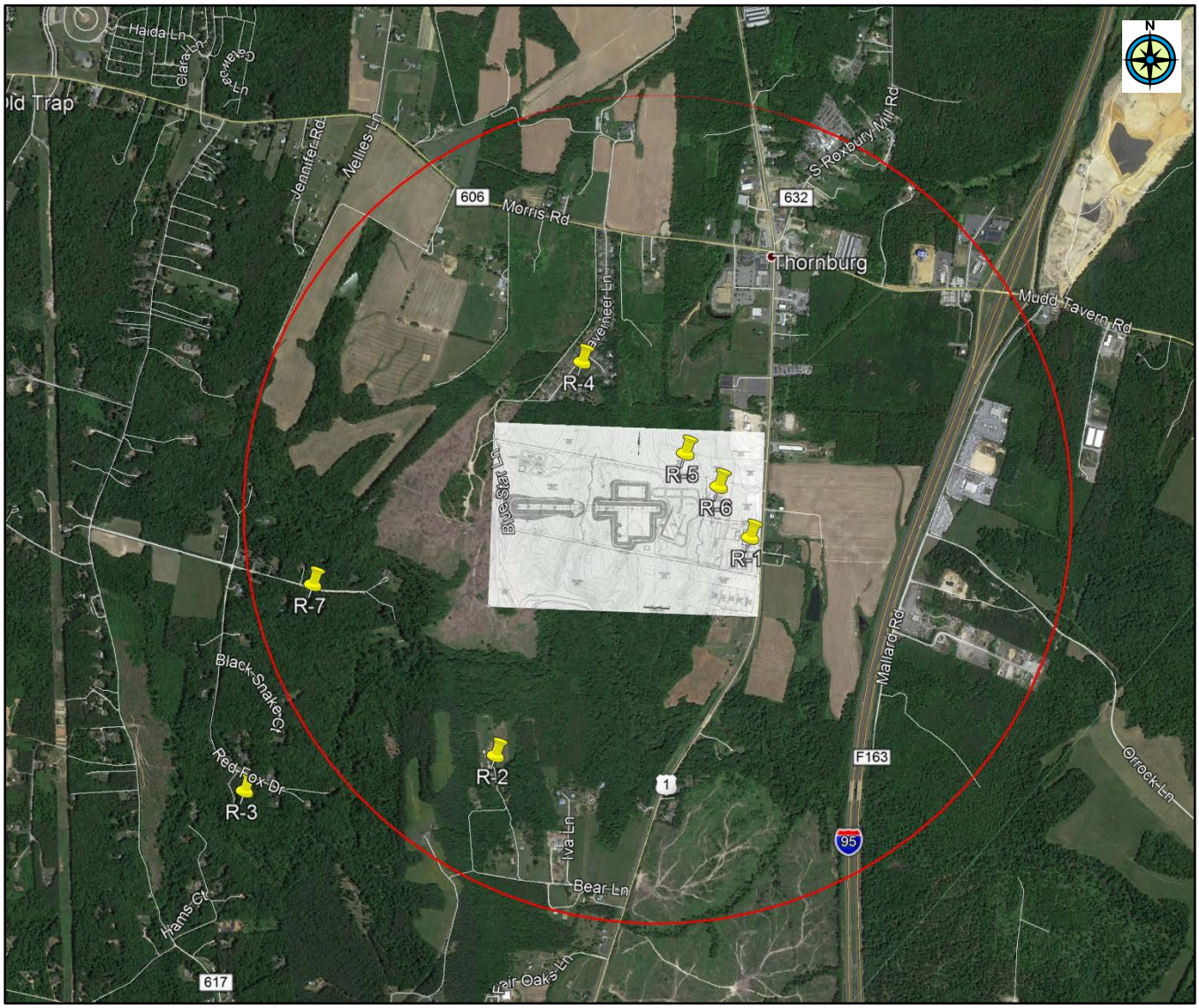
Crucible operates a high level personal and professional defense and security training facility currently located in Stafford County, Virginia. For a variety of reasons, Crucible intends to completely relocate its facilities and operations to a more suitable space located off Jefferson Davis Highway (Route 1) in Spotsylvania County, Virginia.

Crucible intends to complete their new site development over a period of time based on contract activity, which will include an initial lower intense phase build-out (referenced collectively herein as "Phase 1") and eventually a full build-out scenario (referenced collectively herein as "Phase 2"). The site location, surrounding area, noise receptor locations (R-#), and a layout drawing of the full build-out scenario are shown in **Figure 1**. The red circle of approximately 1-mile radius around Crucible's proposed new facility is shown simply for appreciation of scale.

The area surrounding Crucible's site is sparsely populated and may be categorized as rural land-use. While there are some residential and commercial properties to the east along Jefferson Davis Highway, there are very few noise-sensitive receptors westerly of the site.

Once completed, Crucible's new facility will include amongst other things a long-distance 500-yard range, more typical 150-yard and 100-yard ranges, a shorter 40-yard range, a small enclosed "shoot house", and a professional evasive-driving training course. Again, as noted above and limited via Crucible's proposed proffers, Crucible's intended hours of operation will be 8:00 AM to 10:00 PM, Monday through Friday; and 9:00 AM to 5:00 PM on Saturday; and 10:00 AM to 4:00 PM on Sunday.

Figure 1. Crucible Spotsylvania Full-Build Development



Spotsylvania Noise Ordinance

Noise emissions within Spotsylvania, Virginia, are governed by the Spotsylvania County Ordinance (CH 14, Article II: Noise). Section 14-51 contains noise limits at receptor locations for various land-uses based on time of day or night. While not explicitly mentioned, by professional critical evaluation of other sections of the ordinance it may be reasonably assumed that the noise limits are expressed in units of maximum (Lmax), A-weighted sound levels (dBA), using a root-mean-square (RMS) 'slow' sound meter response time. The ordinance also stipulates that if the noise source under question is "of an impulsive character" (such as firearms) then the noise limits for residential and commercial receptors are to be reduced by 5 decibels. **Table 1** summarizes the ordinance's noise limits both with and without the impulsive noise penalty.

Table 1. Spotsylvania County Noise Ordinance Limits

Receiving Receptor Zoning Land-Use	Receptor Noise Limit dBA Lmax 'slow'	
	Daytime 6:00 AM to 10:00 PM	Nighttime 10:00 PM to 6:00 AM
Residential	65 60 (impulsive)	60 55 (impulsive)
Commercial	70 65 (impulsive)	65 60 (impulsive)
Office	65 60 (impulsive)	60 55 (impulsive)
Industrial	79	75

The ordinance also contains language in Section 14-52 defining certain exemptions from the noise limits. Particularly noteworthy exemptions include Items (a)(3) and (b)(8) which exempts the noise produced from firearms (and other noise producing devices) if they are used as a customary part of an established commercial business. The ordinance's relevant verbatim language is reproduced below for convenience:

(a) The following matters are exempt during the daytime (6:00 a.m. to 10:00 p.m.) from this article:

(3) Noise emitted by a commercial or industrial establishment which noise is customarily emitted by such commercial establishments or industries.

(b) The following activities or sources of noise shall be exempt during all hours from this article, except to the extent as herein limited:

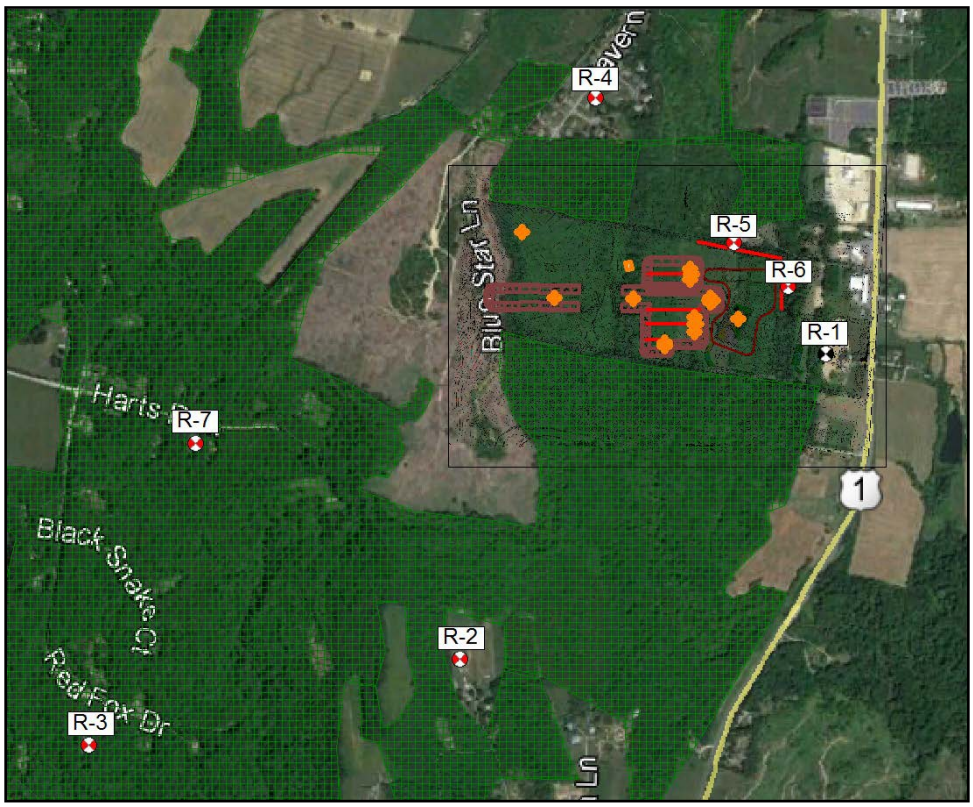
(8) The use of firearms (which use is governed by other provisions of federal, state and county law).

Consequently, Crucible's new facility and business operations at their Spotsylvania site will be <u>exempt</u> from the County Noise Ordinance between 6:00 AM and 10:00 PM to the extent noted above. Any attempt or willingness on Crucible's part to try to comply with the ordinance's noise limits would be done solely on a voluntary basis.

Cadna-A Noise Model

Because Crucible's new Spotsylvania facilities have not yet been built, this noise assessment was analytically based on the expected site layout, type and number of shooting activities, use of simulated IEDs, and use of the evasive driving training course. To analyze the new facility's noise emissions, the Cadna-A® noise model was used to predict the noise levels associated with the expected types of activities. Cadna-A is a comprehensive commercially-available model developed by DataKustik GmbH to satisfy International and USA standards. Compliance or exceedance with the noise ordinance was evaluated from the perspective of receptor locations in the community surrounding Crucible's proposed site. The final configuration of the Cadna-A model, as used for this project, is shown in **Figure 2**. In the figure, orange crosses identify locations of noise sources, brown lines represent range berms and backstops, red lines represent dedicated noise barriers, and the "R-#" designations indicate community receptor locations where noise levels were evaluated.

Figure 2. Cadna-A Noise Model Configuration



Cadna-A is a powerful, three-dimensional, ray-tracing acoustical model that implements International Standards Organization (ISO) Standard 9613 for the prediction and propagation of outdoor sound. Cadna-A and ISO 9613 are used by the acoustics industry on a worldwide basis. Noise sources are entered into the Cadna-A model in the form of point, line and/or area components; with each source emitting sound power levels (PWL) in octave bands or broadband A-weighted format. Distance attenuation, elevation differences, ground absorption, wind effects, foliage, building shielding, and attenuation from barriers and berms are computed in the Cadna-A model. The resulting sound pressure levels (SPL) are predicted at any receptor location ofinterest.

The Cadna-A model for this project was configured by first importing a GoogleEarth® base map of the area. In this manner, the positions of structures, street locations, receptor locations and distances could be modeled to a high degree of accuracy. A scale layout and design of Crucible's new facilities was then superimposed over the base map. The final model preparation step involved entering ground terrain elevation data which was obtained from USGS topographical maps.

The model was then populated with hypothetical rifle and pistol gunshot source locations occurring on the 500 yard, 150 yard, 100 yard and 40 yard ranges; simulated buried IED explosions; and an automobile making use of the driving course. The noise emissions escaping from a nearly fully enclosed "shoot house" were also entered into the model.

Noise emission data for the firearms were sourced from a database of previously measured gunfire noise levels, which in this case included an AR-15/M-4 type rifle and a relatively loud handgun such as those chambered for 9 mm or .357 Magnum ammunition. Representative noise emission levels from other firearms that Crucible intends to use were measured in July 2017. These included an AK-47 type rifle and an AR-10 style rifle. The results of those noise tests are explained further below. Suppressors and shotguns were not tested as they emit less noise than these other firearms.

In general, the rifles emit a sound power level (PWL)[1] of 137 to 138 dBA Lmax 'slow' PWL. Handguns are slightly quieter, producing approximately 134 dBA Lmax 'slow' PWL. Noise emission levels for the IED were computed using the ConWep model developed by the US Army Corps of Engineers. For example, a 1-ounce charge of black powder (Pyrodex RS) is expected to produce 137 dBA Lmax 'slow' PWL. The same charge buried slightly underground produces approximately 10 to 15 decibels less noise. Lastly, vehicles using the evasive driving training course were assumed to be driving at an average speed of 30 mph.

The earthen berms and ballistic dividing walls that Crucible intends to construct around their shooting ranges were entered into the model at their respective heights, namely berms at 20-feet-tall and dividing walls at 10-feet-tall. The majority of lands surrounding Crucible's new site are fully developed forested areas, thus trees of 25-foot nominal height were also entered into the Cadna-A model where these forested areas exist. However, areas with only sparse tree density were not included in the model. The ground surface was assumed to be acoustically absorptive (G=1).

Seven noise receptor locations, as shown in **Figures 1 and 2** and summarized in **Table 2**, were selected for assessment in this study and entered into the Cadna-A model. Except for receptor R-1 which is located at Crucible's future office location, all the receptors are residential land-uses selected due to their relative proximity to Crucible's proposed site.

With the Cadna-A model fully configured and populated with source and terrain data, the resulting noise levels expected from Crucible's use of firearms, IEDs and the driving course were then computed at each receptor's exterior location. The noise levels were computed at the exterior of the receptors using the metric *Lmax dBA 'slow'* because that is where and how the County Noise Ordinance specifies its limits. If desired, interior noise levels could be estimated at each receptor location by subtracting 10 decibels from the exterior noise level if the receptor's windows are open, or subtracting 25 decibels if the windows are closed.

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[1] While decibel values of sound power (PWL) and sound pressure (SPL) may be compared to other sound power levels and sound pressure levels, respectively, the two are wholly different quantities and should not be misconstrued as meaning the same thing. See **Appendix A** for further definition of PWL and SPL.

Initial results of the Cadna-A model indicated that Crucible's noise emissions might exceed County ordinance limits at receptors R-5 and R-6. They are the closest receptors to Crucible, abutting Crucible's northeast property corner. To proactively avoid these potential exceedances, a noise barrier was included in the Cadna-A model to reduce noise affecting these two receptors. Various noise barrier positions and heights were evaluated in the model, with the results finding that a 12-foot-tall barrier of approximately 1,150 feet in length (shown as a red line in **Figure 2**) would reduce noise levels sufficiently to comply with the County ordinance limits for these two receptors.

Table 2. Selected Noise Receptors

Site No.	Receptor Location	Receptor Land-Use	Approximate Compass Direction*	Approximate Distance* (Feet)
R-1	Crucible Office	Commercial	East Southeast	1,540
R-2	5661 Bear Lane	Residential	South Southwest	3,650
R-3	5808 Red Fox Dive	Residential	Southwest	6,140
R-4	6111 Taverneer Lane	Residential	North Northwest	1,920
R-5	6148 Jefferson Davis Highway	Residential	Northeast	920
R-6	6144 Jefferson Davis Highway	Residential	East Northeast	1,110
R-7	6020 Harts Run	Residential	West Southwest	4,210

Note: (*) Direction and distance relative to the approximate geometric center of Crucible's proposed site.

Rifle Noise Emission Measurements

As mentioned above, noise emission levels from two of the firearms that Crucible intends to use were measured in July 2017. They included an AK-47 style rifle chambered in 7.62 x 39 mm, and an AR-10 style rifle chambered in 7.62 x 51 mm (otherwise known as .308 Winchester).

Noise measurements were performed at a distance of 50 feet from both the right and left waysides of each rifle. The rifles were fired at an outdoor shooting range, one shot at a time, using standard factory ammunition until the sound emission levels from a total of 10 rounds (five from the left side and five from the right side) had been measured for each rifle. **Photos 1 and 2** show the AK-47 and AR-10 style rifles, respectively, that were tested.

Photo 1. AK-47 Style Rifle

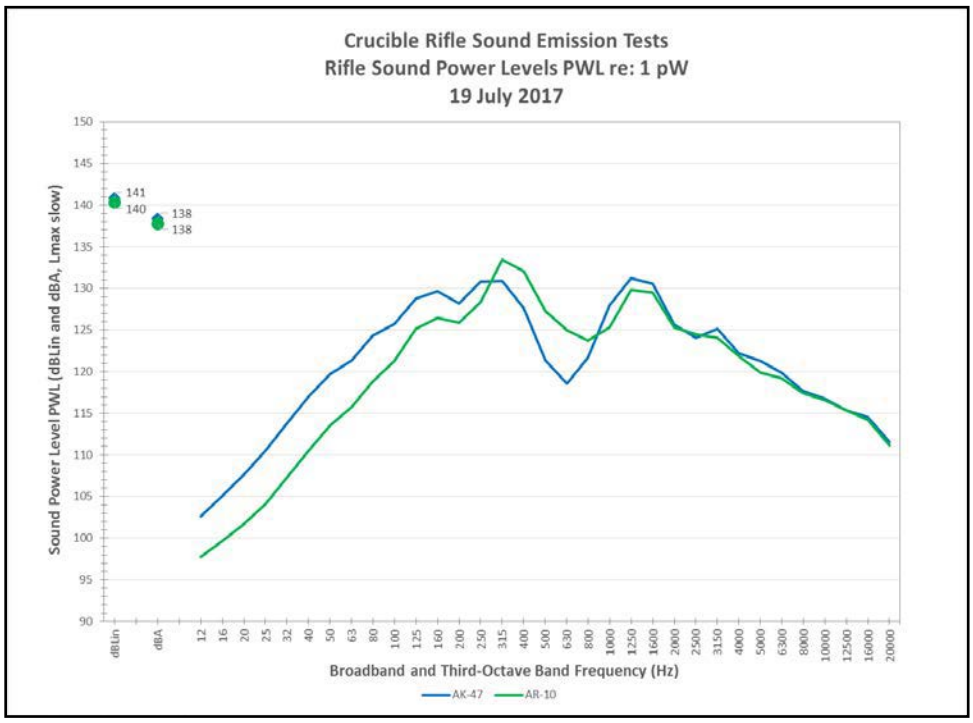
Photo 2. AR-10 Style Rifle

All sound level measurement instrumentation used in this study complied with ANSI Standard S1.4 for Type 1 precisions and accuracy. The instrumentation consisted of a CEL Instruments Model 593 Sound Level Analyzer equipped with a Bruel & Kjaer Model 4189 Microphone. The CEL 593 was programmed to measure and record maximum (Lmax) broadband A-weighted (dBA) and unweighted third-octave band sound pressure levels using an RMS 'fast' time response. Equivalent RMS 'slow' sound pressure levels were then computed by subtracting 9 decibels from the RMS 'fast' results based on the relative difference between 'fast' and 'slow' rise time constants of 0.125 seconds and 1 second, respectively, if applied to an impulsive noise source.

The calibration level of the CEL 593 was confirmed in the field using a Bruel & Kjaer Model 4231 Acoustical Calibrator; a 3½-inch diameter windscreen was used to reduce wind noise affecting the microphone; and the CEL 593 was mounted on a tripod to minimize operator interference. Weather conditions that day (7/19/17) were perfectly acceptable for performing sound level measurements.

After being measured and digitally downloaded from the CEL 593, the measured sound pressure levels (SPL) were converted into sound power levels (PWL) by taking the distance of 50 feet into account and by assuming that the rifles radiated noise into a hemi-spherical, free-field acoustical space. The final A-weighted (dBA) level and unweighted (dBLin) broadband levels and third-octave band sound power levels can be seen graphically in **Figure 3**. The third-octave band sound power levels, summed into full octave band levels, were then entered into the Cadna-A model as point sources to represent AK-47 and AR-10 rifles.

Figure 3. Sound Power Level Emissions of Tested Rifles



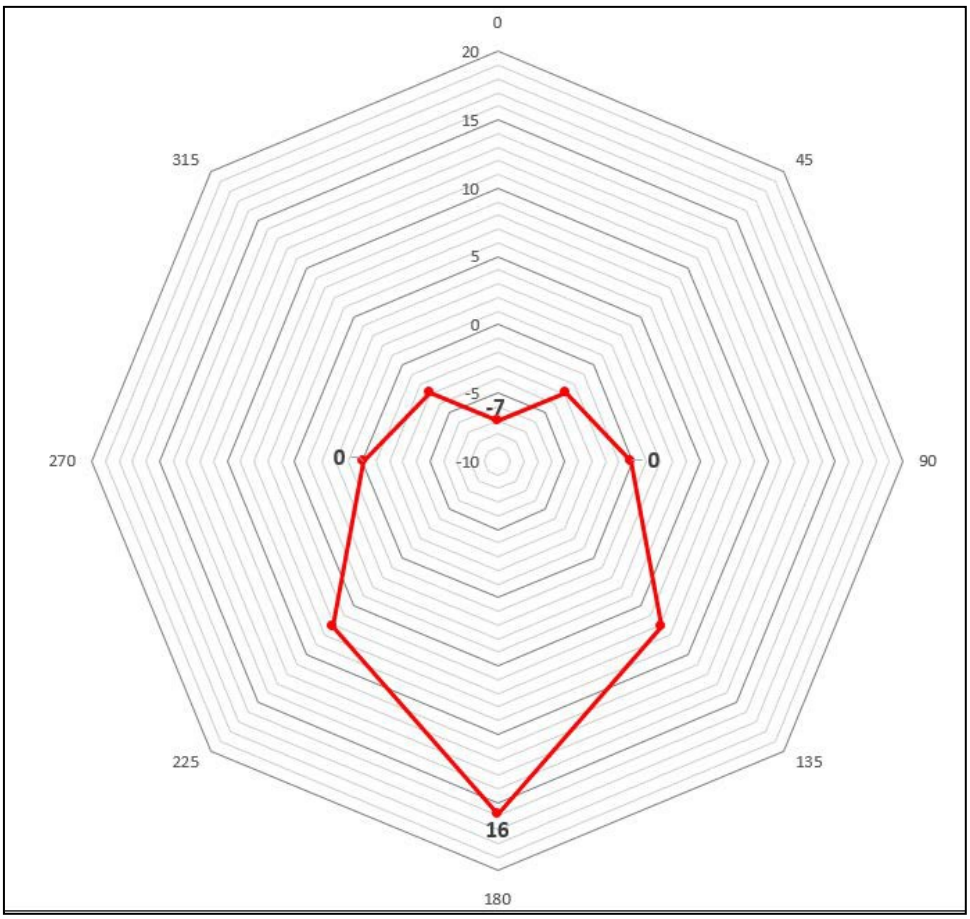
Firearm Acoustical Directivity

Another important aspect of firearms noise emissions is their acoustical directivity. Firearms are not perfect omnidirectional point sources; they radiate noise in different directions with various intensities.

Most of a firearm's acoustical energy is directed downrange in-line with the muzzle. Less noise radiates to the sides, and the least amount of noise radiates backwards behind the shooter. Previous measurements done for other gun range noise projects indicate that shooting noise levels can be 16 decibels louder in a downrange direction (180°) as compared to equivalent distances wayside of the firearm (90° and 270°); and that firearm noise levels behind the shooter (0°) can be an additional 7 decibels quieter than the wayside levels due to the shooter's body acting as a partial sound barrier. Thus, noise levels at equivalent distances can be a total of 23 decibels quieter towards the rear of the shooter than they are straight downrange.

The directivity pattern shown in **Figure 4** was entered into the Cadna-A noise model and applied to all gunshots. In Crucible's case, downrange was defined as heading in a westerly direction.

Figure 4. Firearm Acoustical Directivity Pattern



Noise Prediction Results

The results of the Cadna-A noise model predictions are summarized in **Table 3** for the seven community receptor locations included in this study. The results are segmented into the noise contribution expected to be caused by each of the three separate types of noise sources, namely from gunfire, IEDs and driving. The table also shows the daytime and nighttime noise limits at each receptor contained in the Spotsylvania County Noise Ordinance for impulsive-type noise sources. Again, Crucible is exempt from the noise ordinance so the limits are shown here only for informal comparison only. All decibel levels are expressed as maximum single event A-weighted sound levels using an RMS 'slow' time response (i.e. dBA Lmax 'slow').

As can be seen in the table, noise levels due to Crucible's shooting activities and simulated IEDs are expected to comply with the ordinance's daytime noise limits at all receptor locations included in this study. Noise levels expected from Crucible's evasive driving training course were found to likely be completely inaudible at the receptor locations and thus, not relevant. Lastly, day and night noise ordinance limits are shown for comparison. Crucible's proffers prohibit firearm and simulated IED use during nighttime hours. Therefore, Crucible is expected to be compliant with County Noise Ordinances limits during all daytime and nighttime hours.

Table 3. Predicted Crucible Noise Levels at Receptor Locations

Site No.	Receptor Location	Receptor Land-Use	Spotsylvania County Noise Ordinance Limit* (dBA Lmax 'slow')		Crucible Noise Loudest Single Event (dBA Lmax 'slow')		
			Daytime 6AM–10PM	Nighttime 10PM–6AM	Firearms	IEDs	Driving
R-1	Crucible Office	Commercial	65	60	54	57	13
R-2	5661 Bear Lane	Residential	60	55	58	40	0
R-3	5808 Red Fox Dive	Residential	60	55	51	32	-5
R-4	6111 Taverneer Lane	Residential	60	55	60	46	5
R-5	6148 Jefferson Davis Highway	Residential	60	55	57	55	17
R-6	6144 Jefferson Davis Highway	Residential	60	55	50	59	20
R-7	6020 Harts Run	Residential	60	55	60	38	-2

Note: (*) Noise ordinance limits for "impulsive" noises.

In addition to computing noise levels at discrete points, the Cadna-A model can also compute isopleth contours of equal loudness. In this manner, one can visually interpret how noise from a given set of noise sources and terrain conditions would propagate in all directions.

Figures 5 thru 7 show the sound level isopleth contours expected for Crucible's use of firearms, IEDs and the driving course, respectively. The isopleth lines are shown in 1-decibel increments, and the colored zones are in 5-decibel increments. All sound levels are A-weighted decibels (dBA).

The plotted results may not match up perfectly with the predicted noise level results shown in **Table 3** because the plots assume that all noise sources of a given type (i.e. firearms, IEDs or driving vehicles) are emitting noise at their maximum (Lmax) levels at the *exact same moment in time*. This

is an unrealistically conservative assumption because Lmax sound levels are not additive in that manner. However, the isopleth plots serve to show how sound might radiate away from Crucible's facility in any given direction with the sources emitting sound from anywhere they might be located.

As can be seen in **Figure 5**, the majority of shooting noise radiates in a westerly direction due to the acoustical directivity of the firearms. Careful inspection also shows that the 20-foot-tall range side berms and the 12-foot-tall noise barrier for receptors R-5 and R-6 are very effective for reducing noise propagating in those directions.

As can be seen in **Figure 6**, noise from simulated IED explosions will radiate in more of an omnidirectional spherical pattern because they are modeled as point sources without dominant acoustical directivity. However, their omnidirectional spreading is soon affected by local terrain, berms and foliage areas, resulting in easier propagation towards the east due to less dense foliage.

Lastly, as shown in **Figure 7**, noise emissions from vehicles using the defensive driving course also tend to radiate omnidirectionally as a moving point source. However, the noise levels produced from the driving course are so low that they can be considered as negligible in this case.

Figure 5. Crucible Firearms Noise Isopleth Contours

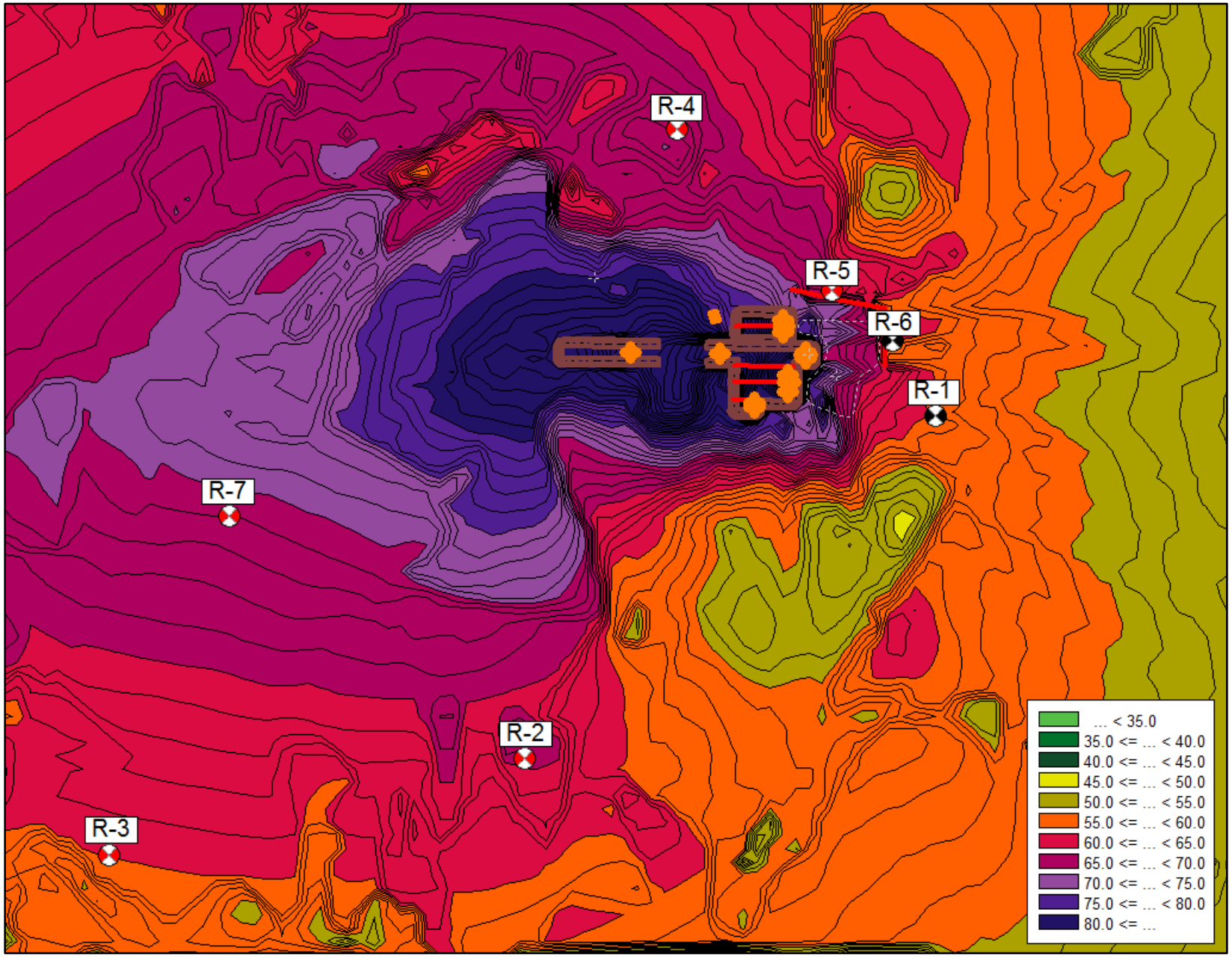


Figure 6. Crucible IEDs Noise Isopleth Contours

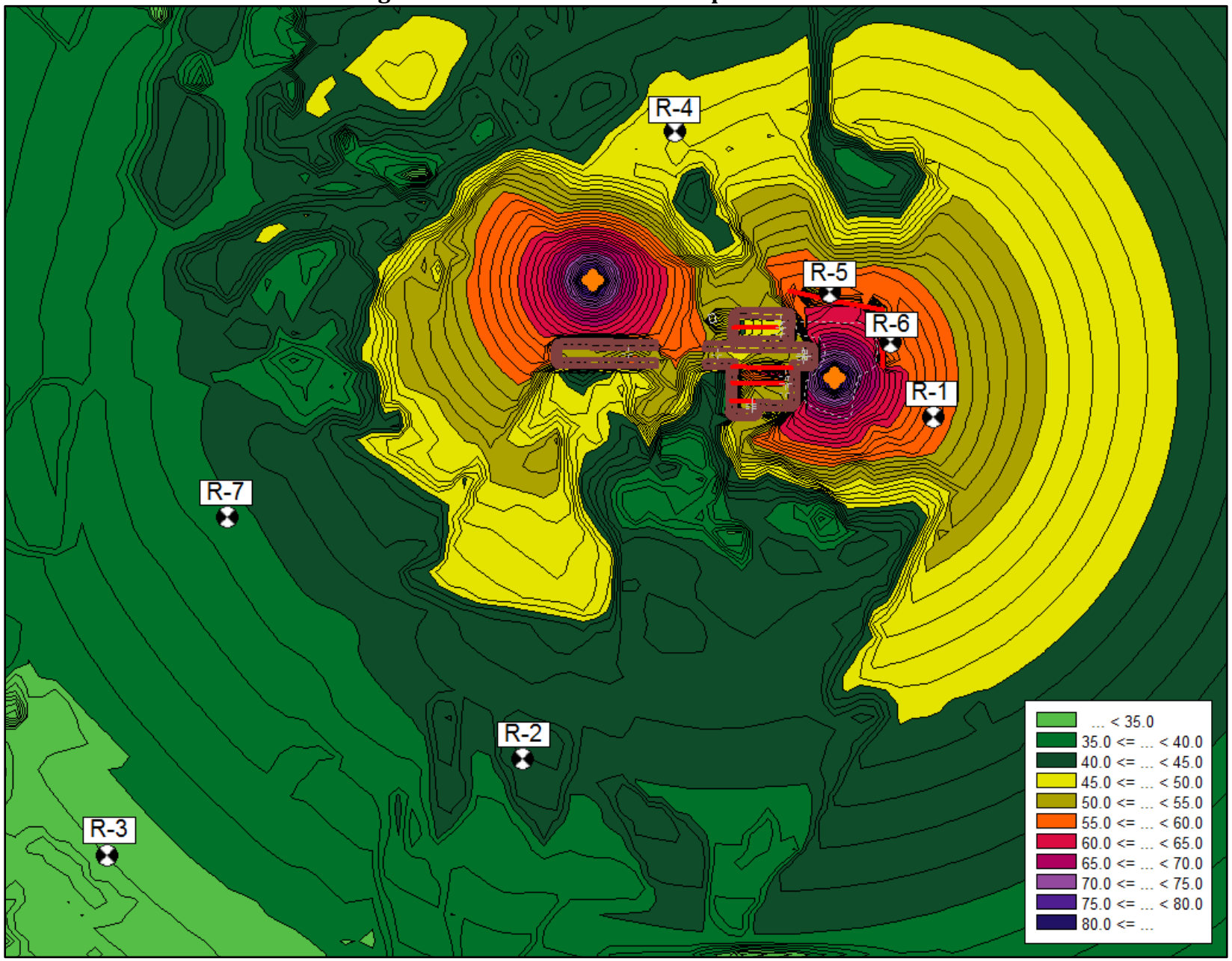
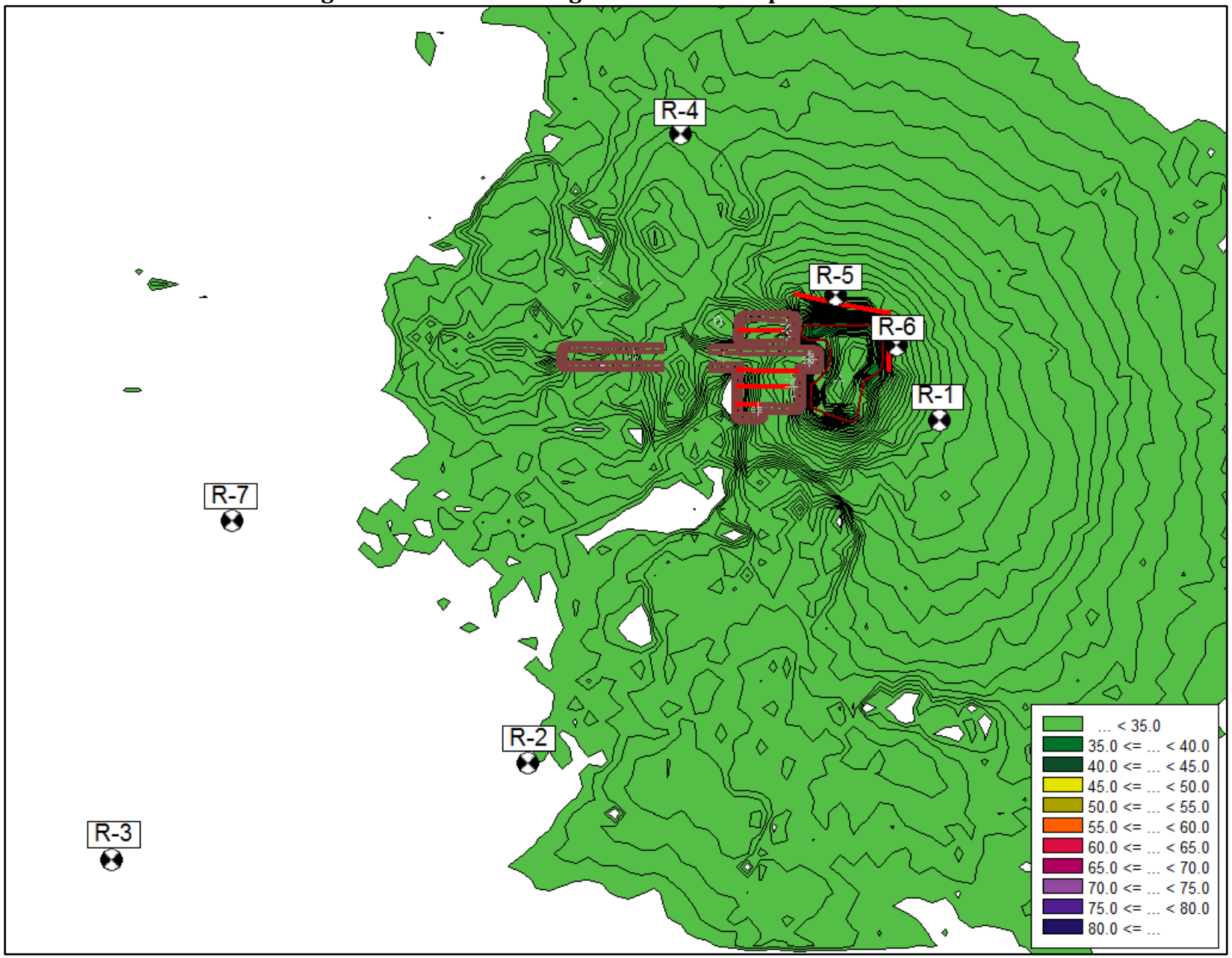


Figure 7. Crucible Driving Course Noise Isopleth Contours

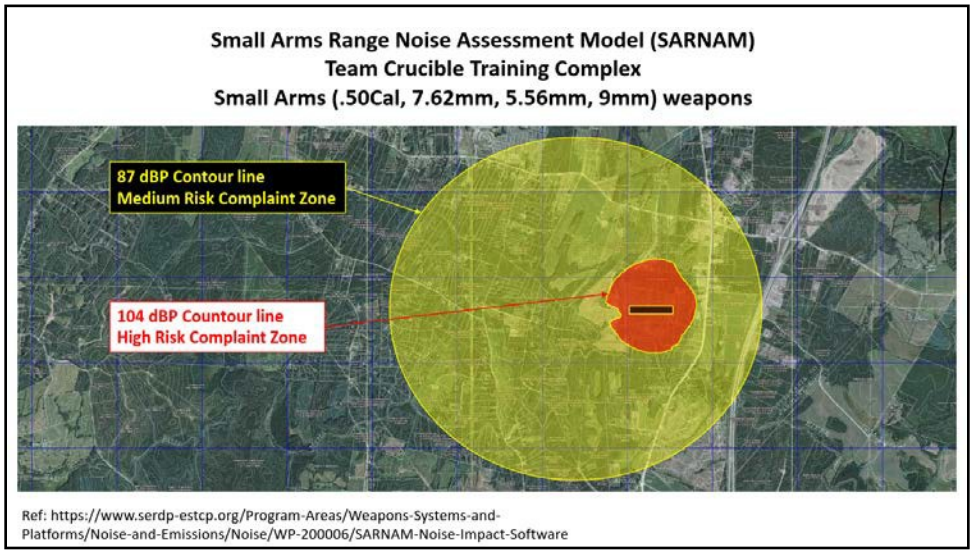


Cadna-A vs. SARNAM

Some members of the public, opposed to Crucible developing and operating their new facility in Spotsylvania, have presented their opinions and alleged noise-related facts in this case to Spotsylvania County officials. Unfortunately, this presentation was fraught with misunderstanding, misapplication and misleading information.

In that presentation, the person(s) addressing those officials and the public attempted to calculate and characterize the potential noise generated by Crucible's proposed new facility by making use of the *Small Arms Range Noise Assessment Model* (SARNAM). Their results, shown graphically in **Figure 6** as sound level isopleth zones surrounding Crucible's facility, indicated that noise from firearms (including 50 BMG rifles that will not be used) could be as loud as 104 dB SPL Peak at a distance of 2,200 feet, and as loud as 87 dB SPL Peak as far away as 10,500 feet. Attempts were then made to explain how these decibel results would significantly exceed the Spotsylvania County Noise Ordinance limits, which again is an inaccurate and misleading conclusion.

Figure 6. Opposition's SARNAM Noise Model Results



SARNAM was developed in the 1990s by a group of researchers working at the US Army's Construction Engineering Research Laboratory (CERL). The main purpose of SARNAM was to aid the Army in land-use planning in and around military bases. The developers of SARNAM chose to characterize noise emission levels from firearms using the "dB Peak" sound level, and limit the output of the SARNAM model to only compute dB Peak, Sound Exposure Level (SEL), Annual Equivalent Sound Level (ALeq) and Annual Day-Night Sound level (ADNL). *However, none of these sound metrics are comparable to the noise limits set forth in the Spotsylvania County Noise Ordinance.*

First and most importantly, a decibel level expressed as dB Peak is not at all the same as one expressed as dBA Lmax 'slow' as specified in the Spotsylvania noise ordinance (see definitions in **Appendix A**). Both metrics describe sound level in some quantitative manner, but they are wholly different in their derivations and their values are not directly comparable. A good conceptual analogy would be that of thermal temperature. While all temperature levels are expressed in units of "degrees", the given scale (i.e. Fahrenheit, Celsius, Kelvin, Rankin, etc.) must also be stated for the absolute value or comparisons of the numeric degree quantity to make sense.

The problems with using SARNAM in this case include the facts that dB Peak is not frequency-weighted (vs. A-weighted); the sound has not been measured with an RMS detector (vs. Lmax); and the sound measurement has a rise time constant of approximately 10 to 100 micro-seconds (vs. 1 second for 'slow'). Consequently, the sound level of an acoustical signal such as a gunshot expressed in dB Peak must by definition have a much higher numeric value than one expressed in dBA Lmax 'slow' for the same acoustical signal (i.e. the same gunshot). For a near perfect sound impulse, the numeric difference could be as much as 47 decibels! Thus, if one were to try to evaluate the opposition's SARNAM results with respect to the limits in the Spotsylvania noise ordinance, the results would roughly be the following:

- 104 dB Peak would become *57 dBA Lmax 'slow'*, where the daytime limit is 60 dBA Lmax 'slow'.
- 87 dB Peak would become *40 dBA Lmax 'slow'*, where the daytime limit is 60 dBA Lmax 'slow'.

Conversely, the Cadna-A noise model, as described previously, is ideally suited for predicting and evaluating noise levels in accordance with the Spotsylvania noise ordinance. Cadna-A incorporates the algorithms and recommended practices contained in ISO Standard 9613 for outdoor sound propagation. And most importantly in this case, Cadna-A can predict sound levels in units of dBA Lmax 'slow' in a manner consistent with the Spotsylvania noise ordinance (i.e. an apples-to-apples comparison).

Proper Acoustical Measurements (Smartphones)

In cases such as this one involving contested sound levels and the legal application and enforcement of noise limits, it is crucial to understand how sound levels are measured properly. The old adage of "garbage in, garbage out" certainly applies to sound measurement data and results.

Sound level meters are certified for proper performance and measurement accuracy in accordance with the test procedures and tolerances described in American National Standards Institute (ANSI) Standard S1.4 and corresponding International Electrotechnical Commission (IEC) Standard 61672. Specifications are provided with respect to a sound meter's amplitude dynamic range, frequency response and weighing filters (e.g. A-weighting), linearity, time response (e.g. RMS 'impulse', 'fast', 'slow'), measurable noise floor, temperature and humidity stability, data collection and display rate, and calibration accuracy. And of course, the sound meter must be able to correctly measure the metrics customarily used in the acoustics profession (e.g. SPL, Lmax, Lmin, Leq, SEL, Ln%, Lave and Peak).

Depending on how well a sound level meter can pass these tests, it will be certified as meeting either Type 0, Type 1 or Type 2 requirements. Type 0 is the highest level of accuracy, nominally +/- 0.5 dB, and is reserved for "laboratory-grade" acoustical instrumentation. Type 1 sound meters are nominally accurate to within +/- 1.0 dB and are used for "precision-grade" sound measurements. Lastly, Type 2 sound meters of nominal accuracy of +/- 2.0 dB are considered acceptable for "general-purpose" community noise surveys and OSHA-type hearing conservation dose monitoring.

If a sound level meter is <u>not</u> certified as being compliant with one of these ANSI S1.4 Type requirements then it should <u>not</u> be used for important sound measurement applications, especially if the results have legal consequences associated with them.

To illustrate, some people have mistakenly thought that performing sound measurements with today's sophisticated smartphones could produce reliable decibel results. However, even though most smartphones have a "sound meter app" in them, they are not, and in fact could not be, certified as meeting one of the Type level requirements described in ANSI Standard S1.4. This is because the microphones and preamps found in smartphones are wholly inadequate for performing proper sound measurements. Their dynamic and frequency ranges are too small because they are intended to only transduce voice and speech. Thus, they only work within a small portion of the audible frequency spectrum, and do so with a non-linear dynamic response. There is also great inconsistency in how these apps define the various metrics used in acoustics.

But the biggest problem is that smartphone "sound meter apps" cannot be properly calibrated with a higher-order more accurate calibration source. Thus, any sound level data collected with a smartphone, and in fact any sound meter not certified as meeting one of ANSI S1.4 Type requirements, cannot and should not be relied upon for dependable and defendable results.

Conclusions

The results of this acoustical study supports the expectation and conclusion that Crucible will be able to successfully manage noise emissions associated with their new facility in Spotsylvania County, Virginia. Noise propagating to the surrounding community from Crucible's use of firearms, simulated IEDs and evasive driving course are expected to fully comply with the impulsive noise criteria limits contained in the Spotsylvania County Noise Ordinance; which Crucible has voluntarily put forth as their goal.

As evidence of their willingness to control noise to the fullest extent reasonably practicable, Crucible has proactively committed to certain physical noise control enhancements to their facility design. Most notable is their plan to build unusually tall 20-foot-high side berms and backstops for their shooting ranges. Moreover, they plan to build a dedicated 12-foot-tall noise barrier along the northeast corner of their property to further reduce noise affecting receptors R-5 and R-6 (which are the closest receptors to Crucible's new facility). And Crucible is voluntarily willing to limit their operational hours to daytime hours only.

In conclusion, given these proactive noise mitigation measures and the quantitative results of this acoustical study, *the new Crucible facility would be a noise-compatible land-use within its proposed location in Spotsylvania, Virginia.*

Appendix A

Acoustical Terms and Definitions

Acoustical Terms and Definitions

As with any field of science, it is critical to understand and make proper use of technical terms and definitions that are used in the acoustical industry. Noise can be quantified in many different manners depending on its temporal/time, tonal/frequency, or magnitude/loudness properties.

Noise magnitude is expressed in units of *decibels (dB)* which is a logarithmic quantity comparing fluctuating air pressure to that of a standardized reference static air pressure of 20 micro-pascals (i.e. dB re: 20 μPa). For this reason the noise levels that humans hear are called *sound pressure levels*. Noise is expressed as a logarithmic quantity because humans are sensitive to relative changes in noise levels. To illustrate, humans can just barely perceive a change in noise levels of +/- 1 decibel, can likely perceive a change of +/- 3 decibels, can easily perceive a change of +/- 5 decibels, and will generally describe a change of +/- 10 decibels as a doubling or halving in noise levels.

With respect to tonal qualities (frequency), a frequency weighting adjustment has been standardized to account for the human auditory response over the audible frequency range of approximately 20 Hz to 20,000 Hz. Humans are less capable of hearing low frequency noise, exhibit a maximum sensitivity to tones in mid-frequency ranges, and are slightly less sensitive to high frequency sound as well. This frequency weighted adjustment is referred to as "A-weighting", with results expressed as *A-weighted decibels, or dBA.* Illustrative examples of A-weighted decibel levels for common outdoor and indoor noise sources is provided in **Figure A-1**.

Another common practice is to separate a sample of noise into its spectral components by using frequency filters of known shape and bandwidth. This approach provides insights into the source and transmission characteristics of the noise and allows for identification of frequency ranges that contain the most acoustical energy. *Octave band and third-octave band* filters are typically used for this purpose because their bandwidths are a constant percentage of their center frequencies, and are better for mimicking how humans perceive discrete frequencies by providing finer resolution at lower frequencies.

Numerous metrics and indices have been developed to quantify the temporal characteristics (changes over time) of environmental noise include the following:

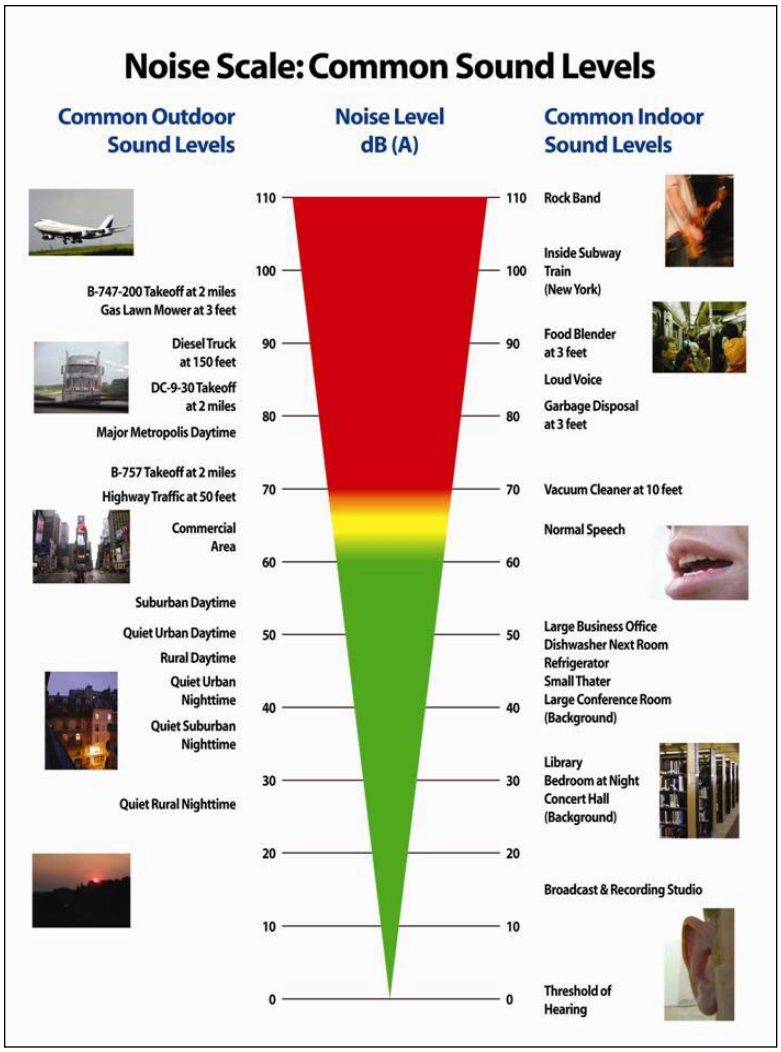
The *Equivalent Sound Level, or Leq*, is the energy-averaged single noise level that represents the same acoustic energy that was contained in the fluctuating noise level over a defined period of time. The Leq is useful for describing the "average" noise level over time, and is expressed in dBA.

The *Maximum and Minimum Sound Levels, or Lmax and Lmin*, are the loudest and quietest instant sound level occurring during a period of time. The Lmax is particularly useful for evaluating loud, impulsive noise events such as gunshots. Lmax and Lmin levels are expressed in dBA, however the root-mean-square (RMS) time constant of the sound level meter's detector has a significant effect on the measured levels. By International agreement, a sound level meter with an RMS response set to "slow" has a rise time constant of 1 second, where a setting of "fast" is about 8x faster with a rise time constant of only 0.125 seconds.

The *Peak Sound Level, or Peak*, is a measure of the highest unweighted raw air pressure level in an acoustical signal. Peak levels have not been rectified through a root-mean-square detector before being measured, and thus should not be confused with Lmax sound levels. Human auditory perception is not related to Peak sound levels. Rather, Peak levels are used for evaluating the potential effects of high intensity air pressure impulses affecting physical structures or damage to people's eardrums.

The *Percentile Level, or Ln*, expressed in dBA is a statistical representation of changing noise levels indicating that the fluctuating noise level was equal to, or greater than, the stated level for "n" percent of the time. For example, the L1, L10, L50, and L90 represent the noise levels exceeded 1%, 10%, 50%, and 90% of the time. The L10 is often used to identify impacts of transportation or construction noise sources, while the L90 is considered to represent steady background noise.

Figure A-1. Common A-Weighted Decibel (dBA) Sound Levels



The *sound power level (PWL)* of a noise source is the strength or intensity of noise that the source produces/emits regardless of the environment in which it is placed. Sound power is a property of the source, and therefore is independent of distance. The radiating sound power then produces a *sound pressure level (SPL)* at any given point of interest which human beings perceive as audible sound. The sound pressure level is dependent on its environment (absorption, reflections, etc.) and its distance from the noise source. And even though both sound power and sound pressure are expressed in decibels (dB), they are not the same thing and should not be confused. Decibel levels of sound power are referenced to a power level of 1 pW, while decibel levels of sound pressure have a pressure reference level of 20 μPa.

Appendix B

Professional Certifications

The following acoustical professional was the principle investigator for this project.

INCE

The Institute of Noise Control Engineering
of the United States of America, Inc.

in recognition of
professional standing and contributions
attests that

ERICH THALHEIMER

a Member of the Institute
is
Board Certified
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For the Board of Directors

Paul R. Donavan
President

David J. Kato
Secretary

2001 June

20104

The following acoustical professional independently reviewed this report for QA/QC.

INSTITUTE OF NOISE CONTROL ENGINEERING

Certificate of Board Certification Maintenance

granted to

Robert Greene

This Member has completed requirements for maintaining status as a

Member, Board Certified

Of the Institute of Noise Control Engineering through the period ending

January 1, 2022

June 12, 2017 — Date

President

Executive Director