In-Depth Survey Report

Development and validation testing of an impulse noise meter

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Engineering and Physical Hazards Branch

Federal and Military Firing Ranges
San Diego, CA and Dayton, Ohio

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Abstract

This report describes the development and validation of a new impulsive noise instrument to facilitate the measurement and characterization of impulsive noise and its effects on hearing of exposed workers. The long term objective of developing an impulsive noise instrument is to improve and expand the collection of empirical data on impulsive noise exposures which in turn should facilitate the development of a universally agreed-upon damage risk criterion. A damage risk criterion for impulsive noise will allow NIOSH to update its criteria document on occupational noise exposure and provide recommendations for safe exposures.

The report provides an overview of the development, system description, operation, and validation of the impulsive noise measurement system. The meter was evaluated in the NIOSH impulsive noise laboratory using a shock-tube that produces impulses from 130-170 decibels (dB) and in the field at several firing ranges measuring impulse noise levels generated by small firearms from 150-185 dB. The meter outperformed current measurement systems with respect to real-time measurements, ease of use and setup, and providing on the spot assessment of the risk to workers.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

This EPHB study is focused on high-intensity impulse sounds which are generally considered to be more damaging to hearing than continuous sounds [Dunn et al., 1991; Starck et al., 2003]. Exposure to impulsive sound can cause acute acoustical trauma, which can be followed by symptoms such as tinnitus and temporary hearing impairment [Salmivalli 1967; Mrena et al., 2002]. Sudden hearing loss may also occur from exposure to impulsive sounds that exceed a critical sound pressure level by causing direct mechanical damage to the inner ear [Ward et al., 1961; Luz et al., 1971].

Considerable research has been performed since the 1950s to document the audiometric and histological effects of impulsive sounds. Much of the impetus for this research came from studies by military agencies in the U.S. and Europe of the impulsive sounds from weapons [Dancer et al., 1998; Ylikoski, 1994]. However, most of those studies lacked the empirical data needed to establish a quantitative relationship between a measure of impulsive sound and the resulting auditory damage. As a consequence, there is no consensus among experts in the occupational, military, and scientific communities as to the extent of the hazard to hearing as a result of exposure to impulsive sounds.

The Committee on Hearing, Bioacoustics, and Biomechanics of the U.S. National Research Council proposed a damage-risk criterion in 1968 [CHABA, 1968], but studies have shown that the CHABA criterion is not adequate for exposure to short-duration impulsive sounds. The CHABA criterion was intended to apply to measurements that could be made using available instruments and did not address characteristics of impulsive sounds such as spectral content or temporal nature, the use of hearing-protection devices, or the protection provided by the nonlinear acoustical reflex and the peak clipping that occurs in the middle ear [CHABA, 1992]. Various criteria other than the CHABA criterion have been proposed, but all have similar limitations. Regulations established by OSHA and the guidelines recommended by NIOSH state that no exposure to impulsive sound should be permitted if the peak sound pressure level exceeds 140 dB [NIOSH, 1998; OSHA, 1992]. The European Union (EU) directive 86/188, the International Organization for Standardization in ISO 1999:1990, and the American National Standards Institute ANSI S3.44-1996 also state that no exposure should permitted if the peak sound level exceeds 140 dB (ECD, 1986; ISO, 1990; ANSI, 1996].

Occupational Exposure Limits and Health Effects

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH investigators use mandatory and recommended occupational exposure limits (OELs) when evaluating chemical, physical, and biological agents in the workplace. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or hypersensitivity. In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in the OEL. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus can increase the overall exposure. Finally, OELs may change over the years as new information on the toxic effects of an agent becomes available.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended short term exposure limit (STEL) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

In the U.S., OELs have been established by Federal agencies, professional organizations, state and local governments, and other entities. The U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) established permissible exposure limits (PEL) that are legally enforceable in workplaces regulated by the Occupational Safety and Health Act [29 CFR 1910]. NIOSH developed recommended exposure limits (REL) that are based on critical reviews of the scientific and technical information available on the prevalence of health effects, the existence of safety and health risks, and the adequacy of methods to identify and control hazards [NIOSH, 1992]. Other OELs that are commonly used and cited in the U.S. include the threshold limit values (TLVs) and biological exposure indices (BEIs) recommended by the American Conference of Industrial Hygienists (ACGIH) [ACGIH, 2012]. ACGIH TLVs and BEIs are considered voluntary guidelines for use by industrial hygienists and others trained in this discipline “to assist in the control of health hazards.” The American Industrial Hygiene Association (AIHA) developed guidelines for chemical and physical agents called the workplace environmental exposure levels (WEELs) “when no other legal or authoritative limits exist.” [AIHA, 2011].

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91–596, sec. 5(a)(1)]. Thus, employers are required to comply with OSHA PELs. Some hazardous agents do not have PELs, however, and for others, the PELs do not reflect the most current health-based information. Thus, NIOSH encourages employers to consider the other OELs when making risk assessment and risk management decisions to best protect the health and safety of their employees. NIOSH also encourages the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace hazards. This includes, in preferential order, the use of: (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation) (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection).

Occupational Exposure Limits for Noise

OSHA's standard for occupational noise exposure (29 CFR 1910.95) specifies a maximum PEL of 90 decibels, A-weighted (dBA), averaged over an 8-hour time period. Noise generated from weapons is classified as impulse noise. The regulation uses a 5-dB exchange rate. This means that when the noise level is increased by 5 dBA, the amount of time a person can be exposed is cut in half. For example, a person who is exposed to noise levels of 95 dBA can be exposed to only 4 hours in order to be within the daily OSHA PEL. The OSHA standard has an action level of 85 dBA, which stipulates that an employer shall administer a continuing, effective hearing conservation program when the 8-hour TWA equals or exceeds the action level. The program must include exposure monitoring, employee notification, observation, an audiometric testing program, hearing protection, training programs, and maintenance of records. The standard also states that when workers are exposed to noise levels in excess of the OSHA PEL of 90 dBA (8-hour TWA), feasible engineering or administrative controls shall be implemented to reduce workers' exposure levels. The OSHA standard states that exposure to impulse noise should not exceed 140 decibels (dB) sound pressure level (SPL).

The NIOSH REL for noise (8-hour TWA) is 85 dBA using a 3-dB exchange rate (see OSHA regulations in previous section for an explanation of exchange rates). NIOSH also recommends that no exposure be allowed above 140 dBA [NIOSH, 1998].

Impulsive Noise Measurement System

System Description

Commercially-available sound measurement instruments, namely the sound level meter and the noise dosimeter, have been designed to measure the level of continuous and intermittent sounds in an industrial setting often are not suitable for measurements of impulsive sounds [Kardous, 2003]. In addition, national standards and guidelines are not yet available for evaluating the performance characteristics of devices intended to protect human hearing from the damaging effects of impulsive sounds.

Hearing loss prevention researchers at NIOSH have developed an impulsive noise measurement software platform called the NIOSH Impulsive-Noise Measurement System (NIMS) [Yan et al., 2004]. The system has been used to evaluate and analyze exposure of law enforcement officers and military personnel training in the use of firearms to impulses generated from firing their weapons. A Cooperative Research and Development Agreement (CRADA) was established with Larson-Davis, a manufacturer of sound measurement instruments, to jointly develop a sound measurement instrument that is capable of acquiring and analyzing impulsive sounds. The system has been patented by the U.S. Patent and Trademark Office under U.S. patent #7,401,519 (System for Monitoring Exposure to Impulse Noise).

This new instrument enables scientific researchers as well as occupational safety and health professionals to measure and characterize impulsive noise exposures accurately and provides them with a list of acceptable and appropriate metrics. The instrument provides a graphical user interface (GUI) to display time domain waveform, frequency spectrum, and (1/1) and (1/3) octave band spectra of the captured impulse noise event. Additionally, parameters such as peak pressure level, equivalent average level, kurtosis, time duration, number of impulses, and temporal spacing between impulses are calculated and displayed [Patterson, 1991; Lei, 1994; Perkins, 1975]. Finally, the instrument calculates the potential risk to hearing based on the major damage risk criteria in use today such as A-weighted 8-hour equivalent sound level (LeqA8hr) [Dancer et al., 1995, DTAT, 1983] and the Auditory Hazard Assessment Algorithms for Humans (AHAAH) [Price and Kalb 1991; Price, 2007].

As part of the system optimization, we worked with Structural Dynalysis, Inc. a subcontractor of Larson-Davis, to procure three measurement systems. Each of the measurements systems were packaged as one integral unit (kit) with the appropriate microphone for high-level impulsive noise measurements, the associated pre-amplifiers and power/conditioning supplies, and a version of the NIMS-based impulsive noise measurement program.

The kit (Figure 1) included the following:

- 4 GRAS 40DP 1/8” condenser pressure microphones
- 4 GRAS 26AC ¼” Preamplifiers
- 2 GRAS 12AA 2-channel power supplies
- 1 National Instruments NI-4432 USB data acquisition board
- A laptop with the NIOSH Impulse Noise Measurement Software developed in Labview

Figure 1. NIOSH Impulsive Noise Measurement Kit

The microphones and preamplifiers were connected to the 12AA power supplies using LEMO cables. Each of the outputs from the two-channel power supplies were connected to NI-4432 data acquisition board using BNC cables. The NI-4432 board was connected to the laptop using a USB 2.0 cable (Figure 2).

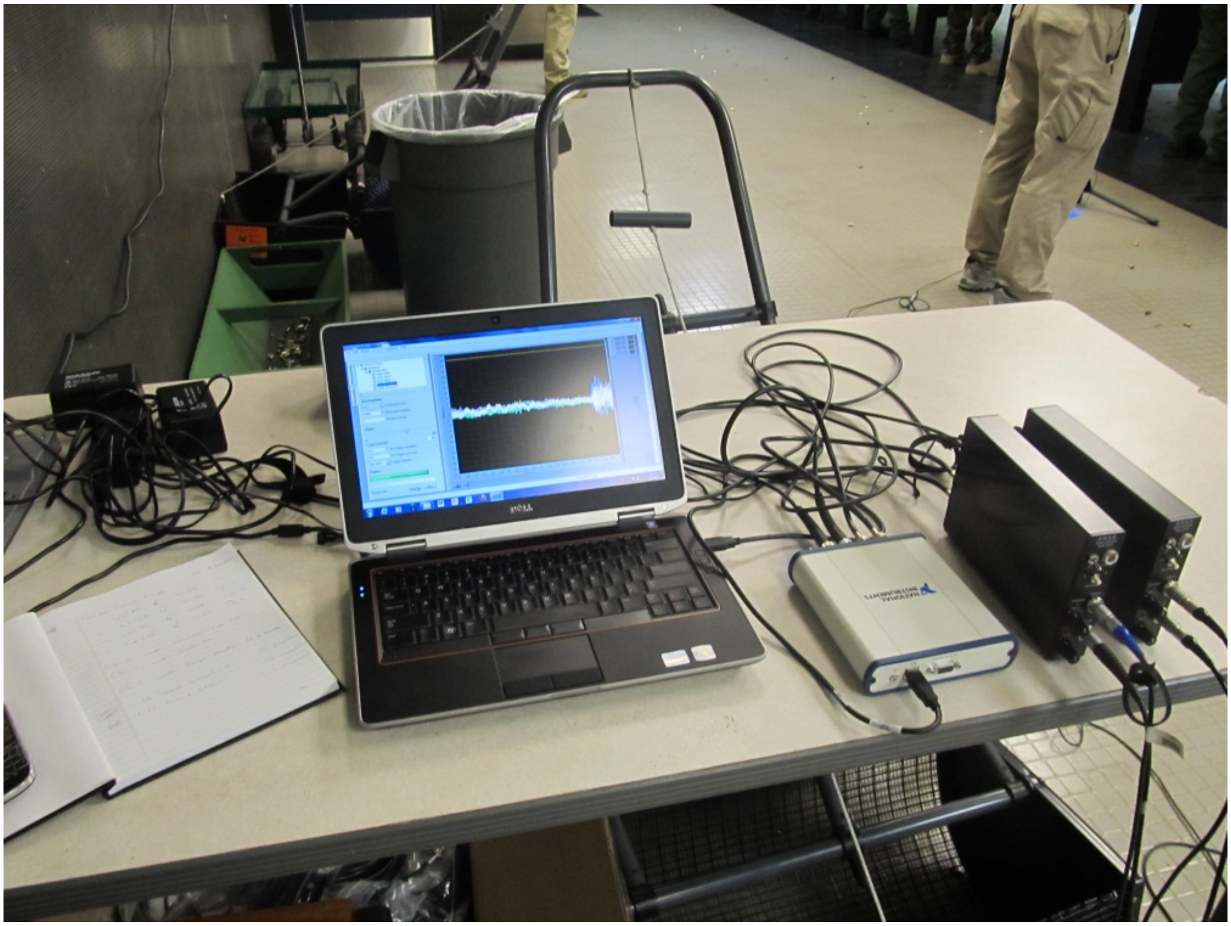

Figure 2. The NIOSH Impulsive Noise Meter Setup

The program is built and runs using the National Instruments LabView software. This program installs an icon on the user's desktop.

The program installs the LabView runtime 2011 64 bit (for Windows 7 or higher). National Instruments DAQMX 93.5 device drivers, and the Microsoft .Net or Visual C redistributable package.

System Operation

The software can be launched by clicking the NIOSH Impulsive Noise System icon. Figure 3 shows the start-up screen.

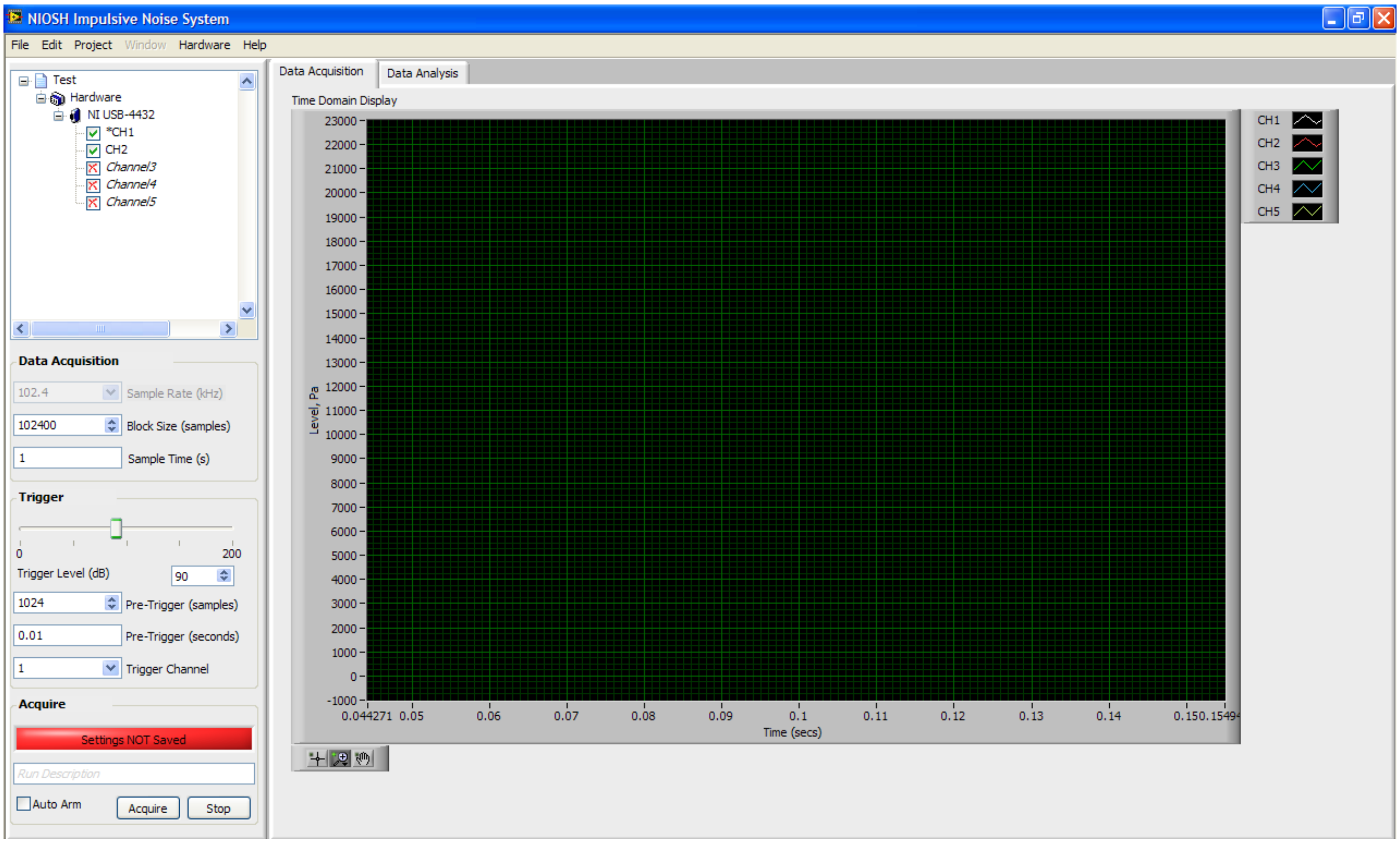

Figure 3. Data Acquisition Start-up Interface

There are several sections on the data acquisition screen (selected by choosing the "Data Acquisition" tab):

- Top left section called Hardware Tree. This section identifies the hardware (NI USB 4432) and the four (or five) microphone channels where setup information and calibration can be done.
- Under the Hardware Tree are the Data Acquisition Settings, in this section the block size (samples) and sample times (seconds) can be selected.
- Under the Data Acquisition is the Trigger Settings. The trigger can be varied via a sliding scale or by selecting the trigger level in decibels (dB). Also, the Pre-trigger (samples or seconds) and trigger channel can be selected using a drop-down menu.

- On the bottom left is "Acquire Data" section that allows the user to start and stop acquiring data. There is a description box and an "Auto-Arm" selection box for automatically acquiring data.
- The main data acquisition screen will show the real-time acquired impulse waveform. The y-axis will show level in Pascal (Pa) and the x-axis shows the time in seconds (secs). If all five channels are used, the waveform will show each channel waveform in the corresponding color. The program allows the user to zoom and select portions of the acquired signal using the buttons at the bottom of the screen.
  

The program has the typical menu structure available to the user, that is: "File", "Edit", "Project", "Window", "Hardware", and "Help". Figure 4 shows the navigation structure for the menu.

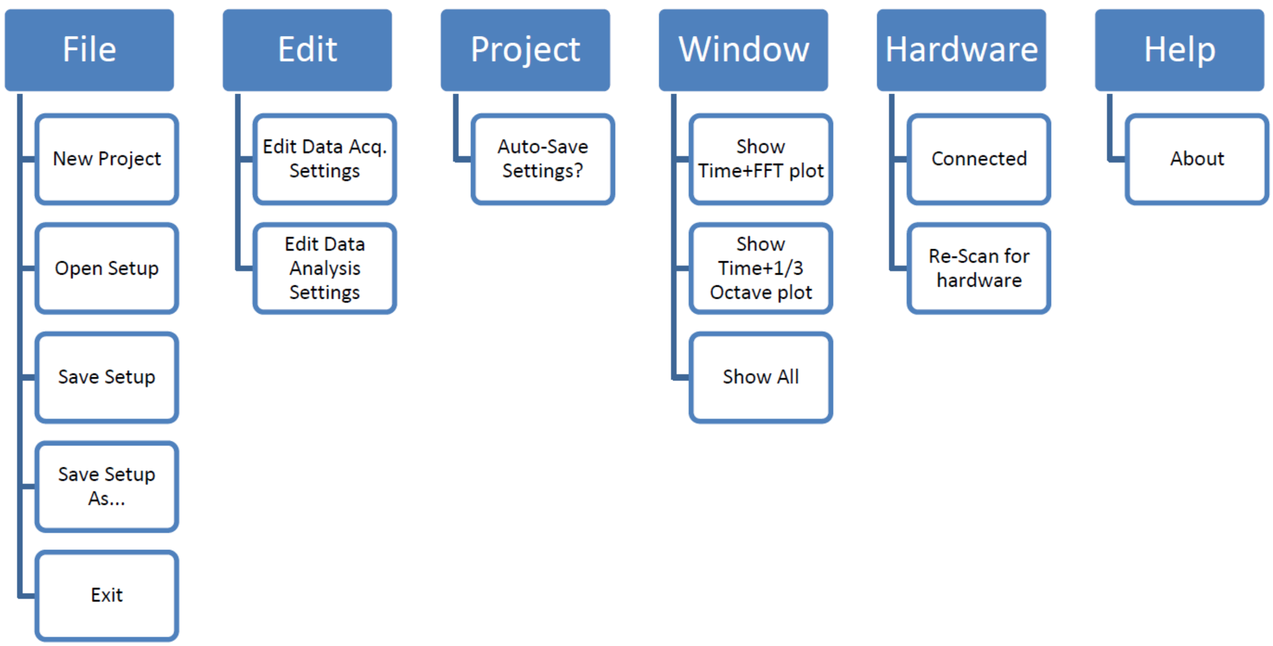

Figure 4. Menu Navigation Structure

The descriptions for each menu item are shown Table 1 below:

Menu	Function
File:New Project	Clears *all* settings and starts a fresh session
File:Open Setup	Opens a previously saved project (minus hardware information).
File:Save Setup	Saves the current project settings
File:Save Setup As	Saves the current project settings as a new project
File:Exit	Exits the program
Edit:Edit Data Acq. Settings	Edits the data acquisition settings (password required), including sample rate
Edit:Edit Data Analysis Settings	Edits the data analysis settings
Project:Auto-Save Settings?	When checked, the program will automatically save the project settings into the current settings file when changes are made
Window:Show Time+FFT plot	When active, displays the time plot and FFT plot on the "Data Analysis" tab (only available when "Data Analsis" tab is active)
Window:Show Time+1/3 Octave plot	When active, displays the time plot and 1/3 Octave plot on the "Data Analysis" tab (only available when "Data Analsis" tab is active)
Window:Show All	When active, displays the time, FFT & 1/3 Octave plot on the "Data Analysis" tab (only available when "Data Analsis" tab is active)
Hardware:Connected	When checked, indicates that the hardware is connected to the PC and has been "found"
Hardware:Re-Scan for hardware	If the program is started prior to connecting the USB-4432 hardware, select this function to search for the USB-4432 after connecting
Help:About	Opens an "about" panel with program information

Table 1. Description of Menu Functions

Data Acquisition Tab

When the USB-4432 is connected, it shows the hardware and the associated acquisition channels. The first line in the tree is the project name. Once the project has been saved, the file name is used as the project name is placed in the tree in place of "generic project". The second line in the tree is the Hardware label. The third line in the tree is the specific hardware detected (USB-4432). The fourth thru eighth lines are the channels available for acquiring data. Each channel starts inactive (indicated with a red "x" checkbox). To setup and activate a particular channel, select it in the menu tree (left click once) and then right click to activate the context menu. Once selected, a dialog box will open, allowing each channel to be configured individually (Figure 5).

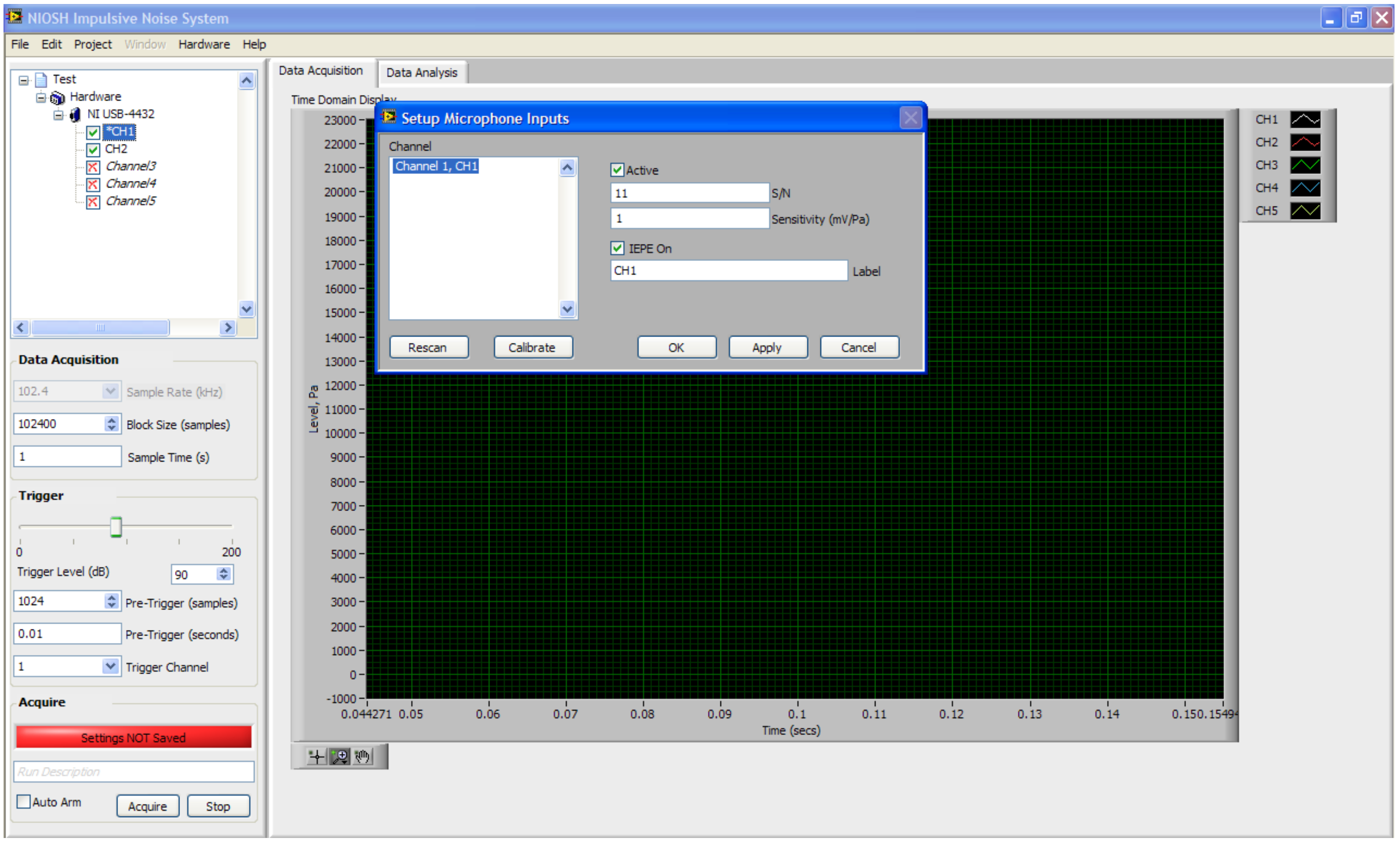

Figure 5. Individual Channel Setup

In order to acquire data from a particular channel, the "active" checkbox in "setup microphone inputs" must be selected. Optionally enter serial number information and a channel label, and also enter the microphone sensitivity and whether or not IEPE/ICP (Integrated Electronic Piezo-Electric) power should be ON (checkbox selected). The sensitivity can be discovered by any of three methods. First, the system is TEDS (Transducer Electronic Data Sheet) enabled, so that if the microphones are TEDS capable and programmed, then the sensitivity will be "read" from the microphone (information will be pre-populated in the sensitivity box). If the sensors were not attached when the program was started, the "Rescan" button is used to find pre-configured TEDS sensors once connected. Alternatively, the user can calibrate the microphone using a handheld-style calibrator. Click the "Calibrate" button to activate the channel calibration menu as shown in Figure 6.

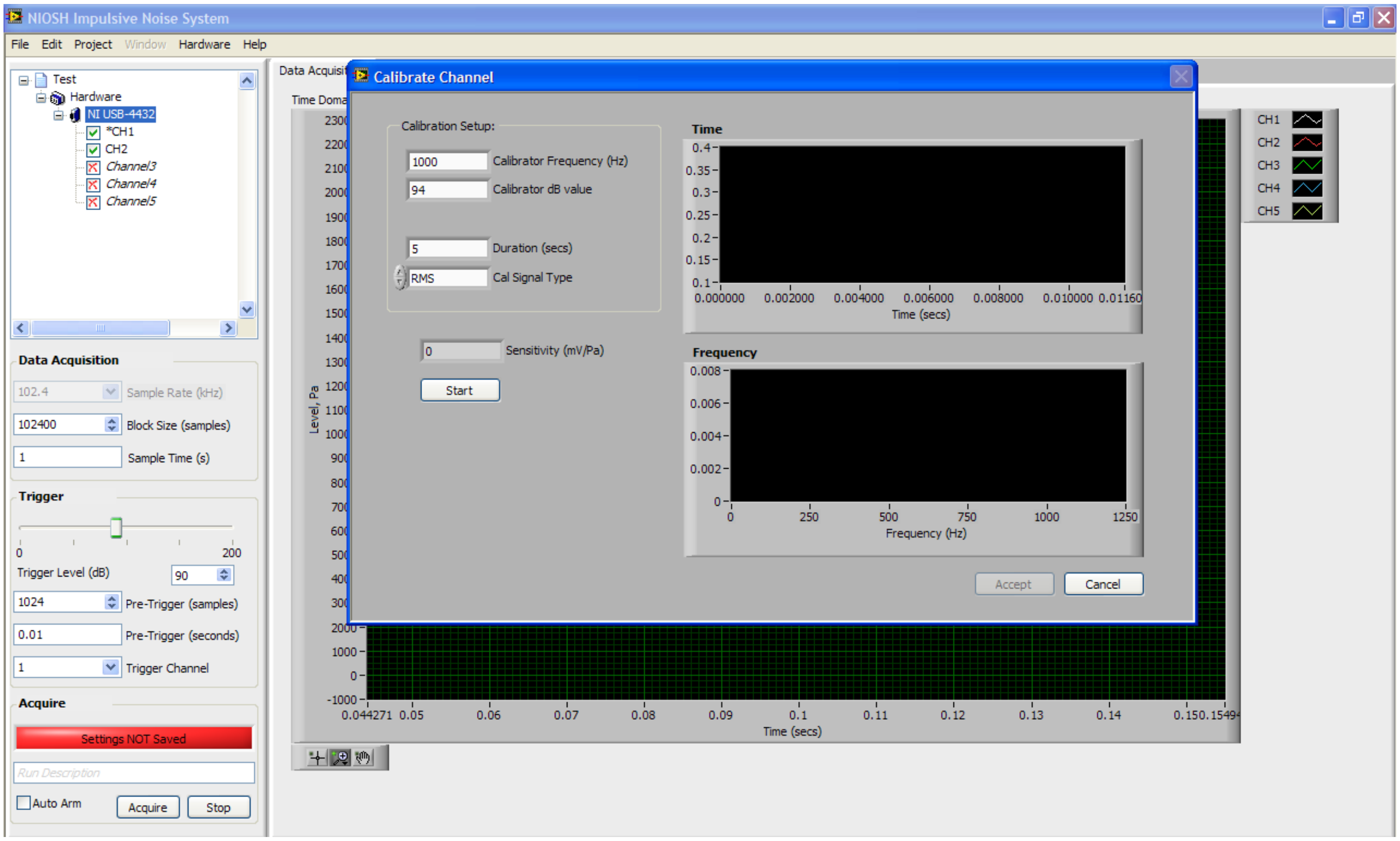

Figure 6. Channel Calibration Window

The user enters the calibrator's frequency and level output, selects the duration for data computation, selects the signal type (normally RMS), and then clicks the "start" button. The program will monitor the voltage level on the current channel and use that information (along with the calibrator frequency and level) to back-calculate the microphone sensitivity. If the sensitivity is acceptable, select the "Accept" button to continue or the "Cancel" button to reject and continue. One can continually calibrate using the "Start" button; only "Accept" or "Cancel" returns to the Channel Setup window.

Finally, the user can always enter the microphone sensitivity by hand. Whatever value is in the sensitivity box when "OK" or "Accept" is selected is what is used by the program. Continue this procedure for each channel desired to collect data during the project. Active channels will be shown in the main tree with a green "check".

Acquiring Data

Figure 3 shows the Data Acquisition screen and associated selections. If the project settings have not been saved, then the indicator will be red, and will show the text "Settings NOT Saved". Settings must be saved prior to acquiring data. Once the settings have been saved at least once, and if "Auto-Save Settings" is selected (Project menu at top of screen), then the program will automatically save settings whenever the "Acquire" button is clicked. When the settings have been saved, the indicator will be green, and will show the text "Settings Saved".

The run description text can be entered in the box under the "Acquire" button and will be pre-pended to any data files saved. Once all these items have been handled, the program is ready to acquire data. The user clicks the "Acquire" button, and the hardware will be placed in an armed state (blue light will blink on front panel of USB-4432 to indicate that it is waiting for a trigger). Once a trigger has been reached, the program will acquire and store the data for the specified time. At the end of the acquire time, a dialog box will open allowing the user to save the data file. The data file dialog box will be pre-populated with a suggested file name that includes the time and date and the run description. Also, the data file default save location is in the same directory as the project settings file (but can be changed if desired).

The data collected will be displayed in the main plot, "Time Domain Display" on the "Data Acquisition" tab. If, for example, there were two channels active in the acquisition, then there will be two curves shown on the plot. To toggle display of individual curves on and off, right click on the graph legend to bring up a context menu. If the "VISIBLE?" text has a checkmark next to it, then the plot will be shown in the chart area. After the data file has been saved on the hard drive, it will be added to the "Channels" tree on the "Data Analysis" tab for review.

Data Analysis Tab

The data analysis tab is usually selected after the impulse data have been acquired. The program allows the user to analyze the data in real-time and report seven "Impulse Metrics" that have been shown to be relevant to characterizing exposure to impulsive noise as well as calculates the three "Damage Risk Criteria" as mentioned in the introduction section.

During a project, the "Channels" tree will keep a running list of all saved data files. The user can use these files to review and analyze data. To review data, simply select a channel associated with a particular data file in the list (one channel at a time) and right-click to activate the context menu. The choices are to "Load Channel" or "Export Channel". Figure 7 shows the Data Analysis screen.

Selecting "Load Channel" will plot the time history pressure data versus time in the Time Domain Display plot, as well as either the FFT and/or 1/3 Octave of the signal (whichever is active, or both). Additionally, the software will look for impulsive peaks in the data, and perform the computations, with the exception of the AHU warned and unwarned values. In order to calculate the AHU values, a peak must be selected for calculation, and that peak is selected by using the “Impulse #” dropdown box.

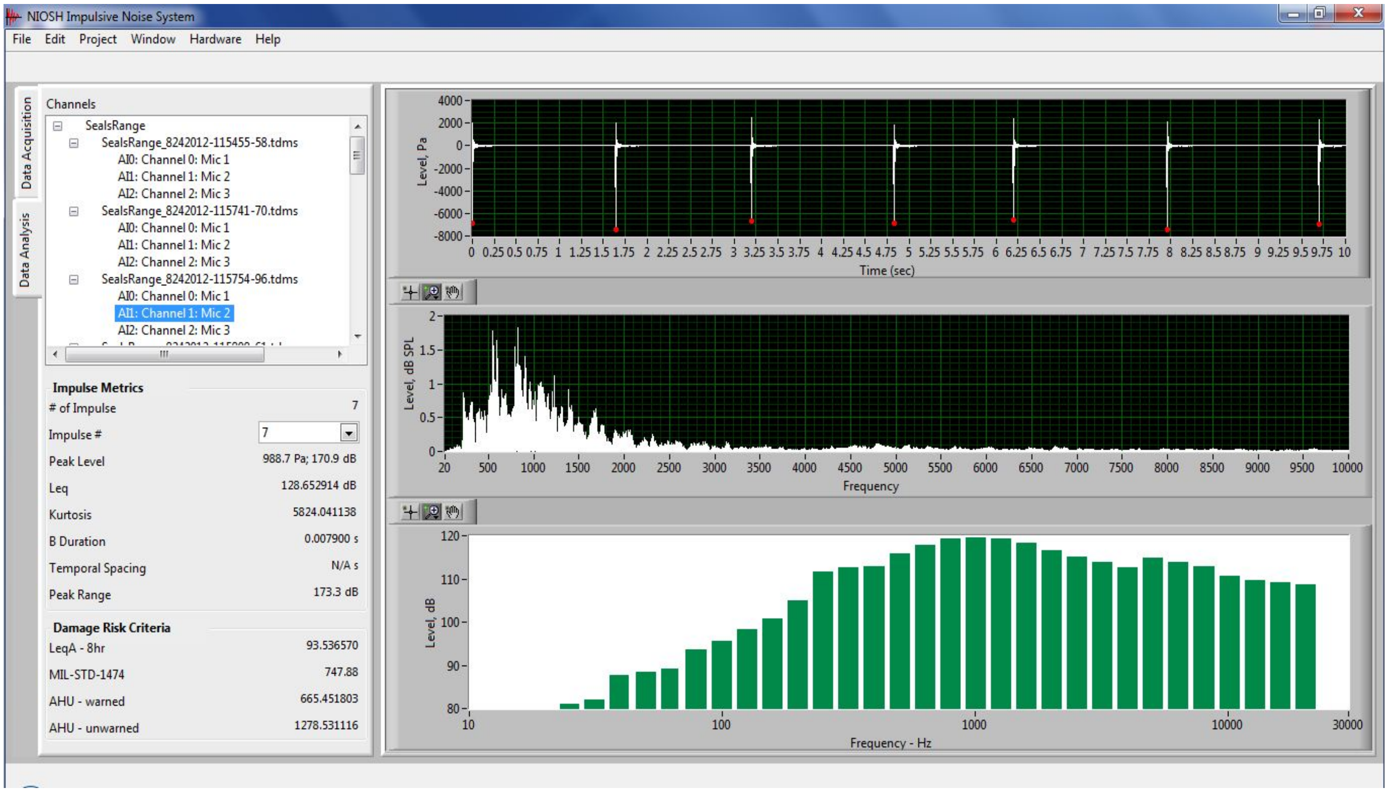

Figure 7. Data Analysis Screen

From the “Channels” tree, and right-clicking on a channel to bring up the context menu, the other item available is “Export” (Figure 8). Exporting a channel saves the current channel as a *.wav file (same file name with a *.wav extension) and also a *.txt file with scale and offset information. The scale and offset information are needed to properly scale the *.wav file back to engineering units. If, instead of right-clicking on a channel, the user clicks on a file name, the user is given the opportunity to export the entire file at once. The result of this operation will be individual *.wav files of each channel contained within the data file (and *.txt scale files).

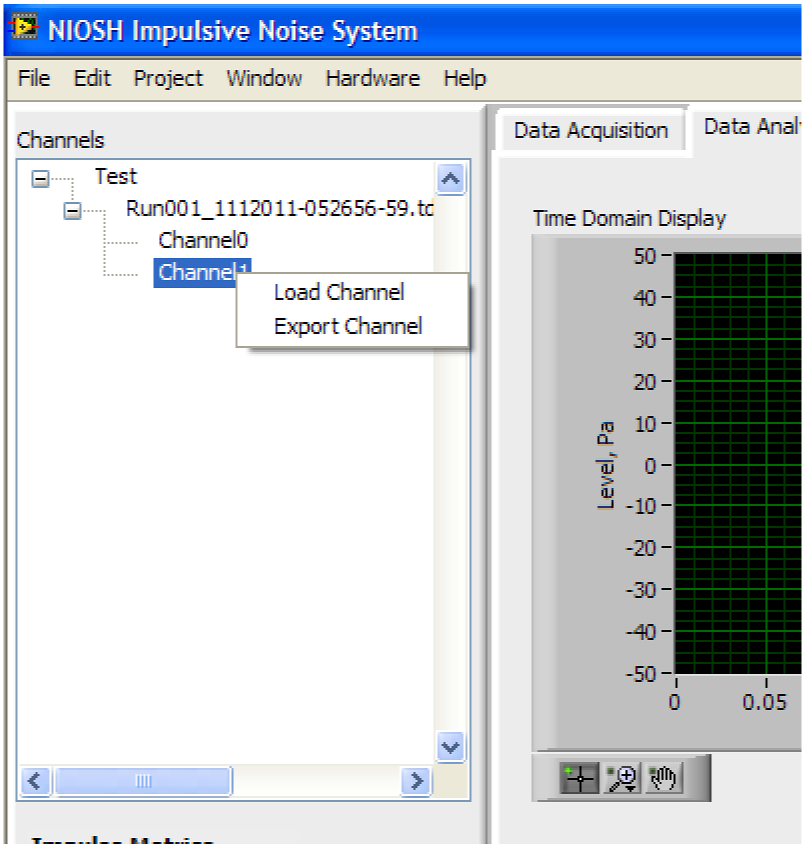

Figure 8. Data File Context Menu

Statistical Analysis

In order to determine if the impulse noise meter is equivalent in capabilities to standard laboratory equipment (reference), we conducted a statistical analysis of the two systems side-by-side in the NIOSH impulse noise laboratory using impulses generated by a shock-tube. Establishing equivalence is not achieved just by concluding that no difference exists between two instruments. For example, one cannot use a t-test and conclude that two means are equivalent simply because the null hypothesis is not rejected. Therefore, we used a commonly-accepted approach to compare the two systems and examine whether the confidence interval of the mean of the differences is entirely enclosed within a range of differences which are considered to be of no importance [Jones et al., 1996]. If so, one may conclude that for a given probability of Type I error and a specified power that the devices are equivalent. We compared the standard laboratory system and the new meter by taking the differences obtained with a series of paired measurements and then calculated the confidence interval of the mean of the differences. If this confidence interval is entirely within the range ($-\Delta$, $+\Delta$) then we will conclude that the devices are equivalent, as shown in the following graph (Figure 9) taken from [Jones et al. 1996]:

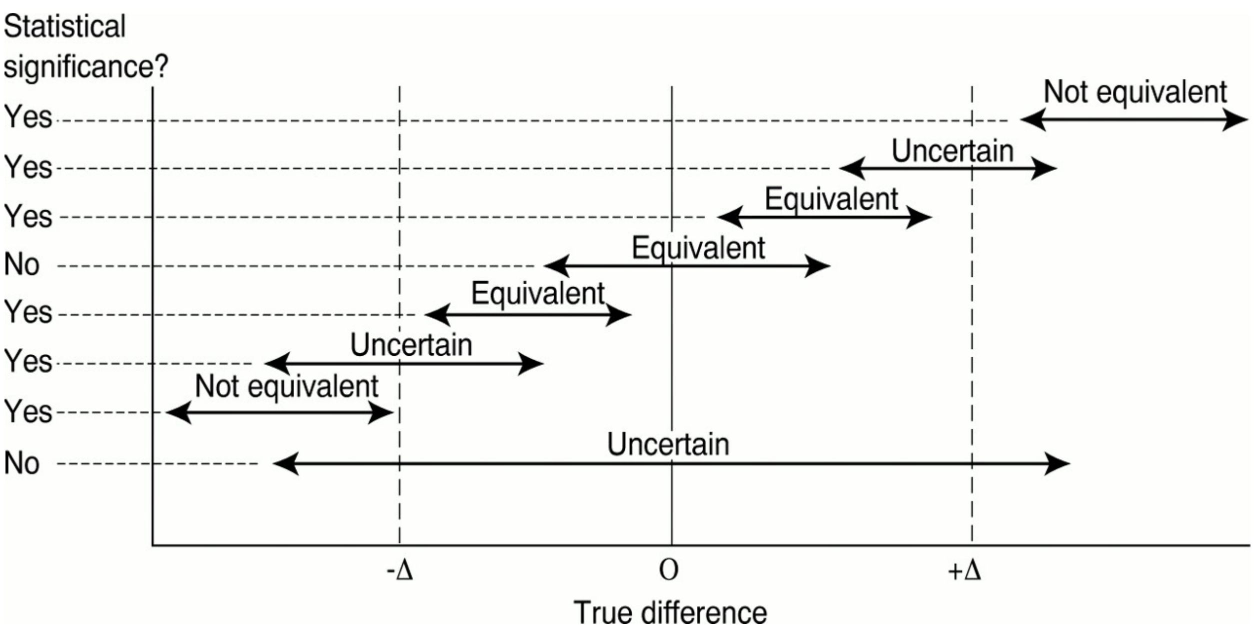

Figure 9. Equivalence determination using confidence intervals

For sample size requirements we use:

$$n = \frac{2s^2\left(t_{n-1,1-\alpha} + t_{n-1,1-\beta}\right)^2}{\delta^2}$$

[Machin, et al. 1997, p. 104]

The definitions of α and β are switched from the usual usage when determining equivalence. In the equivalence test, a Type I error (of probability α) refers to concluding that two devices are equivalent when they are not, and a Type II error (of probability β) refers to deciding that the two devices are not equivalent when they really are.

Machin et al. give this number for a one-sided confidence interval. We used a two-sided confidence interval, and thus we let α=0.025 and β=0.05 to obtain a two-sided 95% confidence interval with a power of 0.9. In doing the sample size calculations, we assumed that the standard error for the mean of the differences is $2s/\sqrt{n}$, where s is the standard deviation of the set of measurements from one of the instruments (and assumed to be the same for the other instrument). Since n determines the value of t in the equation we solved for n iteratively. We do this by starting with $z_{1-\alpha}$ and $z_{1-\beta}$ in place of $t_{n-1,1-\alpha}$ and $t_{n-1,1-\beta}$.

Sample sizes were calculated for Leq and Lpeak (in units of dB) based on exposure data previously collected in the field. For the Leq with s^2 = 66.3716 and δ= 1.4 the sample size, n, needed for a 95% confidence interval with a power of 0.9 is 882. Only two iterations were needed because of the large size of n. For Lpeak with s^2 = 43.791 and δ = 2, the required sample size, n, for a 95% confidence interval with a power of 0.9 is 287. Again, only two iterations were needed.

We collected a total of 51 impulses in the laboratory and 2104 impulses in the field. In order to establish if this meter/system and the reference NIMS are equivalent in calculating the appropriate impulse metrics, we first determined the maximum absolute difference of no practical importance (in other words, we established a range of no practical importance for differences). We removed from consideration variables associated with microphone placement, data acquisition rate possible internal error, and other equipment-specific issues that may affect the measurements. We selected each of the measurements based on a pre-determined acquisition interval and ran the collected impulse waveforms through both systems. For our comparison purposes, we selected the values a Δ of 1 dB for maximum absolute difference of no practical importance for Leq and Lpeak. This value for Δ of $\pm$1 dB is based on our experience with impulse noise measurement techniques and associated relation to current damage risk criteria. Finally, we calculated the 95% confidence interval for the difference between the two systems for each outcome variable (Leq and Lpeak). The 95% confidence interval for the differences between the two systems is shown in Figure 10.

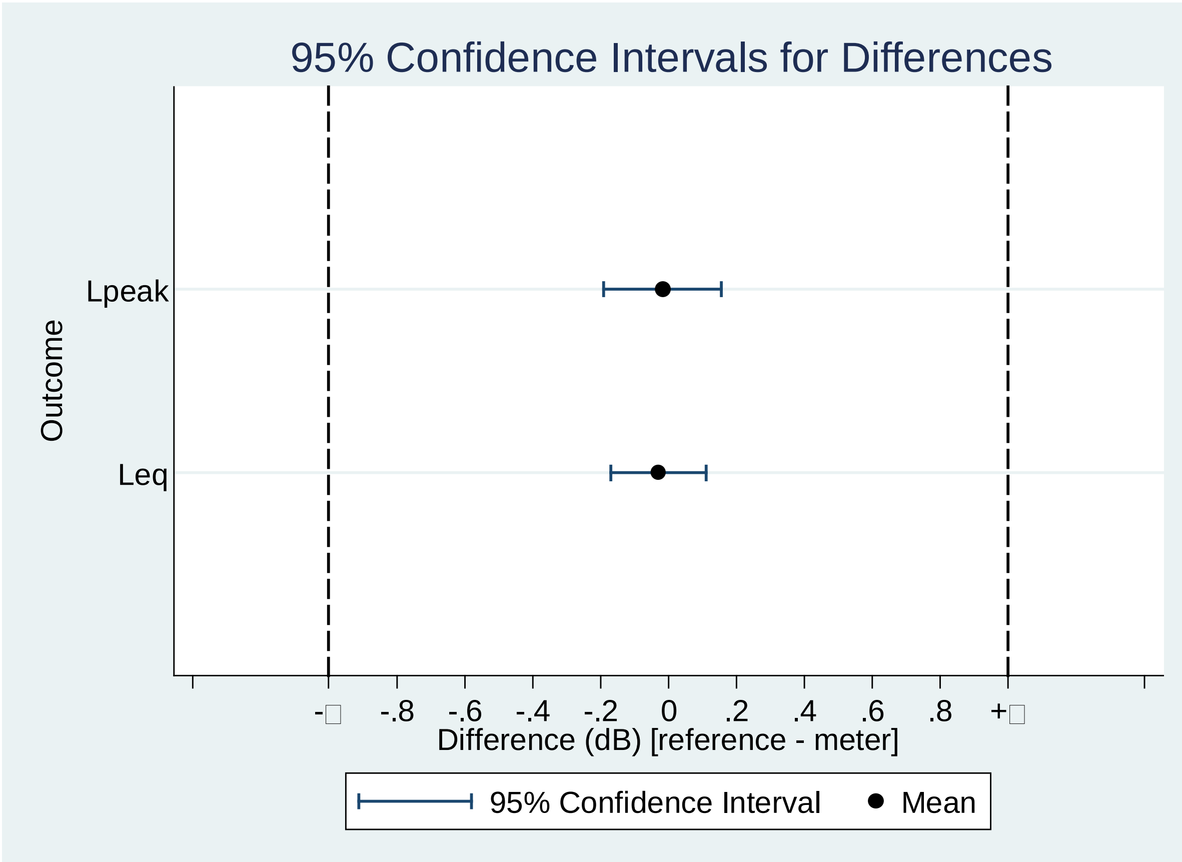

Figure 10. Mean and confidence intervals for the differences between the reference system and the new meter

The results show that the two systems are equivalent for the two major outcomes that were selected (Leq and Lpeak) and are well within the ±1 dB maximum absolute difference of no practical importance that we initially aimed to meet. Similarly, it is possible to obtain similar results for any of the other metrics/outcomes as long as a reasonable value of maximum absolute difference of no practical importance is selected or calculated.

Field Surveys

The new meter was evaluated at several indoor and outdoor firing ranges. This meter outperformed our current standard system in every aspect during our exposure assessments:

1. Ease of use and setup - The new meter was ready out of the case, microphone calibration and set up took on average less than 10 minutes

compared to 60-120 minutes for the standard system we have used over the years to conduct measurements. In addition, after the conclusion of the measurements, the new meter was disassembled and cleared out in several minutes. This is an important factor because law enforcement and military personnel operate on a tight and structured time schedule.

2. Handling and Transportation – Transporting the new meter to and from firing ranges was easily accomplished due to its portability and compact assembly. In contrast, the standard system used to take special delivery, several heavy-duty boxes and cases, and multiple trips. The importance of transporting the system can be a major factor for conducting measurements in remote or not easily accessible locations.
3. Real-time analysis – The new meter (in contrast with the old standard system which required us to conduct analysis once we returned to NIOSH) provided on the spot feedback and information to range operators and OH&S specialists. The significance of this feature of the meter allows us to make real-time adjustments and alert exposed workers on hazardous exposure if needed.

Federal Law Enforcement indoor firing range (San Diego, CA)

NIOSH's Division of Surveillance, Hazard Evaluations, and Field Studies (DSHEFS) researchers conducted two site visits to a Federal indoor firing range in January and December of 2009 as part of an HHE investigating exposure to lead at the indoor firing range located in San Diego, California [NIOSH 2011]. The range operators expressed interest to measure noise exposure of their agents during live training exercises and evaluate the range for possible engineering controls to limit noise transmission inside the range and to adjacent areas. We visited this range in August 2012. The range is comprised of 32 shooting lanes with dividers separating shooters. The range master station is inside the range area and is not enclosed. We conducted measurements at shooters positions, instructor positions, and the range master station. We also conducted measurements in adjacent areas (cleaning room, preparation and office areas). Weapon qualifications for agents included pistols (14 rounds), shotguns (5 rounds), and rifles (70 rounds) in 3 shooting positions: standing, kneeling, and prone. The agents and instructors wore double-hearing protection during the training sessions (Figure 11).

Figure 11. Noise measurements at a Federal law enforcement indoor firing range

The following tables show the impulsive noise metrics and associated damage risk criteria calculated for the shooters, instructors, and range mater.

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (# shots*)	AHAAH (Warned/Unwarned)
Pistol	151-156	124-126	87-88	37-85	361682	2135/2157
Shotgun	156-158	127-129	86-88	90-132	14034	1095/1517
M4 Rifle	150-154	121-122	81-82	79-235	166280	207/264

Federal Law Enforcement Indoor Range – Shooter Position

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots*)	AHAAH (Warned/Unwarned)
Pistol	146-149	124-125	86-88	16-45	7628656	1638/1749
Shotgun	150-151	124-126	84-86	148-252	723923	707/815
M4 Rifle	149-150	122-124	82-83	112-235	187218	49/579

Federal Law Enforcement Indoor Range – Instructor Position

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots*)	AHAAH (Warned/Unwarned)
Pistol	132-136	112-115	73-75	45-67	1426113282	168/175
Shotgun	124-127	107-109	63-65	112-178	4.7x10^10	12.2/12.4
M4 Rifle	127-141	104-112	69-71	146-242	15540282	59/59

Federal Law Enforcement Indoor Range – Range Master Position

**Assumes double protection for MIL-STD-1474D, based on one selected shot*

SPL: Sound Pressure Level
Leq: Equivalent Sound Level
LeqA8hr: Equivalent Sound Level, A-weighted for 8 hours
MILSTD1474: DoD Design Criteria Standard
AHAAH: Auditory Hazard Assessment Algorithm for Humans

Noise levels measured in the cleaning, preparations, and office areas were below the NIOSH REL for the duration of the training exercises, and peak sound pressure levels were between 78-86 dB SPL. No engineering controls measures or additional acoustical treatments were needed and none were recommended. The range master and management at the range required the use of double-hearing protection at all time.

Military indoor firing range (San Diego, CA)

The range facility consists of the range itself, a classroom area, a cleaning area, the range master control room. We conducted measurements on a single shooter using several weapons at shooter and instructor positions. The shooter fired pistol (10 rounds), 10" barrel rifle (10 rounds). 14" muzzle rifle (10 rounds), and the Special Operations Combat Rifle (SCAR) (10 rounds). The following tables show the impulsive noise metrics and associated damage risk criteria calculated for the shooter and instructor position.

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots)	AHAAH (Warned/Unwarned)
Pistol	170-171	128-129	93-94	9-13	748	665/1279
Rifle 10”	177-178	135-136	99-101	21-23	12	1188/2365
Rifle 14”	177-178	131-136	99-100	13-26	21	1067/2099
Rifle W/ Suppressor	151-163	120-124	84-87	12-13	27501	853/2153
SCAR*	179-181	139-140	105-106	10-23	13	929/934
SCAR W/ Suppressor	161-165	121-124	84-86	20-22	4851	526/1088

Military Indoor Range – Shooter Position (Front)

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots)	AHAAH (Warned/Unwarned)
Pistol	150-151	114-115	78-80	36-70	684195	466/831
Rifle 10”	154-155	120-122	85-86	78-83	109926	636/1191
Rifle 14”	151-153	118-120	83-84	94-105	156773	584/1045
Rifle W/ Suppressor	132-137	105-108	70-73	96-261	266658573	85/102
SCAR*	152-155	121-123	85-86	166-212	38108	453/456
SCAR W/ Suppressor	134-138	109-112	72-75	115-257	263622667	130/175

Military Indoor Range – Shooter Position (Back)

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots)	AHAAH (Warned/Unwarned)
Pistol	144-146	111-112	76-77	53-69	7461137	222/340
Rifle 10”	150-154	119-122	83-86	83-219	62001	554/753
Rifle 14”	147-149	116-117	80-81	193-258	418838	480/765
Rifle W/ Suppressor	125-132	106-109	71-74	172-282	220981713	114/122
SCAR*	151-152	119-121	83-84	205-211	98742	455/459
SCAR W/ Suppressor	131-141	108-113	72-76	36-134	300334415	144/163

Military Indoor Range – Instructor Position

*SCAR: Special Operations Combat Forces Rifle

SPL: Sound Pressure Level
Leq: Equivalent Sound Level
LeqA8hr: Equivalent Sound Level, A-weighted for 8 hours
MILSTD1474: DoD Design Criteria Standard
AHAAH: Auditory Hazard Assessment Algorithm for Humans

The range has undergone some experimental acoustical treatments that may not be ideal for protecting the shooters from over-exposure. However, measured sound pressure levels in the control room were under the NIOSH REL. Shooters used single and double-hearing protection during live-fire exercises, based on their preference.

Military outdoor firing range (Miramar, CA)

The U.S. Naval Medical Center staff requested NIOSH assistance in assessing noise exposure and hearing protection of U.S. Marines soldiers during live-training exercises at Marine Corps Air Station in Miramar, CA and the effect of an overhead metal "canopy" on overall exposure. Noise exposure assessments were conducted using the new noise meter and the standard NIOSH system. Hearing protection assessment was conducted using the ISL head fixture. The range consists of 36 open shooting lanes, an enclosed control station, bleachers for waiting, and the weather-protection canopy that was partially treated acoustically. There were 36 shooters at time (others waited in the Bleachers area) and 10 instructors. The shooters fired rifles only (90 rounds total) in the standing, sitting, and prone positions. In addition to the live-fire exercise, we measured noise levels about 5-6 feet outside the canopy to determine the effect of reverberation of the canopy on the overall exposure. Hearing protection use was variable, but most used single-protection earplugs. Figure 12 shows the range, canopy, and a partial view of the bleachers area.

Figure 12. Noise measurements at the Marines Corps Air Station Miramar outdoor firing range

The following tables show the impulsive noise metrics and associated damage risk criteria calculated for the shooters and instructors (under and outside the canopy)

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots)	AHAAH (Warned/Unwarned)
Shooter	159-160	120-121	80-82	74-84	8216	434/897
Instructor	147-149	114-115	76-77	121-163	1435856	261/415

Marines Corps Air Station Miramar – Under Canopy

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots)	AHAAH (Warned/Unwarned)
Shooter	163-164	118-119	80-81	7-10	32906	106/134
Instructor	136-138	101-103	64-65	148-150	158516767	21/88

Marines Corps Air Station Miramar – Outside Canopy

SPL: Sound Pressure Level
Leq: Equivalent Sound Level
LeqA8hr: Equivalent Sound Level, A-weighted for 8 hours
MILSTD1474: DoD Design Criteria Standard
AHAAH: Auditory Hazard Assessment Algorithm for Humans

U.S. Air Force – Wright Patterson AFB indoor firing range (Fairborn, OH)

NIOSH conducted three assessments of the Wright-Patterson AFB indoor firing range initially in November 2009 and February 2010, and again in November 2012. The initial visit was prior to the range installing acoustical treatments. The following visit in February 2010 was conducted after treatments to the walls and ceilings were applied. The third visit was conducted in November 2012 and used both NIOSH systems to validate field data. The facility holds several office areas, multiple classrooms, two firing ranges (a small 2-lane range and a larger 20-lane range). There are two separate control rooms associated with each range. Measurements were conducted inside the control rooms to assess exposure of the range master and instructors.
Hearing protection use was variable but most shooters wore single-protection earplugs or earmuffs while some instructors wore double-protection. Live fire exercises were conducted using pistols (72 rounds), shotguns (18 rounds) and riles (36 rounds). Figure 13 shows the acoustical treatments applied to the overhead panels and walls of the smaller range and Figure 14 shows the 20-lane range.

Figure 13. Acoustical treatments to walls and overhead panels at the WPAFB indoor firing range

Figure 14. Noise assessments at the WPAFB indoor 20-lane firing range

The following tables show the impulsive noise metrics and associated damage risk criteria calculated for the shooters and instructors during the November 2012 visit.

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots)	AHAAH (Warned/Unwarned)
Pistol	153-157	125-127	88-91	28-68	812652	1818/2046
Shotgun	158-162	129-131	88-90	124-230	18023	809/945
M4 Rifle	161-169	123-124	89-91	65-156	88308	118/206

WPAFB Indoor Firing Range – Shooter Position

	Peak SPL (dB)	Leq (dB)	LeqA8hr (dBA)	B-Dur (msec)	MILSTD1474 (#shots)	AHAAH (Warned/Unwarned)
Pistol	148-151	119-121	85-87	16-45	4562586	2163/2630
Shotgun	150-154	121-123	86-88	102-180	821623	987/1046
M4 Rifle	153-156	124-126	90-92	45-127	212536	362/489

WPAFB Indoor Firing Range – Instructor Position

SPL: Sound Pressure Level
Leq: Equivalent Sound Level
LeqA8hr: Equivalent Sound Level, A-weighted for 8 hours
MILSTD1474: DoD Design Criteria Standard
AHAAH: Auditory Hazard Assessment Algorithm for Humans

Licensing Opportunities

The impulse noise meter has received U.S. Patent #7,401,519. The CDC transfer technology office is working with representatives from a fortune 500 company to license the system. Several partners and stakeholders have indicated their intention to purchase the system kits through our development partner, Structural Dynalysis, Inc. As of today, this is the only ready to use impulse noise measurement meter available on the market.

Conclusion

NIOSH has received three complete impulsive noise measurement kits from Structural Dynalysis, Inc. The system has been tested and validated at the NIOSH Impulsive Noise Laboratory using the acoustic shock-tube in June and July 2012. The testing showed wide agreement with a reference system that has been used over the last several years by NIOSH researchers to conduct impulsive noise measurements. In addition to this report, we plan to publish a new NIOSH technical document titled "*Manual for measuring occupational exposure to impulsive noise*". The new system was field-tested in August and November 2012, at Federal and Dept. of Defense indoor and outdoor firing ranges. The system performed exceptionally well, collected data in real-time, and NIOSH researchers were able to provide the range operators and OH&S specialists with immediate feedback on the level and potential hazard generated from weapons firing.

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