Acoustic testing facilities at the Office of Mine Safety and Health Research[1),2)]

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The National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR) maintains a noise control program as part of its Hearing Loss Prevention Branch (HLPB). This program utilizes two large acoustic laboratories—a reverberation chamber and a hemi-anechoic chamber—to assist OMSHR engineers with the development and evaluation of noise controls. This paper discusses the design, instrumentation, and use of the NIOSH acoustics laboratories and the important role they play in noise control development and evaluation. The NIOSH reverberation chamber meets the absorption, reverberation time, and test room broadband qualification requirements specified in the ISO 3741/ANSI S12.51 acoustics standard for precision method sound power testing. As part of a qualification testing program, NIOSH conducted an uncertainty estimate for sound power level testing in the chamber. For an overall sound power measurement, this uncertainty estimate was 0.4 dB. The NIOSH hemi-anechoic chamber, which uses Eckel Industries SuperSoft Panels on the walls and ceiling, is used primarily for noise source identification to determine significant noise sources on equipment. Testing was completed to ensure that the chamber functions as a free-field. The SuperSoft panels met NIOSH requirements and the chamber was verified as a free-field per the test room qualification criteria set forth in ISO 3745.

Primary subject classification: 73; Secondary subject classification: 14.3

1 INTRODUCTION

Noise-induced hearing loss (NIHL) is one of the most enduring occupation-related illnesses and it continues to plague U.S. miners. The National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR) maintains two acoustic laboratories—a reverberation chamber (RC) and a hemi-anechoic chamber (HAC)—in support of its Hearing Loss Prevention Branch (HLPB) noise control program. The OMSHR HLPB noise control projects strive to develop and assess noise controls that reduce the noise emission of mining-related equipment (e.g., horizontal vibrating screens, roof bolting machines, and continuous mining machines) and reduce the sound pressure level at the operators' location. This research leads to lower sound levels at the operators' location and to reduced noise exposures. In the long term, this should result in fewer incidences of NIHL among the nation's mining workforce.

This paper discusses the design and instrumentation setup of the NIOSH acoustic laboratories as well as qualification testing results to ensure that the RC and HAC function as diffuse and free acoustic fields, respectively. Because sound power level testing is a key noise control evaluation technique, it was imperative that NIOSH conduct the necessary laboratory evaluation and qualification procedures to ensure that the RC functions as a diffuse-field and that sound power can be determined reliably and accurately. Similar exercises were required of the HAC, ensuring that it functions as a free-field for the noise source identification

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2) The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Reference to specific brand names does not imply endorsement by the National Institute for Occupational Safety and Health.

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testing, source path contribution (SPC) analysis, and sound level and sound power testing NIOSH conducts.

2 BACKGROUND

In addition to NIOSH, other organizations have similar facilities comprising reverberation and hemi-anechoic chambers used for research and development work. As an example, Caterpillar maintains adjacent reverberation and hemi-anechoic chambers in Mossville, Illinois, in support of its noise control research program[1]. The Caterpillar facility was designed for the testing of machine components and meets ISO 3744[2]/ISO 3745[3] qualification requirements down to 80 Hz. Further, a transmission loss aperture was required between the chambers for noise barrier performance testing. By comparison, at NIOSH, noise control research project objectives drive the work conducted in the acoustics chambers. The NIOSH acoustics labs are located in separate buildings and transmission loss testing is not conducted.

In the early stages of a research project, OMSHR engineers perform baseline sound power level measurements on the equipment in question. This testing is conducted in the RC, a large reverberation chamber that was built in the early 1980s when it was part of the U.S. Department of the Interior's Bureau of Mines. The intended purpose of the RC was to determine the sound power levels of mining equipment, which are typically large. Two ANSI acoustics standards, ANSI S1.31[4] and ANSI S1.32[5], served as guidelines for the design of the RC. The RC is currently equipped with a Bruel & Kjaer Pulse data acquisition system and the requisite hardware and software for measuring sound power levels according to ISO 3743-2[6] and ISO 3741/ANSI S12.51[7]. The RC sound power level program uses the comparison method, employing a calibrated reference sound source (RSS) as its primary reference standard.

Typically, equipment the OMSHR evaluates has multiple noise sources that are difficult to isolate. This prompted NIOSH to build and instrument the HAC in the mid-2000s. The HAC is also equipped with a Bruel & Kjaer Pulse data acquisition system and the associated hardware and software for beamforming, near-field acoustic holography, and SPC analysis. The OMSHR utilizes beamforming and near-field acoustic holography for noise source identification purposes. Source path contribution analysis is used to determine relevant noise paths to the operators' location and to determine whether the important noise paths are airborne, structure-borne, or some combination of the two. In addition, sound level data at the equipment operators' location is collected. Information gathered during this testing allows NIOSH to determine which noise sources should be initially addressed and provides guidance as to the overall noise control approach.

Baseline sound power levels and frequency spectral data are determined in the RC. Then, in the HAC, primary noise sources and paths and their contributions to the sound levels at the operators' location are determined. Noise controls are developed to address those sources and paths and are applied to the equipment under test. The process is iterative—the development and improvement of a noise control and subsequent evaluation in the HAC with noise source identification, SPC, and sound level testing. Noise controls that show promise are tested in the RC to document reductions in the noise emissions of the equipment. This cycle is repeated, reducing the selected noise emissions until research project success criteria are met. These criteria include, but are not limited to, reducing the A-weighted sound power level to 90 dB, reducing the sound power level by 3 dB, or reducing the sound level at the operators' location to less than the Mine Safety and Health Administration's (MSHA's) Permissible Exposure Level (PEL). The MSHA PEL is defined as an eight hour time-weighted average sound level of 90 dBA.

3 THE REVERBERATION CHAMBER (RC)

3.1 Chamber Design

When the RC was constructed, Bureau of Mines design specifications called for the chamber to be able to withstand (with a safety factor of 2) continuous sound pressure levels of 130 dB at any single frequency down to 100 Hz[8]. The chamber also needed to be large enough to accommodate the large equipment, such as jumbo drills and continuous mining machines, the Bureau was investigating at the time of construction. The walls are constructed slightly out of parallel and the general room dimensions are 18.3 m × 10.3 m × 6.7 m (60-ft × 34-ft × 22-ft). The chamber has a surface area of 784 square meters and a volume of 1,286 cubic meters. The floor is poured concrete. The walls are built of 0.4-m × 0.2-m × 0.3-m (1.3-ft × 0.7-ft × 1-ft) hollow concrete block. Each block has two hollow cores. The hollow block cores were completely filled with concrete with horizontal and vertical steel reinforcing bars spaced 0.4 m (1.3-ft) on center. This was done to supply a very stiff wall, improve wall transmission loss, and to ensure safety. The ceiling is pre-cast, pre-stressed concrete sections with a poured 5-cm-thick (2-in) concrete cap. Two layers of block filler were applied to the walls and one layer to the ceiling. To accommodate entry of large equipment for testing, there is a sliding steel 34.8-m^2 door located at the east end of the chamber. This door is constructed of 6-mm-thick (1/4-in) steel plate with stiffeners and is opened and closed by a motor-driven pulley system. The RC has an external load center to provide electrical power for mining equipment.

The current use of the RC is for precision-grade broadband sound power level testing per ISO 3741/ANSI S12.51. This required the OMSHR to conduct a series of tests to qualify the chamber per the Standard. These included: an estimation of the requisite number of microphones and source locations, determination of the reverberation times and the absorption coefficients of the chamber, and an estimation of minimum distance between sampling microphones and noise source locations.

3.2 Estimation of Number of Microphones and Source Locations

ISO 3741/ANSI S12.51 specifies a method to estimate the number of microphones and noise source locations using the standard deviations of the sound pressure levels sampled at the microphone positions. In an ideal diffuse-field, sound pressure level measurements can be collected anywhere in the chamber and the levels would be identical. Given this ideal case, a single microphone location would suffice. In practice, this is not possible, given absorption of the chamber surfaces, air absorption, room modes, etc. Thus, multiple microphone locations or a traversing microphone system are required. Because of the large size of the equipment typically under test and the size of the RC, a traversing microphone system was considered impractical. It was necessary to determine an adequate quantity of microphone locations to ensure that the standard deviation of the microphone measurements met the Standard requirements and that the mean sound pressure level in the chamber is accurately sampled.

To estimate the number of required microphones and source positions, NIOSH set up six microphones to sample broadband noise generated by a Bruel & Kjaer 4204 RSS. NIOSH conducted a series of tests, recording the noise signals with the Pulse system, and determined one-third octave band sound pressure levels at frequencies ranging from 100 Hz through 10 kHz. For these frequency bands, the standard deviation, S_m, among the six microphones was calculated. These were compared to the maximum allowable standard deviations as given in the Standard Annex E of ISO 3741/ANSI S12.51.

As shown in Fig. 1, the chamber meets the requirements listed in Annex E at 4 kHz and below. In these one-third octave bands, the standard deviations, S_m, of the sound pressure levels are less than the maximum allowable standard deviation. Above 4 kHz, the standard deviations increase significantly, exceeding the ISO 3741 criterion. The standard deviations of Fig. 1 are used to estimate the number of microphones required, N_m. For measured standard deviations less than or equal to 1.5, six microphones would meet the requirements of the Standard (Fig. 2). Beyond 4 kHz,

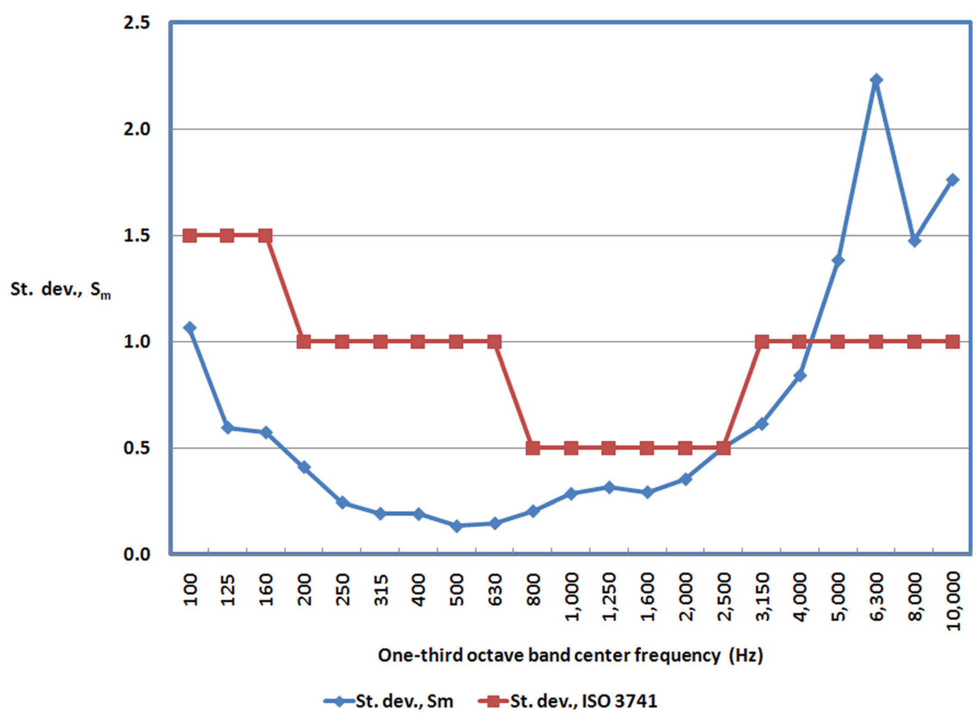

Fig. 1—RC sound pressure levels measurement standard deviations.

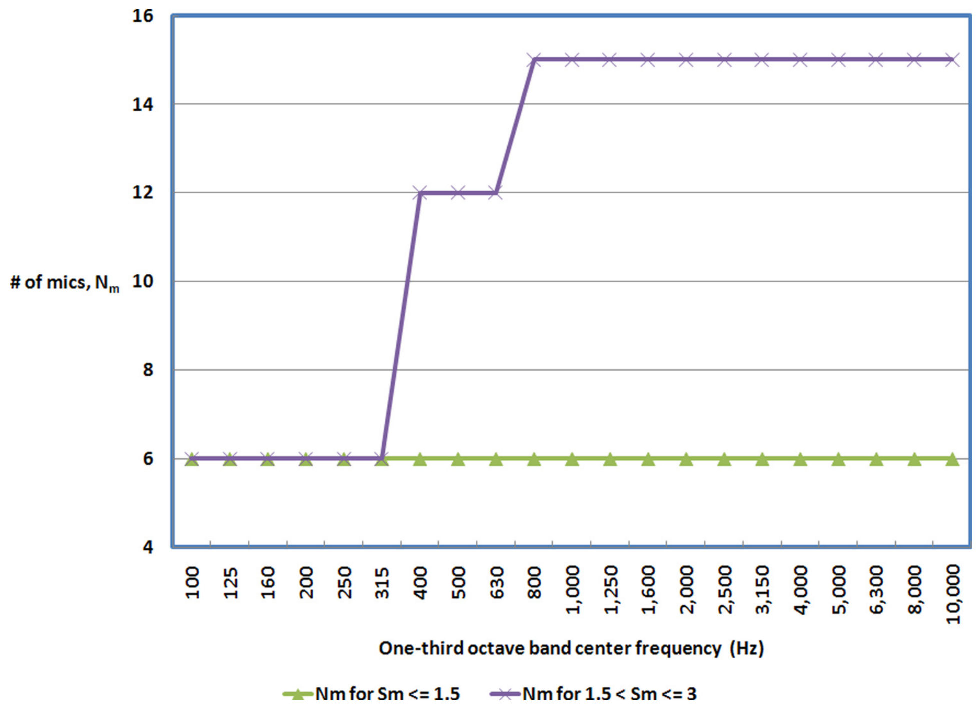

Fig. 2—RC estimation of quantity of microphones needed, N_m.

S_m is greater than 1.5 but less than 3.0, necessitating fifteen microphones. As a result, the OMSHR chose to use a 15-microphone array for sound power level testing.

Per the Standard, the number of noise source locations is set at one in instances where the standard deviation is 1.5 or less. A single noise source position, N_s, or equipment location for NIOSH evaluation is important. The OMSHR is required to test very large equipment. Thus, meeting Standard specifications for minimum distances between the equipment tested, microphones, chamber walls, etc., severely limits possible equipment locations. As shown in Fig. 1, the standard deviations are greater than 1.5 in the one-third octave bands of 6.3 kHz through 10 kHz. In these bands, Equation (1) was used to determine the minimum number of source positions:

$$N_s > K_s{}^*[(T_{rev}/V)^*(1,000/f)^2 + 1/N_m], \quad (1)$$

where

N_s is the number of source locations for the measurement;

K_s is a frequency and standard deviation dependent value given in the Standard;

T_{rev} is the reverberation time expressed, sec;

V is the volume of the room, m^3;

f is the mid-band frequency, Hz;

and

N_m is the number of microphones needed for the measurement, 15.

This calculation determines that a single source position would also suffice in the 6.3 kHz through 10 kHz one-third octave bands.

3.3 Chamber Absorption Requirements

An important attribute of an acoustic diffuse-field is minimal sound absorption. This results in long reverberation times. Higher sound absorption produces shorter reverberation times and larger standard deviations for sound pressure level measurements. At low frequencies, room modes also become a factor. Without some low frequency absorption, standing waves could occur, increasing the standard deviations. However, too much sound absorption might require additional microphone locations beyond the 15 locations discussed earlier.

The minimum value for the reverberation time in any one-third octave band in the chamber is specified in the ISO 3741/ANSI S12.51 as

$$T_{rev} > V/S \text{ sec}, \quad (2)$$

where

V is the chamber volume, m^3.

and

S is the surface area, m^2.

Per Eqn. (2), the RC minimum reverberation time is 1.64 seconds. A set of baseline reverberation time measurements were made using a Bruel and Kjaer 4224 as the sound source. The sound source was driven with a white noise generator for 30 seconds and then the signal was terminated. The Pulse system recorded the sound pressure level decay in the chamber. Post analysis determined the required 60-decibel decay time at each one-third octave band. Eight data sets were collected, with the sound pressure level decay sampled by six microphones in each case. The reverberation times in Fig. 3 show the average of the eight tests. At each one-third octave band, the RC meets the Standard minimum requirements for reverberation times per ISO 3741/ANSI S12.51.

Also shown in Fig. 3 are the absorption coefficients for the RC. These are derived from the Sabine Equation:

$$\alpha = (C^{*}V)/(S^{*}T_{rev}), \tag{3}$$

where

C is 0.161 when dimensions are measured in meters;

V is the chamber volume, m^3;

S is the chamber surface area, m^2;

and

T_{rev} is the reverberation time, sec.

The surfaces of the chamber closest to the equipment tested should be reflective with an absorption coefficient less than 0.06[7]. The RC exceeds these criteria at one-third octave band frequencies of 100 Hz through 4 kHz. It would be expected that absorption would increase at higher frequencies. When sound propagates through air, some of the sound energy is absorbed by the air itself. This energy loss is frequency dependent, and high frequencies are more readily absorbed than low frequencies. Because the chamber is so large, sound energy can travel significant distances during decay.

The absorption of a chamber affects the minimum distance between a noise source (equipment NIOSH is testing) and the sampling microphones. NIOSH determined this minimum distance based on the reverberation time method[7]. This distance, d_{min}, is determined by Eqn (4):

$$d_{min} = C_1(\text{square root } (V/T_{rev})\text{m}, \tag{4}$$

where

C_1 is 0.08, as specified in the Standard;

V is the chamber volume, m^3;

and

T_{rev} is the reverberation time, sec.

Figure 4 shows the reverberation times and minimum microphone distances. The minimum distance is greatest at the higher frequencies. This is because the large size of the chamber leads to a significant contribution due to the absorption of the air at higher frequencies. This minimum distance of 2.1 m was used to assist in the layout of the chamber microphones. In general, this microphone layout is not changed. On occasion, the shape or size of equipment under test may require adjustments in microphone locations to meet minimum microphone distance requirements. Microphone

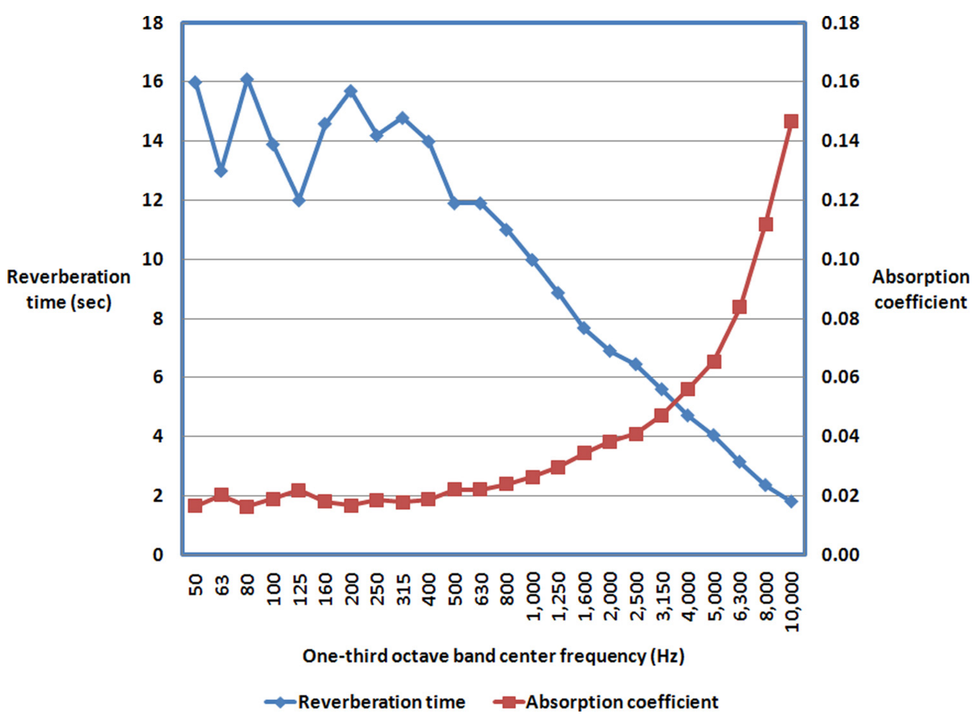

Fig. 3—RC reverberation times and absorption coefficients.

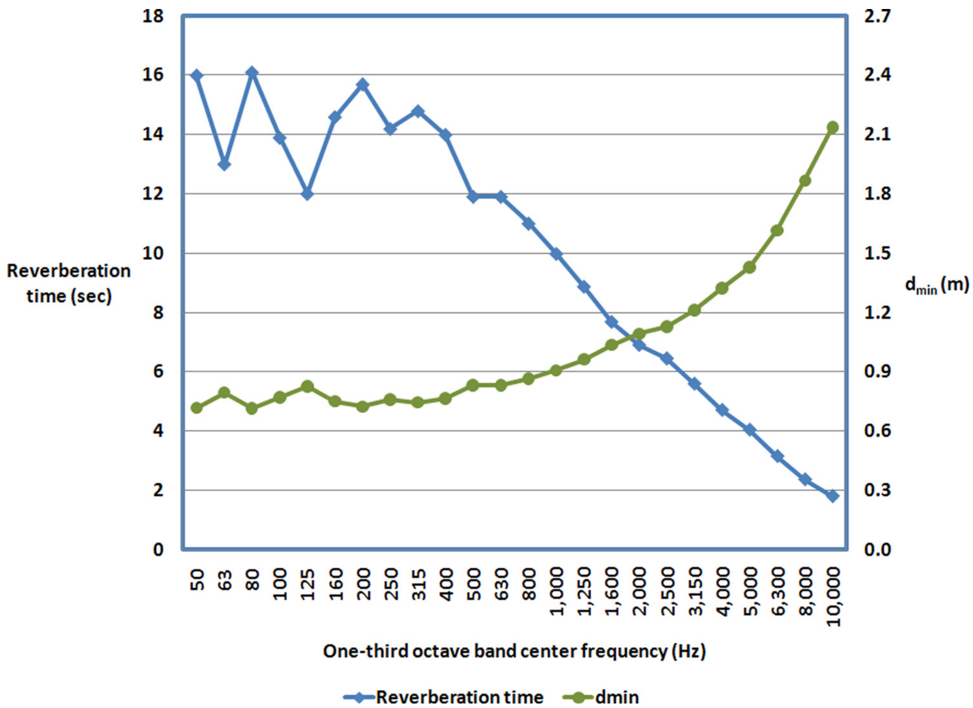

Fig. 4—RC estimation of minimum microphone distance from noise source.

locations can be varied by moving microphone cable support hardware along an overhead rail system or by raising or lowering the microphone with a pulley system.

3.4 Test Room Broadband Qualification

OMSHR engineers conducted a broadband qualification of the RC using the instrumentation setup, test procedures, and data analysis templates used for actual sound power level testing. This qualification followed the requirements and procedures specified in Annex E of the ISO 3741/ANSI S12.51. Sound pressure level data were sampled with a Bruel & Kjaer 4204 RSS operating at six locations. The standard deviation of the average sound pressure level observed during each of the six measurements and the requisite ISO 3741 Annex E criteria are shown in Fig. 5. In each one-third octave band, the sound pressure level standard deviations were less than the maximum allowable criteria set forth in the Standard. Thus, the RC qualifies for sound power level determination per ISO 3741/ANSI S12.51.

As another part of the program, the OMSHR conducted an uncertainty estimate for sound power level testing. This uncertainty magnitude estimate for its ISO 3741/ANSI S12.51 sound power measurement program consists of three terms:

1. calibration uncertainty of the reference sound source,
2. internal repeatability of the measurement, and
3. differences in facilities and test procedures.

The calibration uncertainty is from the ISO 6926 RSS calibration test standard[9]. As part of its sound power level testing program, the OMSHR conducts periodic testing of an Acculab RSS-400 reference sound source. These data are used to determine the internal repeatability of the measurement term listed above.

The term associated with test facilities and test procedures cannot be as easily estimated, but can be inferred from the inter-laboratory studies conducted to date. This uncertainty estimate has set the overall uncertainty to equal the maximum difference observed in the current inter-laboratory studies, and has been used to infer the standard deviation of reproducibility associated with differences in facilities, procedures, and measurement surfaces required to yield the estimated overall uncertainty.

These three factors are considered to be statistically independent; therefore, the overall magnitude of the uncertainty associated with these components is estimated as the sum of the squares of the individual components. Figure 6 shows the uncertainty estimation for an overall sound power measurement to be 0.4 dB. This level of uncertainty was deemed acceptable for the OMSHR needs for qualification of the RC. The standard deviation of the 50–80 Hz band is significantly higher than other frequency bands and is primarily influenced by the calibration uncertainty of the ISO 6926 calibration test standard. The development and performance of the hemi-anechoic chamber will be discussed in the next section.

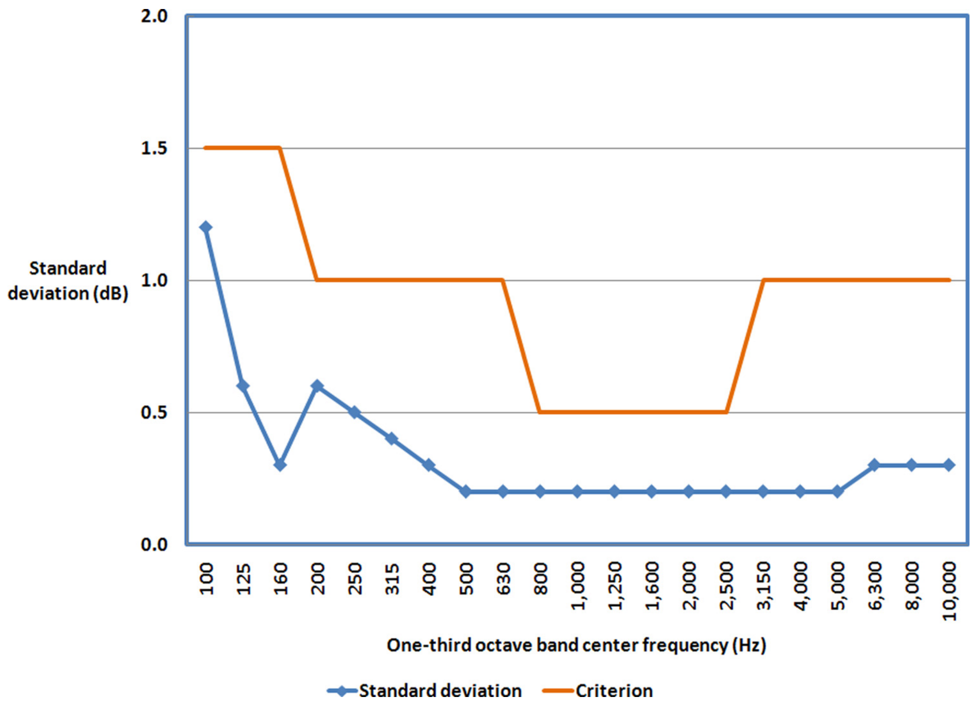

Fig. 5—RC test room qualification sound pressure level standard deviations.

4 THE HEMI-ANECHOIC CHAMBER (HAC)

4.1 Chamber Design

The hemi-anechoic chamber was constructed within an existing building. An 18.3-m × 11.6-m × 7.6-m (60-ft × 38-ft × 25-ft) block-wall room was built to serve as the exterior of the HAC. Each block is 0.4 m × 0.2 m × 0.2 m (16" × 8" × 8") and has two hollow cores. The floor of the chamber is poured concrete. As shown in Fig. 7, the HAC interior dimensions are 16.8 m × 10.1 m × 6.4 m (55-ft × 33-ft × 21-ft). At the south end of the chamber are two hinged 9.6-m × 2.7-m (31.5-ft × 9-ft) steel equipment access doors for the entry of large mining equipment. Figure 8 shows an interior view of the HAC with a continuous

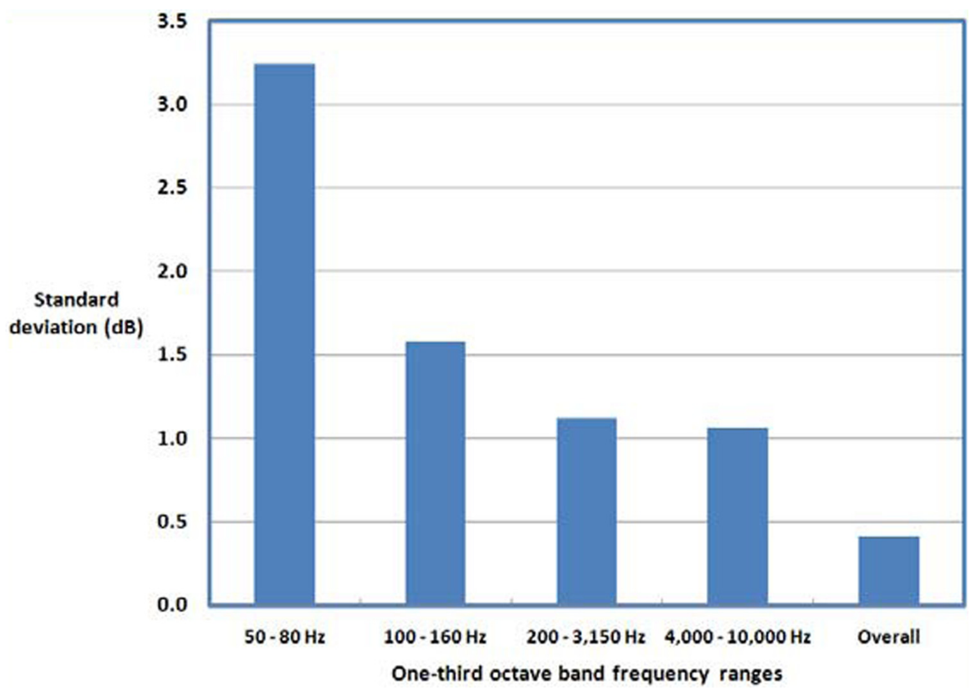

Fig. 6—RC uncertainty estimation.

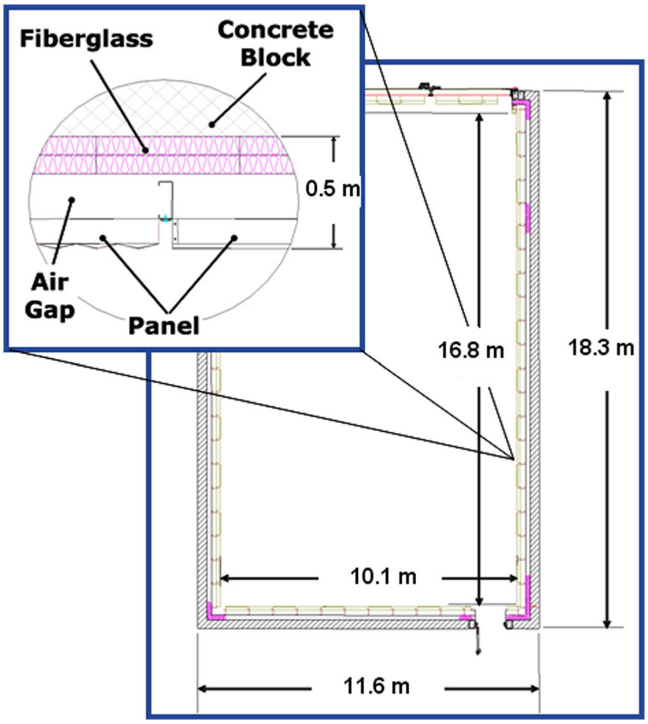

Fig. 7—HAC dimensions.

mining machine, typical of the size and type of equipment that NIOSH tests.

Key to the construction of the HAC was determining which acoustic treatments best fit NIOSH requirements. Initially, standard foam acoustic wedges were considered. However, NIOSH typically tests large equipment and installing foam wedges would limit available working space in the chamber. Further, water is sometimes used during testing, such as when evaluating a roof bolting machine with a wet or mist drilling system. With available floor space at a premium and a potentially wet environment, NIOSH sought alternative treatments for the HAC. The acoustic treatments selected for the walls and ceiling were an Eckel Industries perforated V-ridged SuperSoft panel designed for a 200 Hz cutoff frequency (Figs. 7 and 8). To achieve this cutoff frequency, the total depth of the treatment and air gap is 0.46 m (18”). The panels are fabricated from 22-gauge perforated steel and are 12.1 cm (4.75”) thick. These panels also cover the large equipment access doors of the chamber and personnel doors at the north and south ends of the chamber. Additionally, there are electrical power outlets, communication lines, and a BNC patch panel to connect microphone and other signal cables to the control room. The HAC also has a four-camera video system used to monitor testing. Outside the chamber is a load center to provide electrical power to the equipment under test.

Fig. 8—HAC with continuous mining machine.

The primary use of the HAC is for noise source identification. Thus, it is necessary to conduct this testing in a free-field with minimal sound reverberation. To determine how well the HAC functioned as a free-field, a test room qualification exercise was conducted and reverberation times were calculated.

4.2 Test Room Qualification

In a free-field, the sound pressure level decreases 6 dB every time the distance from the source doubles. This is commonly expressed as the inverse square law in acoustics. A series of measurements were conducted in the HAC to quantify its acoustic performance per the qualification requirements stated in ISO 3745[3,10–12]. The objective was to verify the presence of a free-field by plotting the sound pressure level vs. distance to show a 6-dB reduction in sound pressure level for each doubling of distance from the noise source.

The measurements were collected along five traverses—four into the trihedral corners of the chamber and one directly up to the center of the ceiling. In the NE, NW, SE, and SE directions, at least 23 locations were sampled; in the up direction, 15 were sampled. To conduct the test, a loudspeaker was placed normal to the reflective plane on the floor in the center of the HAC. A Stewart PA-50 Electronics Amplifier providing the noise signal for the loudspeaker. A Bruel & Kjaer 2260 and BZ7210 software served for data collection and one-third-octave band analysis from 50 through 20 kHz. And, a $\frac{1}{2}$-inch-diameter Bruel and Kjaer 4189 microphone was mounted on a taut string extending from the source to the walls and ceiling treatments and positioned at 0.3-m (1-ft) intervals for the sound pressure level measurements. It was attached to the B&K 2260 with a low noise cable.

The allowable tolerances given for the deviation from the inverse square law in ISO 3745 are presented

Table 1—ISO 3745 allowance tolerances.

Frequency range (Hz)	Tolerance (dB)
$\leq$ 630	± 2.5
800 – 5,000	± 2.0
$\geq$ 6,300	± 3.0

in Table 1. These tolerances are given for an anechoic chamber, but are used for the HAC to evaluate its performance as a free-field acoustic environment. Analysis confirms that the HAC meets the ISO 3745 qualification requirements (from 50 Hz through 10 kHz) for measurement points from the source out to 6.1 m (20-ft) for the corner traverses and 5.2 m (17-ft) for the ceiling-center traverse. Thus, qualification requirements were met on the traverses to within 5.6 m (18-ft) of the trihedral corners and 1.2 m (4-ft) of the ceiling. Figure 9 illustrates a sample of the sound pressure level decay data for corner traverses at 100 Hz and 10 kHz. As shown, the decay falls within the specified tolerances. Considering that the SuperSoft panels were designed for a 200 Hz cutoff, the HAC performed better as a free-field than expected.

4.3 Reverberation Time Measurements

After construction of the chamber, NIOSH conducted a series of tests to determine if the 0.6-m (22-in) diameter recessed lighting in the ceiling negatively affected chamber performance. The rationale was that additional un-treated surfaces in the acoustical environment decreased sound absorption. As a test to verify this, NIOSH conducted reverberation time measurements of the HAC, with the lighting uncovered, and again with the lighting covered in fiberglass. Sound absorption is related to reverberation time in that a lower reverberation time would indicate a higher mean absorption coefficient for the HAC—a desirable characteristic.

Testing was conducted with a microphone height of 1.5 m (5-ft) and using a dodecahedral noise source set at a height of 1.5 m. Figures 10 show two source positions and four microphone positions for an initial set of measurements, and a second set of measurements consisting of two additional source locations and an additional four microphone locations. Five reverberation time measurements were collected for each source/microphone combination, resulting in 80 total decays. Figure 11 shows the mean reverberation times (top of the graph) and associated standard deviations (bottom of the graph) of the dataset. It is shown that covering the lighting with fiberglass does slightly reduce the reverberation times at 2.5 kHz and above. This was considered significant enough to warrant installation of smaller, 0.3-m (12-in) diameter recessed lighting to improve the sound field. Given fifteen lights in the chamber, this reduced the untreated ceiling surface area (portion not covered by SuperSoft panels) by 1.5%.

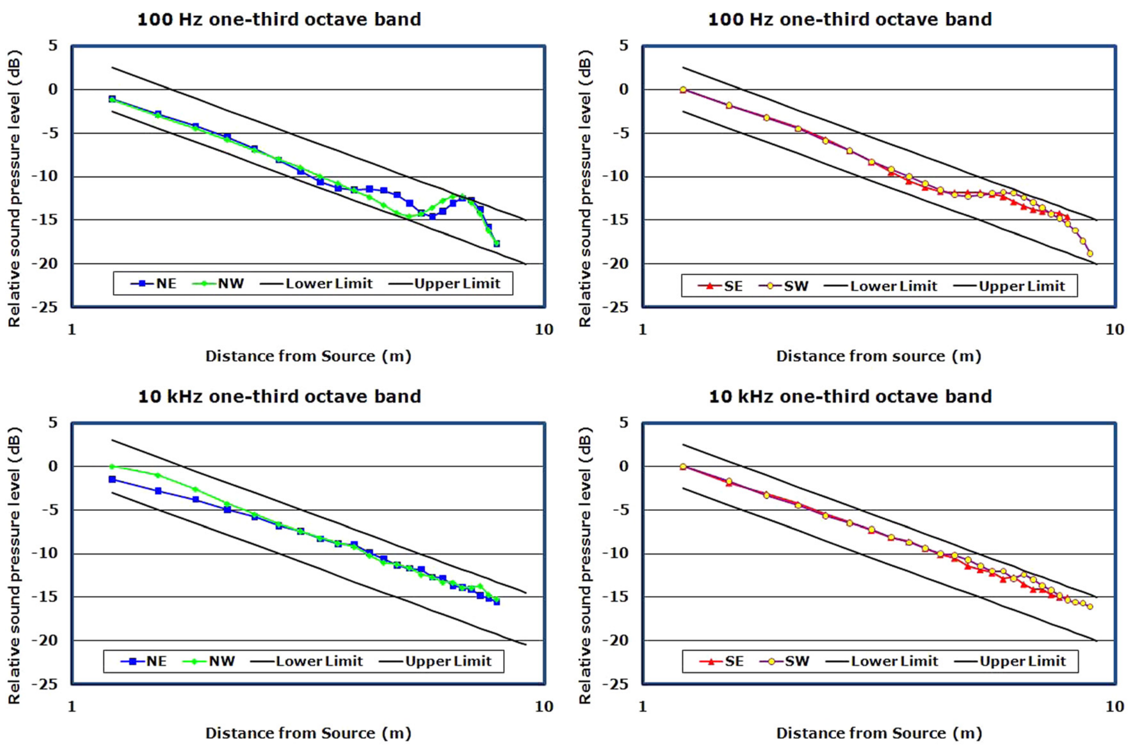

Fig. 9—HAC sound pressure level decay vs. distance.

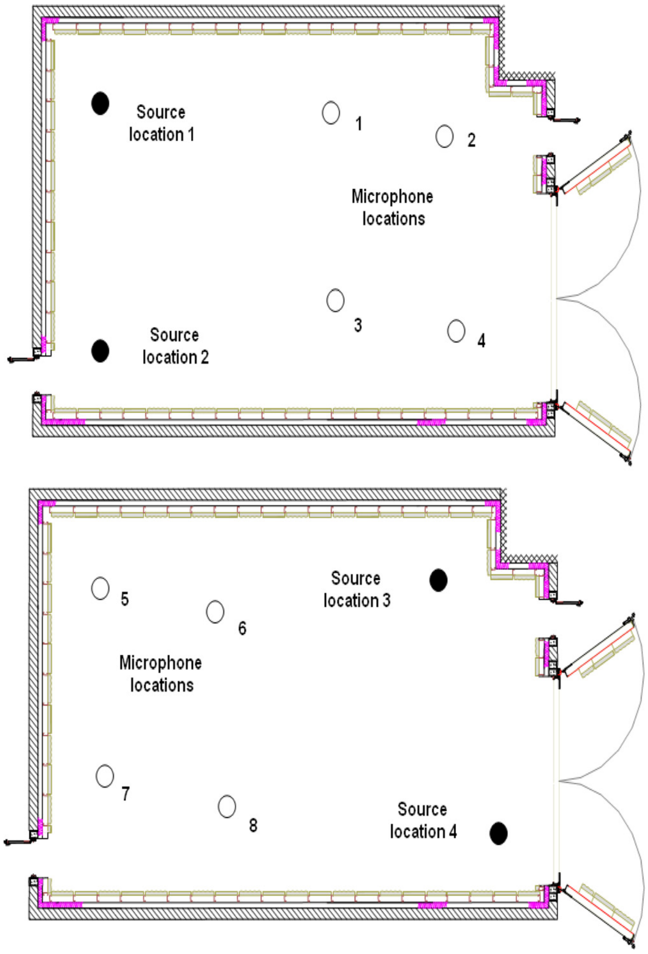

Fig. 10—Reverberation time measurement source and microphone locations.

4.4 Environmental Correction Factor, K_{2A}

While sound power level testing is primarily conducted in the RC, use of the HAC includes such testing per ISO 3744. Thus, the environmental correction factor, K_{2A}, was estimated for the chamber. This is an A-weighted correction factor to account for the influence of reflected or absorbed sound on the measurement surface sound pressure level. Per ISO 3744, K_{2A} shall be ≤ 2 dB for the criterion of engineering grade sound power level measurements to be met. If K_{2A} is greater than 2 dB, then the accuracy of the sound power measurement is reduced. This does not preclude sound power level testing per ISO 3744 in the HAC. The Standard requires that the maximum correction of 2 dB be applied and reference made to ISO 3744, stating that the sound power level is equal to or less than that determined. Or, the full correction factor be applied and reference made to ISO 3746[13], a survey method standard.

As determined by the absolute comparison test method, described in ISO 3744, K_{2A} factor is given by:

$$K_{2A} = L_{WA} - L_{WrA}, \text{dB} \tag{5}$$

where

L_{WA} is the measured A-weighted sound power level of an RSS, dBA;

and

L_{WrA} is the A-weighted calibrated sound power level of the RSS (rel. 1 pW (10^{-12} W)), dBA.

A rectangular parallelepiped served as the measurement surface for an Acculab RSS-400 reference sound source. Considering the relatively small size of the source (0.25 m × 0.25 m × 0.36 m), a measurement distance of one meter was selected and nine microphones were used. Thirty-second sound pressure level measurements were collected with the RSS operating at its stated calibration rotation speed. From these, a mean sound pressure level was calculated using the nine sound pressure level measurements, and the sound power level was calculated by:

$$L_W = L_{pf} + 10^{*} \log(S/S_0), \text{dB} \tag{6}$$

where

L_W is the sound power level, dB;

L_{pf} is the sound pressure level, dB;

S is the measurement surface area, m^2;

and

S_o is the reference surface area, 1 m^2.

The resultant sound power level was then A-weighted and K_{2A} was calculated. A series of five tests were conducted and the mean values for K_{2A} reported.

Shown in Fig. 12 are the K_{2A} factors for one-third octave band frequencies from 50 Hz through 10 kHz. The correction factor meets the requirements of ISO 3744 at all but the 500, 630, and 1 kHz frequency bands. For comparison purposes, K_{2A} criterion for ISO 3745, a precision method standard, is also given in Fig. 12. For ISO 3745, K_{2A} is limited to 0.5 dB.

Shown in Fig. 13 are octave band K_{2A} factors for ISO 3744 and ISO 3745 criteria. ISO 3744 requirements are satisfied for all but the 500 Hz band. ISO 3745 criteria are satisfied for all but the 250, 500, and 1 kHz one-third octave bands.

5 SUMMARY

The NIOSH Office of Mine Safety and Health Research (OMSHR) maintains two large acoustical chambers in support of its noise control program. The OMSHR has a large reverberation chamber (RC) used for sound power level testing. While the majority of testing is completed per the ISO 3743-2 engineering method acoustics standard, the chamber meets the requirements for precision method broadband sound power testing. This was verified per the test room

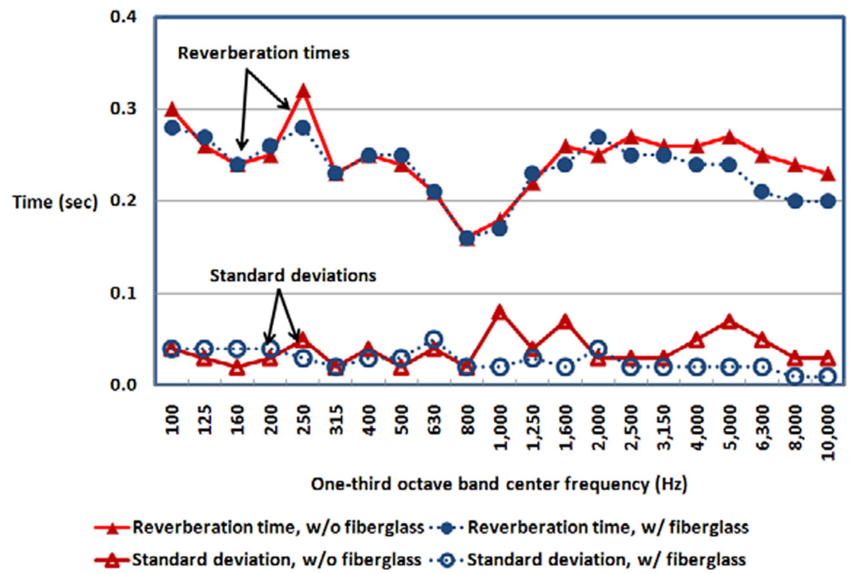

Fig. 11—HAC reverberation times and standard deviations.

broadband qualification criteria of the ISO 3741/ANSI S12.51, and NIOSH is NVLAP-accredited per this Standard.

NIOSH also calculated an uncertainty estimate for sound power level testing conducted in the RC. For overall sound power, this uncertainty estimate was 0.4 dB. In practice, sound power is used to document noise emissions, reductions, and frequency content of the mining equipment NIOSH evaluates as part of its noise control program.

The second acoustical chamber is a hemi-anechoic chamber (HAC) treated with Eckel SuperSoft panels instead of traditional absorption wedges. The primary use of the HAC is for noise source identification, and it is necessary to conduct this type of testing in a free-field. The SuperSoft panels proved to be an excellent alternative to traditional panels, with the chamber verified as a free-field per the test room qualification criteria set forth in ISO 3745.

Reverberation time measurements in the HAC indicated that the 0.6-m (22-in) diameter recessed lighting in the ceiling negatively affected chamber performance. Covering the lighting with fiberglass slightly reduced the reverberation times at 2.5 kHz and above. This facilitated installation of smaller, 0.3-m (12-in) diameter recessed lighting to improve the sound field.

Data to determine the environmental correction factor, K_{2A}, was also collected in the HAC. For one-third

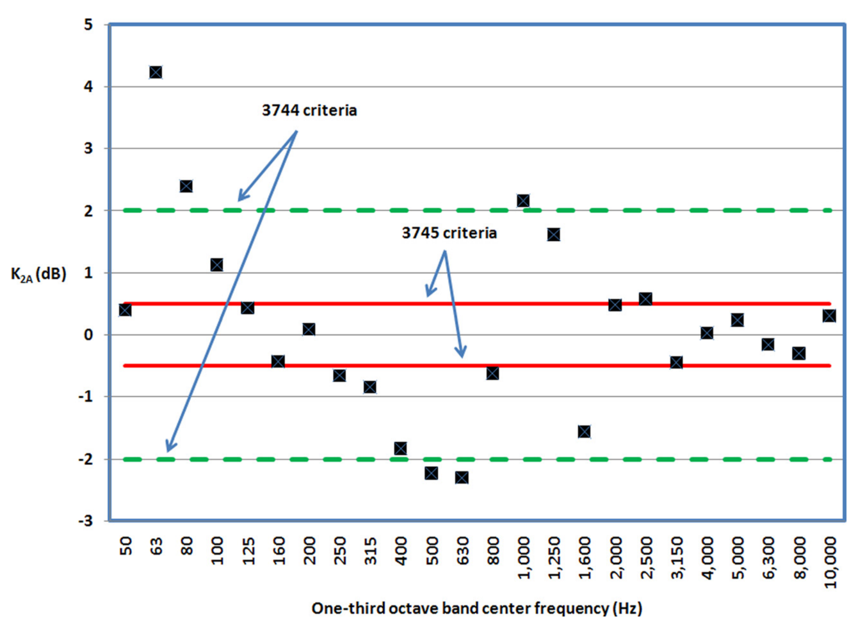

Fig. 12—HAC environmental correction factor, K_{2A}, for one-third octave band center frequencies.

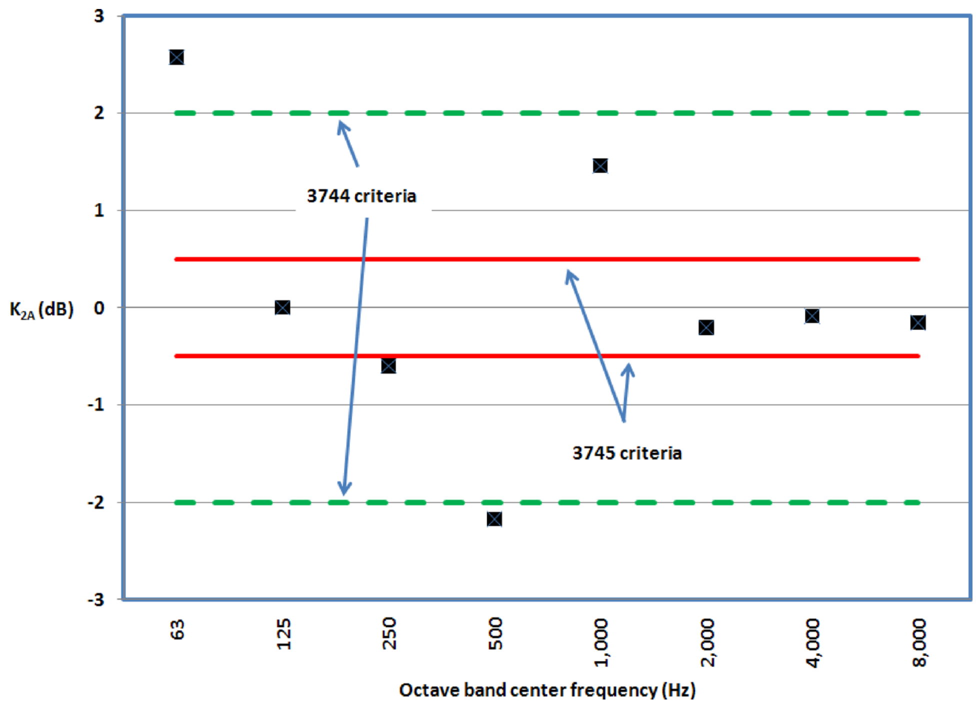

Fig. 13—HAC environmental correction factor, K_{2A}, for octave band center frequencies.

octave band frequencies from 50 Hz through 10 kHz, the correction factor meets the requirements of ISO 3744 at all but the 500, 630, and 1 kHz frequency bands. For octave band frequencies from 63 Hz through 10 kHz, ISO 3744 requirements are satisfied for all but the 500 Hz band.

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