

# Protection for Infrasonic and Ultrasonic Noise Exposure

BY ELLIOTT H. BERGER  
Senior Scientist, Auditory Research

When noise is assessed for its hazardous and/or annoying effects attention is normally limited to frequencies within the range of audibility. However, there are situations that arise in which acoustical energy outside the nominal audible range may become important. If at those times the use of hearing protection devices (HPDs) is required, hearing conservationists are at a disadvantage since HPD attenuation measurements conducted in accordance with standardized methods<sup>1,2</sup> are normally limited to the frequency range of 125 Hz - 8 kHz. This EARLog, #14<sup>3</sup>, addresses the problem by not only providing extended frequency attenuation data for a representative sample of devices, but by also briefly discussing suggested limits for exposure to very low and very high frequency acoustical energy.

## Definitions

Although the range of audible frequencies is classically defined as extending from 20 Hz to 20 kHz, sounds of sufficient intensity can be aurally detected at both lower and higher frequencies. Acoustical energy falling outside the "audible" range is designated as either infrasonic (below approximately 20 Hz) or ultrasonic (above approximately 16 - 20 kHz).

Infrasound can be generated by both natural and man-made events. Examples of the former are thunder, volcanic activity, winds, large waterfalls and the impact of ocean waves, whereas examples of the latter are high-powered aircraft and rocket propulsion systems, explosions, sonic booms, bridge vibration, ships, and air heating and cooling equipment<sup>4</sup>. Airborne ultrasound can be generated by a wide variety of industrial processes, including cleaning, drilling, welding plastics, mixing, and emulsification. Infra- and ultrasonic acoustical energy do not usually occur in the absence of sounds within the nominal audible range due to the nature of the processes by which such sounds are generated.

## Exposure Limits

Currently, there are no U.S. or international standards defining permissible exposure limits to infrasound. However, von Gierke and Nixon present an excellent review of the topic area<sup>4</sup>. Since they found that "infrasound, which is not subjectively perceived in some way, has no effect on performance, comfort, or general well-being," they developed proposed limits with respect to the safety and preservation of the auditory system. Their 8-hr. exposure limits range from 136 dB at a low frequency of 1 Hz to 123 dB at the upper end of the infrasonic

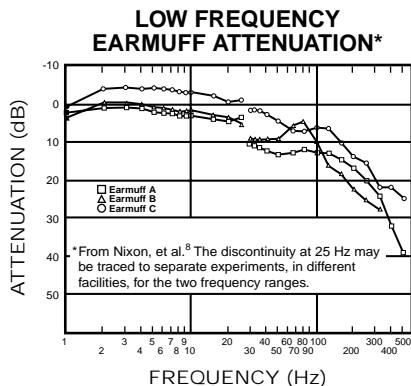


Figure 1

range (20 Hz). The limits may be approximately adjusted for shorter or longer duration exposures using a 3-dB exchange rate, i.e. if the duration is halved, the level may be increased by 3 dB, and vice versa.

Exposure limits to airborne ultrasound have been recommended by a number of national and international organizations<sup>5</sup>. The available data and the exposure criteria have been reviewed and summarized by Acton<sup>5,6</sup>. The criteria are similar, typically limiting exposures to 110 dB SPL for the frequencies at and above 20 kHz<sup>5,7</sup>, which has been translated to a 1/3 octave band criterion of 110 dB

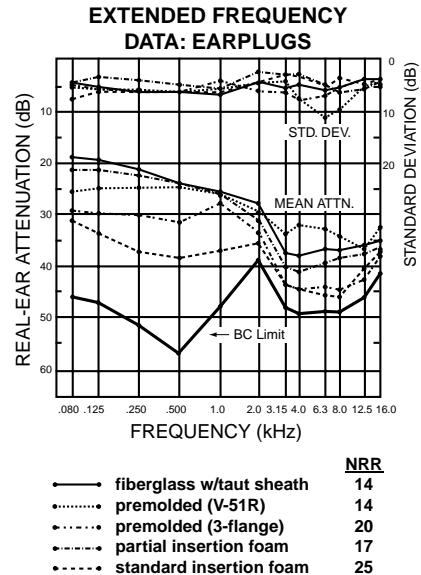


Figure 2

SPL for the bands at and above 25 kHz, and 75 dB SPL for the 20-kHz 1/3 octave band<sup>8</sup>.

The criteria for the high audio frequencies (up to approximately 18 kHz) are based upon subjective and psychological rather than auditory effects - an unpleasant sensation of fullness or pressure in the ears, headaches, in-head localization<sup>9</sup>, and possibly nausea and fatigue - since they are the more sensitive indicators of potential harm in that range. Above 18 kHz the limits are intended to avoid potential hearing loss in the audio frequency region that could result from the generation of lower frequency aural distortion due to high level ultrasonic noise. The severity of the subjective effects is mainly dependent upon sound level rather than exposure duration, and the aural distortion phenomena result from nonlinear processes. Thus it is questionable whether ultrasonic exposure criteria are amenable to adjustment via an exchange relationship such as the 3-dB rule<sup>5</sup>, although some groups have made such proposals<sup>7</sup>.

## HPD Attenuation At Low Audio and Infrasonic Frequencies

In the frequency range below 50 Hz available attenuation data appear to be limited to only one study<sup>10</sup>. The authors utilized both subjective (real-ear attenuation at threshold, 35 - 500 Hz) and physical (microphone in earmuff, 1 - 500 Hz) measurement methods. Representative data are shown in Figure 1. They indicate generally constant attenuation from 30 Hz to 100 Hz, with very limited protection or even amplification for the infrasonic frequencies. The data confirmed subjective impressions also reported by the authors.

No measurements were conducted on insert-type protectors, but subjective reports that were cited<sup>10</sup> suggested that a tightly sealed earplug could provide appreciable attenuation, as would also have been predicted based upon early theoretical studies<sup>11</sup>.

Although most test standards do not require testing below 125 Hz, many authors have reported data in the 50 - 125 Hz range. Data from our laboratory<sup>12</sup> are depicted in Figures 2, 3, and 4 for insert semi-aural, and circumaural HPDs. The results, extending down to the 80-Hz 1/3 octave band may be compared to the standard test frequency results which are also shown. All of these data, measured in conformance with ASA STD 1, indicate that the 80- and 125-Hz values are substantially similar.

## HPD Attenuation At High Audio and Ultrasonic Frequencies

At the upper end of the audio range hearing sensitivity decreases at the rate of approximately 100 dB/octave, compared

to 10 - 20 dB/octave (as frequency decreases) for low audio and infrasonic frequencies. This fact, combined with the relatively good inherent attenuation of HPDs at high frequencies, makes generation of ultrasonic acoustical stimuli at levels sufficient to be detected by hearing protected test subjects very difficult. As of this writing there do not appear to be any studies reporting HPD performance at ultrasonic frequencies and only two that even discuss the range above 8 kHz<sup>12 13</sup>.

Representative published data<sup>12</sup> combined with recent results from our laboratory are plotted in Figures 2 - 4. HPDs were fitted by the subjects under experimenter supervision. The fitting of the vinyl foam earplug was an exception in that it was tested with two distinctly different experimenter insertions: partial (about 15 - 20% in the ear canal) and standard (typical laboratory fit with 50 - 60% in the canal).

The data extend up to the 16-kHz 1/3 octave band, which includes energy to 17.8 kHz. The bold line at the bottom of the graphs represents an estimate of the bone conduction (BC) limits to HPD attenuation<sup>12</sup>.

Except for the 3-flange earplug, standard-insertion foam plug, and semi-aural data, the 8-kHz attenuation approximates that at 12.5 and 16 kHz. For the two earplugs mentioned, the highest frequency test data are 8 - 9 dB less than at 8-kHz. This is probably attributable to the nearness with which the attenuation of those plugs approaches the BC limits which exhibit the same apparent behavior in that test range.

Berger<sup>12</sup> also evaluated an earplug plus earmuff combination and found that in the frequency range from 2 - 16 kHz the measured performance was essentially equal to the BC limits.

## Conclusions

HPD attenuation at low audio frequencies (down to 50 Hz) can be estimated to an accuracy of approximately 5 dB by assuming it is equal to 125-Hz data. At high audio frequencies (up to 17.8 kHz) all HPDs tested were very effective, providing at least 32 dB noise reduction. Thus, at those frequencies, exact estimation of attenuation becomes somewhat academic.

At infrasonic frequencies earmuffs provide little or no protection and may even amplify sound, whereas properly fitted imperforate earplugs should provide appreciable protection. No ultrasonic HPD

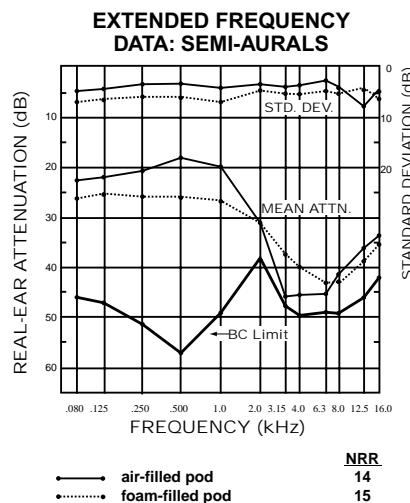


Figure 3

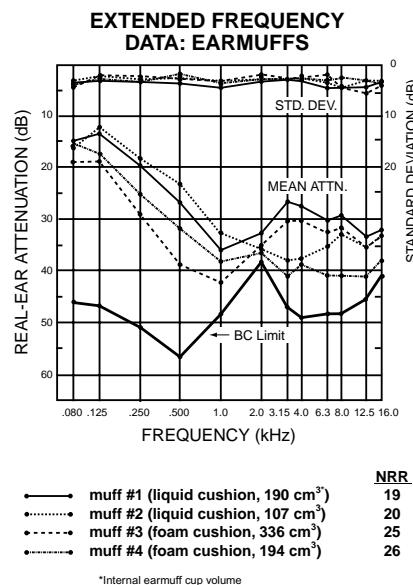


Figure 4

attenuation data are available, but it would be reasonable to assume that the general behavior observed in the high audio range should prevail at frequencies up through 32 kHz.

## References and Footnotes

- Acoustical Society of America (1975). "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs," Standard ASA STD 1-1975 (ANSI S3.19-1974), New York, NY.
- International Organization for Standardization (1981). "Acoustics Measurement of Sound Attenuation of Hearing Protectors -Subjective Method," ISO 4869, Switzerland.
- Berger, E.H. - The EARLog series is available upon request from Aearo Company.
- von Gierke, H.E. and Nixon, C.W. (1976). "Effects of Intense Intrasound on Man" in *Intrasound and Low Frequency Vibration*, edited by W. Tempest Academic Press, New York, NY, 115-150.
- Acton, W.I. (1983). "Exposure to Industrial Ultrasound: Hazards, Appraisal, and Control," J. Soc. Occup. Med. 33, 107-113.
- Acton, W.I. (1974). "The Effects of Industrial Airborne Ultrasound on Humans," Ultrasonics 12, 124-128.
- International Radiation Protection Association (1984). Interim Guidelines on Limits of Human Exposure to Airborne Ultrasound," Health Phys. 46(4), 969-974.
- The much lower limit for 20 kHz results from the fact that the nominal bandwidth of a 1/3 octave centered at 20 kHz extends down to 17.8 kHz, within the upper end of the audible frequency range.
- The perception that occurs when environmental noises appear to emanate from within the head or ears.
- Nixon, C.W., Hille, H.K. and Kettler, L.K. (1967). "Attenuation Characteristics of Earmuffs at Low Audio and Infrasonic Frequencies," Report AMRL-TR-67-27, Wright-Patterson AFB, OH.
- von Gierke, H.E. and Warren, D.R. (1953). "Protection of the Ear From Noise: Limiting Factors," Benox Report, Contract N6 orl-020 Task Order 44, Univ. of Chicago.
- Berger, E.H. (1983). "Attenuation of Hearing Protectors at the Frequency Extremes," in 11th Int. Cong. on Acoustics, Paris, France, Vol. 3, 289-292.
- Townsend, T.H. and Bess, F.H. (1973). "High Frequency Attenuation Characteristics of Ear Protectors," J. Occup. Med. 15(11), 888-891.