
A. Sound, Noise, and Vibration

1. Noise cf. Sound

“Noise” is, generally, “any unwanted sound,” or precisely, “audible acoustic energy that adversely affects the physiological or psychological well being of humans.” Noise is sound that varies in intensity, frequency, temporal pattern of exposure and contains no information or aesthetic content, or interferes with communication or other desirable activity (e.g., sleep).

Sound and noise are described in terms of three variables: (1) amplitude (perceived loudness expressed in engineering units of decibels – a dimensionless, logarithmic unit), (2) frequency (expressed in engineering units of Hertz (Hz) – waves or cycles per second (cps)), and (3) temporal pattern – constant, intermittent, or impulsive – expressed in seconds (or fractions thereof), minutes, and hours.

Noise may be sinusoidal (i.e., a single frequency and amplitude), tonal (i.e., having a fundamental frequency – typically the center frequency of a dominant one-third octave band and amplitude), or random (complex variations in frequency and amplitude). The perception of sound as “noise” is a subjective psychological reaction to a physical stimulus.¹

2. Infrasonic Noise

Infrasonic noise is noise below the human auditory threshold – optimally 20-20,000 Hz in a young, healthy person. Infrasonic noise should not be confused with noise-induced resonance. Infrasonic noise is also referred to as “infrasound” or low frequency noise (LFN).

3. Noise Effects

Beyond mere irritation, as documented in the U.S. Environmental Protection Agency’s (“EPA”) seminal “Levels Document,”² sound levels in the environment may reach the point of becoming a public health and welfare concern. Noise can cause hearing loss; interfere with

human activities at home and work; annoy, awaken, anger, and frustrate people; disrupt communications and individual thoughts; and become a biological stressor.\textsuperscript{3} The noise generated by drilling, hydraulic fracturing, and compressor stations is typically constant and tonal (in a relatively low frequency region of the audible spectrum (< 200 Hz)), and infrequently punctuated with impulsive noise (e.g., decompression events – blowdowns). Impulse noise (particularly high amplitude) and tonal noise are generally more irritating to receptor humans.

4. **Sound cf. Vibration**

Sound is the perceived effects of pressure waves created in ambient air by the human ear in the audible spectrum (~ 16-20,000 Hz); whereas, vibration is the cyclical displacement of a structure by an external force – a mechanical process. Transmission of whole body vibration is usually through a supporting system (e.g., a vehicle seating system or platform). Segmental vibration is usually transferred though the distal upper extremities as the consequence of coupling between the hands and a vibrating power tool (e.g., dental drill, impact hammer).

Vibration may be *sinusoidal* (occurring at a single amplitude, frequency and direction) or *random* (complex vibration varying in amplitude, frequency, and direction – linear and angular). *Transient vibration* (i.e., shock) may or may not be periodic and may or may not be of constant amplitude. The properties of vibration are amplitude (expressed as acceleration in meters per second squared), frequency (expressed in Hertz [Hz] or cycles per second [cps]), duration (expressed as unit time), and direction (expressed in three orthogonal axes – x, y, and z). *Angular acceleration* is non-linear and occurs in three non-linear planes – roll, pitch, and yaw. Angular acceleration is a potential confounding factor in the measurement of linear vibration because vibration is seldom truly linear. For simplification, angular vibration is not considered for the purposes of human exposure guidelines. Human exposure to vibration is characterized as *segmental* (affecting a particular segment of the human musculoskeletal system – most often the distal upper extremities) or *whole body vibration* – mechanical energy oscillation transferred to the body as a whole (importantly, through the spinal column).

All structures, including human systems (e.g., spinal column) have a *natural resonance frequency*. Natural resonance frequency is determined by the physical properties of the structural system – mass and stiffness. When the external forcing frequency coincides with a structure’s natural resonance frequency, vibratory motion of the structure is amplified. The structure may fail, or the physical properties of the structure may be altered. Determination of the natural resonance frequency of a structure predicts whether resonance will occur as result of vibration exposure.

Various areas of the human body exhibit different resonance frequencies. Spinal resonance is “directional”: (1) Longitudinal (vertical) resonance frequency is ~ 4-8 Hz; (2) Transverse (lateral and anteroposterior) resonance frequency is ~ 1-2 Hz. *Frequency weighting* weights whole body vibration in the range of greatest human sensitivity, utilizing electronic filtering that places greater weight on vibration measurements in the range of human sensitivity. The *primary frequency* (a/k/a *fundamental* frequency) of system resonance is the

\textsuperscript{3} EPA Condensed Levels Document at 1.
dominant frequency of the total vibration signal (generally the center frequency of a dominant third-octave band). Determination of the resonance frequency of a structure enables engineers to predict whether resonance will occur, and if so, the severity of resonance.

B. Quantitating Noise

1. Decibel

Generally, a decibel is an expression of a degree of loudness. A decibel is 1/10th of a bel. One decibel equals approximately the smallest difference in acoustic power between two sounds that the human ear can distinguish. (As a practical matter, most humans are insensitive to differences less than 3 dB.). An increase of 1 bel is perceived as a 10-fold increase in loudness.

The decibel is simply a unit of comparison – a ratio of one sound to an established reference level. The reference level is either implied or specifically stated, but the ratio is expressed as a single number. In physical noise measurements, the reference level utilized is a sound pressure of 0.0002 µbar (one-millionth of one barometric pressure or one atmosphere), which is known as acoustic zero decibels.4

Technically, a decibel (dB) is an engineering unit used to measure the intensity of a sound pressure level (SPL) by comparing it relative to a reference pressure level. Hence, the ratio can be expressed as Pressure 1:Pressure 2 (P₁/P₂). However, an additional factor must be considered; the computation of the ratio in decibels is logarithmic. If only this logarithmic function were considered, then the formula evolves as follows: dB = log(P₁/P₂). But the formula is not yet complete. When the decibel was adopted from the engineering field, it was a comparison of sound powers, not pressures, and it was expressed in bels not decibels. A decibel is 1/10th of a bel, and sound pressure is proportionate to the square root of the corresponding sound power; therefore, it remains necessary to multiply the logarithm of the ratio of pressures by 2 (to account for the square root conversion) and by 10 (for the bel-decibel conversion). The sound-pressure level formula for dB is, therefore, the ratio equal to 20 times the common logarithm of the pressure produced by a sound wave to the reference pressure, expressed as follows:

\[\text{dB} = 20 \log \frac{P_1}{P_2}\]

2. A-Weighting

Most literature and regulatory provisions refer to A-weighted sound level, a metric that reflects the relative sensitivity of the human ear to sounds at various frequencies and applies “weighting” to sound pressure levels at different frequencies across the audible spectrum to derive a single number that describes the aggregate perceived amplitude of sound. The amplitude of sound may be alternatively measured and expressed as an instantaneous peak (impulse), minimum level, maximum level, or route mean squared (rms) (“steady-state”) level in decibels. A-weighting has been universally adopted for regulatory initiatives.

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3. EPA Sound Descriptors

In the 1970s, the EPA developed a system of four “sound descriptors” to summarize how humans perceive sound and determine the impact of noise on public health and welfare. The four descriptors are: (1) A-weighted Sound [pressure] Level; (2) A-weighted Sound Exposure Level; (3) Equivalent Sound Level; and (4) Day-Night Equivalent Sound Level. The EPA’s Sound Exposure Level provides a summation of the energy of the momentary magnitudes of sound associated with a noise event. The Equivalent Sound Level (L_{eq}) provides a measure of the average environmental noise levels to which a population is exposed, considering both the magnitude and duration of noise over a specified period (generally expressed in hours). The Day-Night Sound Level (L_{dn}) characterizes noise levels in residential areas throughout the day and night, and adds a 10 dBA weighting factor (often described as a “penalty”) to nighttime noise (i.e., noise occurring during the hours from 10:00 p.m. to 7:00 a.m.) as a surrogate for the relatively increased irritation of residential recipients to nighttime noise. As described in the *EPA Levels Document*, these four descriptors are related, but the latter two – L_{eq} and L_{dn} – are most important for regulations and industry standards.\(^5\)

Another important consideration for evaluating noise generated by compressor stations is sound attenuation in accordance with the inverse square law.\(^6\) Estimates of sound attenuation can be approximated by applying a reduction factor of 6 dBA for each doubling of distance at distances exceeding 50 feet (i.e., beyond the “near field”).

C. Federal Noise Regulations

1. The Noise Control Act of 1972 and Quiet Communities Act of 1978

The Noise Control Act of 1972\(^7\) and the Quiet Communities Act of 1978\(^8\) sought to establish programs requiring the federal government to establish and enforce uniform noise control standards for, *inter alia*, aircraft and airports, interstate commercial motor carriers, interstate carriers by rail, various industrial workplaces, medium and heavy-duty trucks and construction equipment, portable air compressors, and federally assisted housing developments situated in urban and industrialized noise environments. The EPA’s Office of Noise Abatement and Control (“ONAC”) established rules for aircraft and airport noise control, noise emissions labeling for industrial equipment, construction industry air compressors, and heavy trucks.

In 1981, the Reagan administration determined that noise control initiatives should be the province of state and local governments. The ONAC was de-funded in 1992. However, Congress has never rescinded the Noise Control Act or the Quiet Communities Act.

\(^5\) See FN 1.  

The Federal Energy Regulatory Commission (FERC) has promulgated a specific rule governing noise emissions from compressor stations involved in the interstate transmission of natural gas, which states, in pertinent part:

(A) The noise attributable to any new compressor station, compressed added to an existing station, or any modification, upgrade or update of an existing station, must not exceed a day-night sound level (L_{dn}) of 55 dBA at any pre-existing noise-sensitive area (such as schools, hospitals, or residences).
(B) New compressor stations or modifications of existing stations shall not result in a perceptible increase in vibration at any noise-sensitive area.

18 C.F.R. § 380.12(k)(4)(v)(A) and (B)(2016).

(5) Describe measures and manufacturer’s [sic] specifications for equipment proposed to mitigate impact to ... noise quality, including emission control systems ... mufflers, or insulation of piping and buildings, and orientation of equipment away from noise-sensitive areas.


The FERC regulation does not apply to compressor stations involved in intrastate transmission of natural gas. Nevertheless, the FERC regulation is often referenced as a “guideline” for noise generated by intrastate compressor stations.

D. State and Local Noise Regulations – The West Virginia Experience

In the absence of a comprehensive federal regulatory regime, regulation of noise has been delegated to state and local governments. For example, West Virginia enacted the Natural Gas Horizontal Well Control Act\(^9\) (the “Act”) in December 2011 in reaction to the proliferation of shale gas exploration in the state. Among other standards for horizontal wells, the Act established new well location restrictions requiring the center of all new horizontal well pads to be located at least 625 feet from any existing occupied dwelling.\(^10\) To evaluate the adequacy of this setback restriction, the Act required the West Virginia Department of Environmental Protection (“WVDEP”) to report to the legislature “on the noise, light, dust, and volatile organic compounds generated by the drilling of horizontal wells as they relate to the well location restrictions regarding occupied dwelling structures[].”\(^11\)

In response to this legislative mandate, WVDEP commissioned a study by the West Virginia University (“WVU”) School of Public Health on air, noise, and light emissions from the

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drilling of horizontal gas wells.\textsuperscript{12} WVU conducted noise monitoring at seven well pads in various stages of development (site preparation, drilling, hydraulic fracturing, and completion). WVU’s monitoring data indicated that noise levels frequently exceeded 55 dBA EPA guideline for preventing outdoor activity from interfering with the ability to hear normal conversation and causing annoyance.\textsuperscript{13}

The study ultimately concluded that a 625 foot setback from the center of the pad would not assure that residences would not be exposed to contaminants, including noise, from operations, but that specification of a single setback distance would not eliminate all potential exposures.\textsuperscript{14}

Based on the results of the WVU study, WVDEP provided a report to the West Virginia Legislature on May 28, 2013.\textsuperscript{15} WVDEP’s report recounted WVU’s key findings with respect to noise, and indicated that WVDEP had shared the study’s noise reduction recommendations with oil and natural gas operators.\textsuperscript{16} The report indicated that WVDEP collaborates with individual operators on a case-by-case basis to facilitate discussion and resolve citizen noise complaints, and that WVDEP inspectors would continue to encourage operators to deploy noise abatement measures based on site-specific circumstances.\textsuperscript{17} WVDEP’s report ultimately recommended that the legislature adopt a location restriction for occupied dwellings that relied on the so-called “limit of disturbance” (the outermost perimeter) of the pad rather than its center point, but advanced no other specific noise control recommendations.\textsuperscript{18} Neither WVDEP nor the legislature has promulgated noise abatement standards in response to the WVU report.

E. Relegation of Noise Abatement to Common Law Nuisance Doctrine

The void created by the absence of a specific noise control regulation \textit{de facto} relegates determination of what constitutes “excessive noise” to the common law doctrine of nuisance. In \textit{Burch v. NedPower Mount Storm, LLC}, 220 W.Va. 443; 657 S.E.2d 879 (2007), seven homeowners challenged the order of the Circuit Court of Grant County granting judgment on the pleadings in favor of two wind energy operators against whom plaintiffs had asserted nuisance claims and sought an injunction to enjoin the construction of a wind powered electric generating facility in proximity to their residences, which were situated within one-half to two miles from the proposed wind turbines.

\textsuperscript{12} Michael McCawley, PhD, Air, Noise, and Light Monitoring Results for Assessing Environmental Impacts of Horizontal Gas Well Drilling Operations (ETD-10 Project) (2013) (prepared for WVDEP Division of Air Quality).
\textsuperscript{13} \textit{Id.} at 9-10, 18 (citing EPA Condensed Levels Document at 24).
\textsuperscript{14} \textit{Id.} at 19.
\textsuperscript{15} Office of Oil and Gas, W. Va. Dep’t. of Envtl. Prot., Noise, Light, Dust, and Volatile Organic Compounds Generated by the Drilling of Horizontal Wells Related to the Well Location Restriction Regarding Occupied Dwelling Structures (2013).
\textsuperscript{16} \textit{Id.} at 3.
\textsuperscript{17} \textit{Id.}
\textsuperscript{18} \textit{Id.} at 5.
Plaintiffs’ complaint averred that construction and operation of the wind power facility would create a private nuisance because residents would be negatively impacted by, *inter alia*, constant noise, exposed to equipment hazards, and would incur diminution of their property value. *Id.* at 449, 647 S.E.2d at 885. The trial court granted appellees’ motion for judgment on the pleadings and dismissed the suit on several grounds, including lack of jurisdiction to enjoin construction of the project, since the Public Service Commission of West Virginia (PSC) had approved the project. *Id.*

The Supreme Court of Appeals of West Virginia reversed and remanded the case to the trial court for further proceedings, including a trial.

In determining the meaning of a statute, it will be presumed, in the absence of words ... specifically indicating the contrary, that the legislature did not intend to innovate upon, unsettle, disregard, alter or violate ... the common law[.] Syllabus Point 27, in part, *Coal & Coke Ry. Co. v. Conley*, 67 W.Va. 129, 67 S.E. 613 (1910). Further, “[o]ne of the axioms of statutory construction is that a statute will be read in context with the common law unless it clearly appears from the statute that the purpose of the statute was to change the common law.” Syllabus Point 2, *Smith v. W.Va. State Bd. of Educ.*, 170 W.Va. 593, 295 S.E.2d 680 (1982).

*Id.* at 451, 647 S.E.2d at 887.

Examining the various statutes granting authority to the PSC, the Court found no language expressing any legislative intent to abrogate the common law doctrine of nuisance as it applies to electric generating facilities. *Id.* at 453, 647 S.E.2d at 889. Accordingly, the Court “presume[d] that the Legislature left intact the circuit court’s jurisdiction in equity,” and the fact that the PSC had granted the utility companies a siting certificate did not preclude the landowners’ nuisance claims. *Id.* (internal citation omitted).

The Court defined private nuisance: “A private nuisance is a substantial and unreasonable interference with the private use and enjoyment of another’s land.” *Id.* at 451, 647 S.E.2d at 887 (citing Syl. Pt. 1, *Hendricks v. Stalnaker*, 181 W.Va. 31, 380 S.E.2d 198 (1989)). The Court further observed, “An interference with the private use and enjoyment of another’s land is unreasonable when the gravity of the harm outweighs the social value of the activity alleged to cause the harm.” *Id.* (citing *Hendricks*, 181 W.Va. at Syl. Pt. 2, 380 S.E.2d at Syl. Pt. 2).

The Court found that the landowners’ noise allegations were legally sufficient to state a claim to prospectively enjoin a nuisance, predicated on assertions that their use and enjoyment of their properties would be impinged as a consequence of constant noise generated by the wind turbines:

This Court has held that “[n]oise alone may create a nuisance, depending on time, locality and degree.” Syllabus Point 1, *Ritz v. Woman’s Club of Charleston*, 114 W.Va. 675,173 S.E. 564 (1934). We have further held that “[w]here an unusual and recurring noise is introduced in a residential district, and the noise prevents sleep or otherwise disturbs materially the rest and comfort of the residents, the
noise may be inhibited by a court of equity.” Syllabus Point 2, Ritz, supra. See also Snyder v. Cabell, 29 W.Va. 48, 1 S.E. 241 (1886) (affirming injunction against skating rink’s operation where it was found that noise from the rink materially interfered with the comfort and enjoyment of nearby residents). These holdings are grounded on a principle that is essential to a civil society which is that “every person . . . has the right not to be disturbed in his house; he has the right to rest and quiet and not to be materially disturbed in his rest and enjoyment of home by loud noises.” Snyder, 29 W.Va. at 62, 1 S.E. at 251.

Id. at 455, 647 S.E.2d at 891.

The Court next examined whether “unsightliness” is actionable under nuisance doctrine, explaining that courts have refrained from exercising their authority in equity to abate a purported nuisance “merely because it is offensive to the sight.” Id. (citing Parkersburg Builders Material Co. v. Barrack, 118 W.Va. 608, 610, 191 S.E. 368, 369 (1937)). The Supreme Court previously admonished that courts should exercise their inherent equitable jurisdiction with restraint:

[E]quity should act only where there is presented a situation which [sic] is offensive to the view of average persons of the community. And, even where there is a situation which [sic] the average person would deem offensive to the sight, such fact alone will not justify interference by a court of equity. The surroundings must be considered. Unsightly things are not to be banned solely on that account. Many of them are necessary in carrying on the proper activities of organized society. But such things should be properly placed, and not so located as to be unduly offensive to neighbors or to the public.

Id. (citing Barrack, 118 W.Va. at 613; 191 S.E. at 371).

Expounding upon “proper placement,” the Court stated, “When an unsightly activity is not properly placed, when it is unduly offensive to its neighbors, and when it is accompanied by other interferences to the use and enjoyment of another’s property [e.g., industrial noise and illumination], this Court has shown a willingness to abate the activity as a nuisance. Id. (citing, Syl. Pt. 3, Mahoney v. Walter, 157 W.Va. 882, 205 S.E.2d 692 (1974). An automobile salvage yard with incident noise, unsightliness, hazardous materials, and resultant depreciation of residential property values, together with loss of use, comfort, and enjoyment, may constitute a nuisance subject to abatement.). The Court held that “[w]hile unsightliness alone rarely justifies interference by a circuit court applying equitable principles, an unsightly activity may be abated when it occurs in a residential area and is accompanied by other nuisances.” Id. at 456, 647 S.E.2d at 892 (emphasis added).

The plaintiffs further alleged that construction of the wind turbines would cause a reduction of their property valuation. Id. The Court explained that the legal effect of mere diminution in the value of property alone is not generally actionable:
Upon the question of reduction in value of the plaintiffs’ properties ... we find this statement in Wood on Nuisances, 3rd Edition, § 640: “Mere diminution of the value of the property, in consequence of the use to which adjoining premises are devoted, unaccompanied with other ill-results, is *damnum absque injuria*.” Also in 66 C.J.S., Nuisances, § 19, P. 771, it is stated that: “However, a use of property which does not create a nuisance cannot be enjoined or a lawful structure abated merely because it renders neighboring property less valuable.”

*Id.* (citation omitted) (footnote added).

However, the Court held that when an activity not only results in property value depreciation and otherwise constitutes a nuisance, may be abated, and legal damages may be awarded:

An activity that diminishes the value of nearby property and also creates interferences to the use and enjoyment of the nearby property may be abated by a circuit court applying equitable principles. In addition, the landowners may seek compensation for any diminution in the value of their property caused by the nuisance.

*Id.*

*Burch* also contains analysis of whether the activities of a lawfully established and conducted business might nevertheless be subject to abatement as a nuisance, distinguishing between the doctrines of nuisance *per se* and private nuisance. The Court first articulated the general rule that a lawful business or a business authorized to be conducted by the government cannot constitute a nuisance *per se*, but it may become so based on surrounding places and circumstances, or the manner in which it is conducted. *Id.* at 456-457, 647 S.E.2d at 892-93 (citing McGregor v. Camden, 47 W.Va. 193, 35 S.E. 935, 937 (1899); Martin v. Williams, 141 W.Va. 595, 93 S.E.2d 835, 838 (1956); and Frye v. McCrory Corp., 144 W.Va. 123, 129; 107 S.E.2d 378, 382 (1959)) (internal quotation omitted).

However, the Court qualified the necessary burden to prove that a lawfully established and operated business nevertheless constitutes a private nuisance:

“[T]o sustain a[] [prospective] injunction inhibiting ... [a] business, not *per se* constituting a nuisance, it must be shown that the danger of injury from it is impending and imminent, and the effect certain.” . . . With regard to whether an injury in nuisance is certain, this Court has explained that “[m]ere possible, eventual or contingent danger is not enough. That injury will result must be shown beyond question . . . not resting on hypothesis or conjecture, but established by conclusive evidence. If the injury be doubtful, eventual, or contingent . . . an injunction will not be granted.” . . . Essentially, the proper test to determine whether a proposed activity should be enjoined on the basis that

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19 L. Literally, “loss without injury.” There are cases when the act of one may cause a damage or loss to another, but for which the latter has no remedy at law or in equity. See www.lectlaw.com/def/d101.htm.
the activity will constitute a nuisance has been stated as follows: “To warrant the perpetuation of an injunction restraining, as a threatened nuisance, the erection of a building proposed to be used for legitimate purposes, the fact that it will be a nuisance if so used must be made clearly to appear, beyond all ground of fair questioning.”

Id. at 457, 647 S.E.2d at 893 (emphasis added) (internal citations omitted).

Applying these legal precepts, the Court determined that the allegations pleaded in the plaintiffs’ complaint – “constant loud noise from the wind turbines, the turbines’ unsightliness, and reduction in the appellant’s property values” – were legally sufficient to prospectively enjoin the nuisance, provided that the plaintiffs proved these allegations “beyond all ground of fair questioning.” Id.

Although the remedy sought by the Burch plaintiffs was an injunction in equity, it is still apparent that the industrial noise, facility lighting, unsightliness, location and orientation of a facility, and property value depreciation may constitute an actionable private nuisance, even if the business activity is both lawful and lawfully conducted. Additional considerations might include the magnitude and frequency of noise; the reasonable expectations of those affected by the noise; and the ability to reasonably control it.

F. Industry Standards for Compressor Station Design and Noise Control


The Southwest Research Institute21 prepared the Handbook for Noise Control at Gas Pipeline Facilities (the Handbook) for the Compressor Committee of the Pipeline Research Committee in 1977. The Handbook is a highly technical document issued in two volumes. Volume I is comprised of seven chapters, including, inter alia, chapters characterizing the “noise problem,” characterizing the environment and isolating noise sources, generalized “treatment methods” for noise control, a description of “common gas pipeline industry noise sources and their control, facility design and construction, and computerized modeling methods.” The introduction to Volume I references two prior publications from the late 1950s and 1960s that specifically addressed noise abatement at natural gas pipeline and transmission facilities.22 Volume II is intended to provide ready access to the various proposed testing methods, equipment procurement guidelines, and computer models of noise propagation. The documents included in Volume II are not intended as “final standards or rigorous mathematical models of


21 The Southwest Research Institute, established in 1947 and headquartered in San Antonio, Texas, is one of the oldest and largest independent, non-profit organization applied research and development organizations in the United States.

acoustic behavior.” They do, however, provide “a set of effective methods” for use in noise control in the midstream sector.

The introductory chapter of the Handbook contains the following statements concerning early industry awareness of noise emissions from compressor stations:

The natural gas industry has traditionally maintained a position of leadership in industrial noise awareness and control. Through both individual company and industry-wide sponsorship, the industry has maintained vigorous research and engineering activities in noise control for over 20 years. An early example of this activity was the American Gas Association’s NQ-23 Program, “Noise Abatement at Gas Pipeline Installations,” conducted by the Pipeline Research Committee from 1958-62. The ... objective of this program was to define noise effects and criteria both for ... prevention of community noise intrusion, and ... development of analytical and engineering techniques to identify ... and control noise problems at gas pipeline installations. A second major research effort (“Noise Control for Reciprocating and Turbine Engines Driven by Natural Gas and Liquid Fuel” – published in 1969) sought to update and extend noise control technology specifically for compressor [stations].

Id. at 1-1.

This project was undertaken “[i]n response to the growing need to more effectively and efficiently respond to industry’s expanding responsibilities regarding noise control,” including the following objectives:

• Develop a set of standardized measurement methods tailored to the specific noise problem of the gas pipeline industry.

• Develop noise sections for inclusion in the procurement specifications for gas pipeline equipment ... 

• Compile and extend the state-of-the-art of noise control technology into a form which members of the gas pipeline industry might effectively utilize in defining and solving its individual noise problems.

• Explore the practical limits and feasibility of noise control treatments at gas pipeline installations.

• Develop analytical techniques for predicting noise levels at plant boundaries and the intrusion of noise into nearby communities.

• Develop or adapt simplified and predictable design techniques for special noise control devices and treatments applicable to gas pipeline noise problems.

Id.
Compressor station noise abatement is addressed exhaustively in the Handbook in furtherance of these objectives.

Chapter 2 of the Handbook is dedicated to describing “the noise problem,” including sensitivity of community receivers of compressor station noise from a physiological and psychological perspective. The scope of the “noise problem” is characterized in the introduction to Chapter 2:

The nature and type of noise problems ... have changed within the past 10 years due, at least in part, to an increase in the proliferation of noise criteria and legislation, and a growth in public noise awareness. These factors have added a new dimension to industrial noise control programs aimed at protection of ... surrounding communities. The promulgation of new standards and regulations with differing and sometimes arbitrary provisions has required ... continuing review and ... modification of industrial noise programs. This activity [suggests] that the criteria levels will be reduced even further and that ... present solutions to noise control problems will ... be rendered obsolete or insufficient.

Id. at 2-1.

Particular attention is directed at factors influencing the perception of noise by sensitive receptors, observing that the magnitude and existence of an “annoyance or community intrusion noise problem” is significantly dictated by the subjective response of receptors. The Handbook indicates that community response is affected not only by the amplitude and frequency of industrial noise, but also by psychological factors such as “fear of accidents” and “lowered property values,” as well as the activities conducted at receptors’ properties. Id.

Acknowledging that “there is no general agreement as to acceptable noise level criteria [in the absence of specific legislation] for ... prevention of environment noise pollution,” the Handbook admonishes that “mere compliance with standards ... will not avoid all possible individual complaints unless such standards are extremely conservative.” Id. “The ambient ... noise levels in rural areas are typically from 40 to 50 dBA and for quiet urban areas, 45 to 55 dBA.” Consequently, “annoyance criteria are generally set at 35 to 45 dBA criterion for no annoyance.” Id. (footnote omitted).

The Handbook recognizes that “[m]any annoyance complaints have not been caused by excessive sound levels[,] but rather by an implied fear for personal safety or loss of property value. In such cases, lowering sound levels is not usually sufficient to ... eliminate the problem.” Operators “should seek to educate the adjacent community. In addition, the facility may be unobtrusive.” Construction of compressor stations “in sites isolated by dense planting is common.” Id. at 2-5.

Chapter 4 relates to “generalized treatment methods” to attenuate compressor station noise and discusses suitability, effectiveness, and limitations of commonly adopted noise countermeasures. Typically, an effective noise reduction program can be designed to reduce
noise in three areas: (1) The source of noise may be modified to radiate lower sound pressure levels; (2) The acoustic path of noise (i.e., direction of propagation) can be deflected or “blocked”; and (3) The receptor can be modified by removing sensitive receptors from the area or constructing barriers and earthen berms in near proximity to receptors. Id. at 4-1. Various noise control strategies are enumerated and discussed in detail in Chapter 4, including:

- Equipment substitution, “although not generally practical, ... to reduce the noise problem by replacing the source with equipment which [sic] produces a lower noise level.”

- Modification of equipment and operating conditions in an effort to decrease the magnitude of noise, although the Handbook acknowledges that such approaches are frequently expensive, and in particular instances, technically infeasible. This category includes the following:
  - Damping metal cowlings;
  - Decoupling vibration-generating equipment from structural components of the compressor building;
  - Altering operating conditions (e.g., reducing radiator and cooling fan speeds);
  - Scheduling operating times (e.g., blowdowns, engine starts, pigging and blocking decompression, etc.) at certain critical times – typically daylight hours;
  - “Detuning” (through various damping measures including increasing mass, adjusting stiffness for greater or lesser compliance, acoustical insulation, and deflection of noise propagation paths) of component and subassembly resonances and forced vibration; and
  - Elimination of acoustic “leakage” using compressible acoustic gaskets or edge seals in enclosures, between equipment and floors, around door edges and access panels, grommets around building perforations, etc.

Various measures to achieve these general objectives are described in the Handbook. Id. at 4-1, et seq. It is crucial to recognize that initial site selection, proximity of sensitive receptors, topological features between the site and sensitive receptors, orientation of compressor stations and appurtenances on the site, consideration of regional meteorological conditions (e.g., prevailing wind direction), acoustic and visual shielding, and compressor station design and construction criteria are more effective and technically and financially feasible methods for noise control than subsequent remedial measures and administrative controls. Id. Although not exhaustive, the advantages and limitations of the most commonly deployed noise control methods follow.

Arbitrarily reducing the radiated noise from any given component will not necessarily produce a significant reduction in the total radiated noise levels. To lower equipment sound
levels, the component selected for treatment must be either the component producing the highest noise level or a component radiating a level within about 3 dB of the total power level.

**a. Enclosures**

Enclosures serve to isolate a noise source or a receiver from the adjacent environment. As such, compressor buildings are the prime example of enclosures that may provide attenuate noise. Proper structure design and construction may provide, in particular instances, approximately 10 to 25 dBA of isolation between the compressors and the outdoor environment. Another example is pipe lagging.

For certain mechanical noise sources (e.g., compressor engines, starter motors, turbines, and fans) and confined aerodynamic sources (e.g., piping), enclosures provide one of the most effective control techniques. Transmission loss (TL) between the source and the receiver is the predominant performance variable.

In reverberant enclosures, sound is reflected repeatedly from walls and surfaces, increasing the sound level as a result of each reflection. Theoretically, the sound level within a reverberant enclosure could continue to increase without limit. Practically, however, reverberation increases seldom exceed 10 dBA. Accordingly, the design transmission loss for an enclosure should include the desired noise reduction plus an additive value for reverberation. In practice, enclosures do not achieve the design (or theoretical) performance levels because critical details are disregarded in either the design or construction of acoustic enclosures.

Direct acoustic leakage (“air leaks”) is the most common reason for substandard enclosure performance. Insufficient ventilation and thermal considerations also may compromise enclosure performance because of direct acoustic radiation from the vents or overheating of the enclosed equipment. Extreme care must be taken to ensure that sufficient ventilation is available (based on manufacturer’s data) to prevent overheating. Selection of a cooling fan delivers sufficient airflow pursuant to manufacturer’s specifications. The next measure is to ensure that fan noise and noise within the enclosure does not propagate into the surrounding environment. Installation of a properly designed, acoustically lined duct (sized for the air flow area required) will mitigate acoustic leakage.

**b. Noise Barriers**

Barriers are not usually the most efficient form of noise control, but situations may exist where they offer the most practical choice for noise control. If the required noise attenuation is not too great, barriers may be useful. Barriers are most effective in non-reflective fields when located near the noise source or near the receptor. Existing terrain, earthen berms, or adjacent structures may also act as barriers in preventing sound from propagating directly into a sensitive area.

Partial barriers function most effectively in a directional sound field. Such barriers should have a transmission loss of at least 6 dB and should be constructed with dimensions exceeding...
the longest wavelength of noise to be attenuated or the largest source dimension (i.e., a compressor building).

Placing barriers on several sides of a noise source will provide increased noise reduction. Because these barriers change the radiation pattern of the noise source, higher noise levels may be produced on the unshielded sides of the source. The magnitude of this increase will depend on the effectiveness of the absorption material on the source side of the barrier(s). A well-designed, multi-sided barrier (partial enclosure) may provide a noise reduction of 5 to 10 dB in the low frequency octave bands and 10 to 16 dB in the higher bands. The final attenuation achieved is dependent upon barrier design, noise source (e.g., point source, line source, or line source of infinite length), receptor distances, and source size and noise characteristics (e.g., magnitude, frequency, direction).

c. Panel Resonance

It is crucial to recognize that noise barriers themselves are comprised of panels that are subject to acoustical and mechanical excitation; therefore, discussion of panel behavior is applicable to analysis of noise barrier design. Most of the noise radiated from mechanical structures results from vibration of large area panels – typically metal surfaces. Many sources of noise within a compressor station have enclosures, casing, guards and shields, inspection panels, and other large area panel surfaces. The noise radiated by panels will normally be approximately proportional to the exposed area and the vibration velocity amplitude on the panel.

Panels integral with a vibrating machine are usually excited by mechanical vibration. Vibration isolation, vibration damping, or vibration detuning (altering the frequency of the vibration) all might be appropriate methods for noise control. If the offending panels are removable (e.g., bolted on), they may be both isolated and damped by proper edge-mounting fasteners and gaskets. Further damping may be achieved by dissipative coatings applied to the panels or by tuned dampers (e.g., rubber snubbers). These types of treatment are generally limited in application to relatively low gauge (i.e., thin) panels (e.g., sheet metal) because the addition of absorbent coatings to thicker panels usually has a negligible contribution to the mass damping already present. Noisy piping cannot be damped significantly by dissipative coatings or lagging, although lagging may have some benefit as an acoustic insulator at higher frequencies.

Another method for suppression of panel vibration is to add stiffening members (e.g., cross bracing) where the frequency characteristics of the excitation are broadband. In such instances, the increased stiffness may actually alter the resonance frequency of the panel nearer to the predominant external forcing frequency, and the panel becomes a tuned radiator generating amplified noise, rather than attenuating the original noise.

In practice, however, stiffening often proves effective, particularly for low-frequency noise, essentially subdividing large-area panels into smaller, stiffer panels and disrupting long wave length vibration and noise and increasing mechanical damping of the system. Thus, for large areas (e.g., sheet metal building walls, noise barrier panels), the addition of stiffening members often reduces vibration due both to structure-borne vibration and airborne noise.
d. Deflectors

Although a type of barrier, deflectors alter the sound radiation path (i.e., re-direct noise propagation). Although the total sound power is not reduced, pressure waves associated with noise are deflected away from sensitive areas. The effectiveness of a deflector is enhanced when it is placed near the source, is large relative to the source, has a transmission loss of 10 dB or more, and is structurally damped to prevent large amplitude structural resonances. Noise barriers can be deflectors and deflectors can and do function as barriers.

e. Vegetation Barriers

Vegetation barriers (foliage of any type) offer nominal effective noise reduction. The noise attenuation of dense foliage ranges from less than 1 dBA to 5 dBA (depending on frequency) per 100 feet of depth. If vegetation barriers are deployed to abate noise, it should be realized that in the autumn and winter, the barrier effect will be significantly diminished by loss of leaves from the deciduous growth.

f. Silencers

The term silencer is used to define any device for attenuating the magnitude and propagation (radiation) of noise in piping and duct systems. In contrast to lagging, which is utilized as an acoustic insulator to absorb piping noise and limit its propagation into the surrounding environments, silencers are normally used to control the propagation of generated noise inside a flow system (e.g., exhaust system, piping) and/or suppress the generation of turbulence noise before it is discharged into the atmosphere. The most prevalent forms of silencers include catalyst silencers on compressor engine exhaust systems, engine intake silencers, noise absorbing duct work, and blow-off silencers (e.g., blowdowns, decompression events, sectional “blocking” discharges during pigging). The vast majority of silencers are passive devices that merely suppress noise at the terminus of a system; any internal generation of noise due to high velocity flow, turbulence, or hydraulic behavior within the silencer is of trivial concern.

Exhaust and intake noises normally constitute the most severe noise sources on reciprocating compressor engines. The design and utilization of an effective exhaust and intake system can, therefore, be a central consideration in controlling compressor station noise. In the development of an optimal silencer design, it is impossible to predict performance of a muffler (noise reduction and back pressure) without considering the entire acoustic system comprising the exhaust (or intake) piping system, and precise specification of the engine noise spectrum (frequency and relative amplitudes). Since the muffler is usually but one part of the piping making up the exhaust system, the designer must also define the acoustic impedance properties of the exhaust manifold and exhaust piping before the effectiveness of the exhaust system in reducing noise can be predicted or optimized. Accordingly, a “one size fits all” approach to selection of silencers is inappropriate.

Intake and exhaust noise from internal combustion engines usually contains pure tone components harmonically related to cylinder firing frequency and broadband noise generated by
aerodynamic turbulence through valves, regulators, and inductance and exhaust piping systems. Compressor engine noise is dominated by low-frequency periodic noise, and it is this noise that is most difficult to suppress.

This predominating low-frequency noise is normally below 500 Hz for pipeline engines and often peaks in the octave bands with center frequencies between approximately 60 to 125 Hz center frequencies. Because of the inability of absorbing walls and noise barriers to effectively absorb low-frequency noise, engine silencers are a major consideration in abating compressor station noise.

g. **Isolators (Dampers, Resilient Mounts, Snubbers, Etc.)**

Isolators are a group of noise abatement devices that either absorb or decouple the transfer of energy from one point to another. Isolators will normally refer to vibration isolators and as such include mounts or supports designed to prevent the transmission of equipment-generated or structure-borne energy into the adjacent flooring, walls, or ground.

Vibration control includes both vibration isolation, which is used to decrease the transmission of vibration from one structure to another, and vibration absorption, which decreases the vibration level of a given piece of equipment. The acoustical necessity for such control arises when vibrations cause a subassembly, adjacent component, or nearby structure (wall or panel) to vibrate, and as a result, radiate noise into the area.

On large compressor units, vibration isolation is increased by placing the unit on a separate foundation isolated from the main building foundation with resilient dampers. This approach generally reduces vibration except for that transmitted through the piping and piping supports and vibration transmitted through the ground. Vibration isolating treatments decouple vibration energy from adjacent structures that might radiate noise. The most common example is vibration mounts utilized independently or in conjunction with separate equipment foundations for machine support. Such mounts should combine the properties of resilience and viscous damping with two objectives: (1) decouple the noise radiators (panels, etc.) from the source of vibratory energy, and (2) limit vibration resonance frequency amplitude.

h. **Altering the Sound Field (or Path)**

The concept of altering the sound field includes interventions or modifications that produce changes in the field without altering the source or receiver. This includes, but is not limited to, the addition of absorbing material to decrease reverberation, construction of barriers and deflectors, including earthen berms, and the use of vegetative barriers – the latter of which is primarily to counteract the psychological preconditioning influencing community perceptions of noise.

In 1992, the Interstate Natural Gas Association of America Foundation, Inc. (INGAA) commissioned a report to review noise legislation and investigate noise control technology applicable to the natural gas transmission industry. The resultant *Gas Compressor Industry Noise Regulation and Control Review Handbook* (the Handbook) was developed to assist INGAA members with “noise-related decision-making issues.” The Handbook summarized state, local, and federal regulations (as of May 1992); collated “information concerning noise-source specifications and control technology”; and presented the results of an industry questionnaire, the purpose of which was to “obtain a more realistic idea of problems experienced by the gas industry in attaining specific noise levels, as well as to determine what types and techniques of noise control are in use by the industry.” *Id.* at 1-1. The Handbook incorporated an appendix of noise control reference materials.

EE contacted all “lower 48” states and the District of Columbia regarding enforceable noise legislation; “enforceable” refers to “measurable noise as opposed to nuisance noise, which is not measured” – an interesting contradistinction. In 1992, nine state governmental agencies had enforceable noise regulations; West Virginia was not among them. Most of the regulations governed noise based on land use or zoning designations. *Id.* at 2-1 and 2-2.

According to the Handbook, “local noise ordinances are not typically tracked by state agencies.” The Handbook determined, in consultation with an expert on community noise standards, that “[b]ecause of the large number and ever-changing nature of local noise ordinance, any prepared summary would probably be inaccurate before it could be published.” *Id.* at 2-2.

EE also reviewed noise information from USEPA, HUD, and FERC. USEPA only issues noise guidelines; it does not enforce noise control. HUD has “acceptable” noise standards that do not affect compressor station operation. “FERC is the only agency that specifically regulates noise emitted from gas compressor stations.” *Id.; see also § C, supra.*

The Handbook defines a “community noise source” as “one which [sic] radiates perceivable sound continuously or cyclically, such as a compressor.” Four community noise sources “present at gas compressor facilities” are specifically identified, among “many potential community noise sources present at gas compressor facilities,” including:

- Heat Exchangers
- Heater-Treaters
- Regulators
- Compressors

Each of these community noise sources is independently discussed in the Handbook:

a. **Heat Exchangers**

Most noise is generated by the heat exchanger fan, which produces a broad band [sic] sound spectrum with a broad low frequency peak. The most effective noise-control treatment is to choose a fan with a good aerodynamic profile. Another effective treatment is minimization of blade loading per unit length, which can be accomplished by increasing the number and length of blades and/or reducing the fan speed. The motor and/or fan drive transmission may also produce unwanted noise. This can usually be controlled by enclosing the unit(s) in an acoustically lined housing.

In addition to treating noise-producing portions of a heat exchanger, it must also be remembered that any piping attached to the unit or any mechanical connection to structural members will act as a conduit to allow noise to travel away from the unit and manifest itself elsewhere in the facility. Lagging\(^\text{24}\) should be installed on piping and care should be taken to avoid mechanical connections between the pipe wall and structural members. Mechanical connections between the heat exchanger and structural members, including the ground, should be minimized. Connections should be isolated from the structure itself following vibration isolation procedures.

*Id.* at 3-2 and 3-3 (emphasis added).

b. **Heater-Treaters**

Heater-treaters are not major noise sources ....

*Id.* at 3-3.

c. **Regulators**

Regulators are used at several locations within the gas compressor facility boundaries. The pressure-reducing process causes high frequency noise to be produced. The most cost-effective method of control is to enclose the regulator(s) in an acoustically lined housing. Any inspection panels/doors must be tight fitting to preclude the transmission of noise produced by the regulator.

d. **Natural Gas Compressors**

Compressors are the dominant noise source present at gas compressor facilities. There are two basic types of compressors, reciprocating and centrifugal ....

\(^{24}\) Thermal or acoustic insulation/isolation, respectively, of piping. Pipework can operate as a conduit for noise to excursion from one part of a building to another. Acoustic insulation can prevent this noise transfer by acting to damp the pipe wall and acoustic decoupling wherever the pipe passes through a fixed wall or floor and wherever piping is mechanically fixed. Pipework can also radiate mechanical noise. In such circumstances, the breakout of noise from the pipe wall can be achieved by acoustic insulation incorporating a high-density sound barrier.
This positive displacement type of compressor is generally used for smaller volumes and when high compression pressure is required. The unit typically operates at slower speeds than centrifugal units. Many units are integral – the compressor and engine are on the same frame. The sound spectrum attributable to reciprocating compressor operation is generally in the lower frequencies. The unit’s massive casing, however, provides considerable sound transmission loss.

One noise-control technique is enclosure of the unit in an acoustically lined housing. Because of the low-frequency sound produced, it is very important that any enclosure be airtight and that all inspection covers and doors be tight fitting to prevent noise transmission. Bear in mind that additional cooling may be required for the enclosed unit and any penetrations must also be airtight. All cooling air intakes and exhausts must be acoustically treated to avoid the escape of sound to the outside.

Attention must also be directed to structure-borne noise. This can be controlled through the use of vibration isolation techniques. Vibration isolation must also be performed on any piping attached to the compressor. Lagging should be installed on piping and care should be taken to avoid mechanical connections between the pipe wall and structural members.

e. Compressor Buildings

Sound produced by compressors and drive engines within a building can be magnified by building acoustics and by the physical placement of the equipment.

To prevent the establishment of a reverberant field in the building, walls and ceilings should be acoustically lined. As is the case with acoustic equipment enclosures, doors, windows, and penetrations should be adequately sealed to prevent the escape of interior noise.

Buildings should be situated or acoustically treated to prevent them from ... directing radiated noise toward the adjacent community.

3. Environmental Noise Assessment and Control for Compressor Stations (2001)

By virtue of the extreme sound power levels associated with compression equipment, there is ... no such thing as a compressor installation that is free of environmental noise concerns. Typically, the sound power produced by an unsilenced [sic] gas turbine, for example, is on the order of a thousand times greater than other common types of industrial sources of sound. The potential radius of environmental noise impact of a compressor station, depending on the degree

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of noise control included in the design, can range up to several miles. Thus, even for the most remote compressor installations, there are usually one or more sound sensitive receptors ... Accurate noise assessment and effective noise control are essential in allowing a compression facility to co-exist in harmony with surrounding land uses.\(^{26}\)

a. Environmental Sound Emission Limits

Acceptability limits for environmental noise emissions vary from jurisdiction to jurisdiction. In general though, the principle upon which environmental noise limits are premised is that of avoiding disturbance or annoyance to neighboring residents.

The onset of adverse noise impact, as evidenced by demonstrable loss of enjoyment of property and concerted community reaction to noise, occurs at much lower sound levels (e.g., often on the order of 40 to 50 decibels) than the onset of the risk of hearing loss (80 to 90 decibels).

These factors emphasize the importance of considering noise impact early in the design process of a new compressor facility, or a contemplated expansion. The need for an environmental noise assessment of an existing facility may be triggered by:

- Requirements for a baseline study in anticipation of an expansion;
- In response to complaints over existing noise emissions;
- As an acoustic performance qualification with regard to contractual responsibilities for newly installed equipment; or
- To satisfy regulatory requirements for periodic acoustical auditing.

*Id.* (emphasis added).

b. Sound Sources and Mitigation

[T]he dominant sound source is usually the engine. In order of significance, the engine sound is comprised of the exhaust noise, the intake noise (in the case of a turbine engine) and the casing radiated noise. Since most compression equipment is housed indoors or inside some type of enclosure, the sound radiated by the engine casing is typically an environmental issue ... insofar as the sound transmits through the walls of the enclosure and through ventilation openings.

Compressor sound is also carried out through the suction and discharge piping and will re-radiate through the walls of any above-ground [sic] piping. For several reasons discussed here … for many modern compressor stations.

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\(^{26}\) *Id.* at 42.
Other secondary sources of sound include noise radiated from exposed exhaust and intake ductwork, and ancillary equipment such as oil coolers and gas after-coolers, and occasional activities such as blow-downs, purges, and bleed-valve venting during startup.

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1. Improved Exhaust Silencers. Another major advance in controlling noise emission from compressor facilities has been a growing understanding of the acoustical characteristics of exhaust silencers ...

While it has been long recognized that the elevated temperatures in a gas turbine exhaust stack result in longer wavelengths of sound than at room temperature (due to the increased speed of sound), it is only recently that work has been done to understand the effects of the high temperatures on the acoustical properties of the sound absorbing media. The results of this work have revealed that, at higher temperatures, absorptive silencers generally provide less low frequency absorption and more high frequency absorption than at room temperature.

2. Quieter Cooling Fans. [T]here have been recent improvements in fan blade design that have allowed significant reductions in fan generated noise emissions. Aerodynamically designed ‘high-solidity’ fan blades offer significant increases in airflow efficiency, such that the necessary rotational speed of the fan to move a given quantity of air can be reduced.

[L]ower speed fans generate considerably less noise.

3. Optimized Acoustical Pipe Lagging. The most common method of controlling pipe-radiated noise is ... ‘acoustical lagging.’ The Pipeline Research Committee of the American Gas Association commissioned a study in 1998 to investigate thoroughly and optimize the acoustical performance of pipe lagging systems.

• [A]t low frequencies (below about 200 Hz), ... lagging actually amplifies the sound radiated by the pipe, for virtually all pipe diameters and lagging configurations. [L]agging is only effective for controlling high frequency sound … but not low frequency ... turbulent flow noise.

• The noise reduction possible through acoustical lagging is limited by the fact that the wrapping makes contact with the pipe surface. If more than about 30 decibels of noise reduction is required overall ... other means of mitigation may need to be considered (e.g., enclosing the piping with a structure that does not touch the pipe surface, or burying the pipe).

[P]iping radiated sound is the primary residual source of environmental noise emission at many otherwise well-silenced compressor installations. [I]t is important to recognize that the sound typically radiated from above-ground piping is tonal ... (composed of an identifiable pitch ... ), and is therefore generally more audible and disturbing to offsite receptors than ... ‘broadband’ sounds …
The perceived sound level near any given section of pipe may not seem excessive, when considered in conjunction with the size of the radiating surface, thus apparently modest sound level can represent a large amount of total radiated sound power.

Some sources which are located high above ground level, or which have upwardly directive characteristics, such as the exhaust stack, may tend to sound less significant at ground level than other essentially innocuous sources.

[O]ff site receptors ... may also be shielded from the ground level sources by intervening topography, buildings or brush ....

*Id.* at 46.

c. Modern Acoustical Measurement and Analysis

Whether the overall station sound level meets a sound level limit at a receptor ... does not assist in determining which of the station components contribute most to the overall sound level.

The term, ‘sound intensity’, refers to the flow\(^\text{27}\) of acoustic energy outwards from a sound source. Unlike a simple microphone, such as those connected to traditional sound level meters, a sound intensity probe measures both the magnitude and the direction of the propagating sound.

Sound intensity methods are an indispensable tool in conducting a modern environmental noise assessment for a compressor station because the significant sound sources are located close together and cannot be operated in isolation from one another.

Once the sound power levels of all of the major sound sources have been accurately quantified, the measurement data can be used in conjunction with predictive modeling methods to determine the contribution of each source to the overall sound levels at the residences. The International Standards Organization (ISO) has recently published a standard prediction method for modeling outdoor sound propagation, knowing the sound power levels of the significant sources, the topographical information between the sources and the receptor locations, and the prevailing meteorological conditions in the vicinity.

*Id.* at 47.

d. Summary

The technology exists, both in regard to measurement techniques and mitigation methods, to control environmental noise emissions effectively from gas compression facilities.

\(^{27}\) Technically, “propagation,” which are the directional characteristics of the noise source. It is also important to determine whether the source of noise is a point source, line source, or line source of infinite length.
Without proper noise control measures, the considerable sound power associated with compression equipment has the potential to create adverse environmental impact at a significant radius of up to several miles. Proper utilization of the available means of noise assessment and control are critical in responsible operation of a modern compressor installation.

_Id._ at 47-48.


The intention of the *Compressor Station Piping Noise* report is to provide a more thorough understanding of the mechanisms that create audible noise from within the compressor station piping and available methods of predicting pipe flow noise apart from the machinery produced noise at a station. Nevertheless, the report addresses the influence of non-piping-related equipment (e.g., compressor engines) to piping-generated noise, which is a noise source that is deceptive and difficult to control. Various methods are described to identify abatement measures for the control of noise from compressor station piping and avoid operational deficiencies through proper piping design.

Consistent with general industry practices, which are largely reactive to noise complaints, the report observes:

_At present, noise measurements and analysis of the compressor station is an “after the fact” scenario._ Acoustic barriers, piping insulation, buried piping, diffusers, and silencers are used to reduce noise. Often, the noise issue is addressed ... after start-up, although this could be part of the compressor station design effort.

_Id._ at 1.

Accordingly, “best industry practices” are largely post-design and construction countermeasures implemented to abate noise. Although, “[a]s part of a station design project, it should be possible to avoid major noise issues through resonance avoidance, design mitigation for reducing turbulent, flow-induced excitation, and vibration controls in specific areas.” _Id._

The report recognizes an important principle in noise generation at compressors stations: “Noise ... can cause an object such as a pipe wall to vibrate. This vibration can be a forced response, which tends to vibrate at relatively low amplitudes, or the vibration can manifest itself as a resonant response, in which the noise related vibration of the pipe wall can be much louder.” _Id._ at 15. This general principle also explains why residents near a compressor station may complain about vibration; such vibration is not ground-borne vibration, but rather noise can cause objects such as windows in residences to vibrate.

Noise is generated by turbulence of the gas moving under varying degrees of pressure within piping. Noise outside of the pipe can also be induced by the movement of the pipe wall,
which may be vibrating due to the turbulent flow inside of the pipe. Just as important is excitation from mechanical sources, such as compressor engines, particularly if mechanical sources are mechanically coupled with piping. Regardless, the vibrations of the pipe wall themselves cause additional noise in the system, which noise component can be greater than the noise produced by internal turbulence alone. *Id.* at 23.

Another mechanism for excitation of resonance in piping systems, in addition to mechanical coupling, is the consequence of compression machinery, which introduces cyclical pulsation into the fluids and gases during the compression process. This type of excitation specifically occurs for reciprocating compressors. Pulsation-related noise is amplified when the compressor excitation frequency corresponds to the acoustic resonance frequency in the piping system. The resonance can create high-magnitude noise, which does not dissipate due to its low frequency content. *Id.* The report states, “This can be avoided through careful design of the acoustics within the system.” *Id.* The critical frequency range tends to be less than 300 Hz for reciprocating compressors.

Noise in the low frequency spectrum is especially difficult to control, particularly if panelized noise barriers are primarily relied upon as a noise countermeasure.

Transmission loss (desirable) through a panel is dependent on the frequency range of interest and the material composition of the panel. Transmission loss is the ratio of transmitted noise intensity to the original noise intensity. The characteristics will change if the panel is double-walled or if the material of the panel is not homogenous. Transmission loss will be controlled more by stiffness of the panel at low frequencies. Above the first fundamental frequency of the panel, transmission is modulated by resonance but increased panel mass will increase the transmission loss (*i.e.*, diminish noise transmission).

Noise barriers and enclosures constructed with panels comprised of metal sheeting and an insulating material are common at compressor stations. Noise transmission characteristics depend on the material stiffness, damping, and mass of the metal sheeting, insulation, and the system as a whole. Additionally, the response of a panel and how it transmits noise depends on whether an acoustic or mechanical resonance is excited in the panel. Mechanical excitation will produce radiated noise related to the panel natural resonance frequency. If acoustic excitation occurs (sound waves interact with the panel), the resonant frequencies will transmit noise above the critical frequency of the system. Below the critical frequency, the non-resonant modes of the panel will transmit the majority of the noise (typically low frequency noise) without attenuation.

G. The West Virginia University-Physicians Scientists & Engineers for Healthy Energy Literature Review

*Public health implications of environmental noise associated with unconventional oil and gas development* (Hays 2016) is a review of the scientific literature relating to the adverse health effects potentially caused by exposure to noise generated by oil and gas operations authored by

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Hays and Shonkoff are employees of PSE Healthy Energy, a self-proclaimed “scientific research institute that supports the adoption of evidence-based energy policies.” PSE received initial funding for parts of the research from the California Council on Science and Technology. McCawley “is supported by Environmentally Friendly Drilling, a consortium that is jointly funded by government and industry groups.” McCawley is also “supported by grants from the U.S. Department of Energy and has served as a consultant to the state of West Virginia on drilling issues.” The article indicates that McCawley has been retained by the U.S. Department of Labor as an “expert witness in a case involving drilling.”

The WVU-PSE review cites 76 references, the majority of which relate to the potential adverse health effects associated with low frequency industrial noise, generally; however, a few references relate specifically to noise associated with natural gas extraction and transmission, and several references do not pertain to industrial noise. In addition to the 76 cited references, an appendix cites an additional 54 references relating to environmental noise.

1. Abstract

Modern oil and gas development frequently occurs in close proximity to human populations, and increased levels of ambient noise have been documented throughout some phases of development. Noise pollution related to “unconventional oil and gas development” (“UOGD”) is understudied in the public health literature. Data on noise levels associated with UOGD are limited, but measurements can be evaluated amidst the large body of epidemiology assessing the non-auditory effects of environmental noise exposure and established public health guidelines for community noise. The authors reviewed non-auditory health outcomes associated with environmental noise exposure. Potential non-auditory adverse health outcomes associated with noise exposure include annoyance, sleep disturbance, and cardiovascular disease. UOGD produces noise at levels that may increase health risks. Additional noise exposure research related to UOGD is needed. Policies and mitigation techniques that limit human exposure to noise from UOGD should be considered to reduce health risks.

2. Characterization of Noise in the Oil and Gas Industry

Many operations in various phases of oil and gas development produce transient and chronic noise. Although noise pollution has been cited as a primary concern among residents in areas of oil and gas development, few researchers have evaluated noise levels and noise exposure associated with this industry. To date, there have been “only a handful” of reports that have evaluated noise associated with UOGD in the context of public health. The types of noise associated with UOGD can be complex in nature, owing to a wide variety of sources. Some of these noises are intermittent, some are continuous, and many vary in their intensity. Certain
sources, such as compressor stations, produce low frequency noise. There are also numerous source-dependent and subjective factors that may influence health outcomes, such as noise sensitivity, noise reduction technologies, and synergistic effects of noise and air pollution. Further, noise exposure, like other health threats, may disproportionately impact vulnerable populations, such as children, the elderly, and the chronically ill.

Many noise sources from UOGD are similar to those associated with conventional oil and gas development; however, some aspects can differ. Drilling a horizontal well can take 4 to 5 weeks of 24 hours per day drilling to complete; whereas, a vertical well usually takes less than a week. Hydraulic fracturing requires a greater volume of water and higher pressures to stimulate a horizontal well, resulting in more pump and fluid handling noise than traditional operations. However, estimates from certain traditional oil and gas activities that are also relevant to horizontal wells were included because the data are limited.

3. Annoyance

Annoyance is source dependent; accordingly, noise levels alone are not always sufficient to gauge annoyance thresholds. Noise annoyance may produce a host of negative responses, such as anger, displeasure, anxiety, helplessness, distraction, and exhaustion. Noise sensitivity is a strong predictor of noise annoyance, and may also predict the risk of future psychological distress.

4. Sleep Disturbance

Sleep disturbance is a common response among populations exposed to environmental noise. Noise can impact sleep in numerous ways and can have immediate effects (e.g., arousal and sleep stage changes), after-effects (e.g., drowsiness and cognitive impairment), and long-term effects (e.g., chronic sleep disturbance). Noise sensitivity has a significant role in sleep disturbance and is influenced by both noise dependent factors (e.g., character of noise, intensity, and frequency) and other subjective factors (e.g., age, personality, and self-estimated sensitivity). There is a large body of research on sleep and health with variable and controversial results. Because the effects of noise exposure on sleep are dependent on a number of objective and subjective factors, it is difficult to determine a clear dose-response relationship; however, review of evidence produced by epidemiological and experimental studies have identified relationships between noise exposure at night and adverse health outcomes.

According to the World Health Organization, there are no adverse effects on sleep at exposures less than 30 dBA $L_{\text{night}}$ ($L_n$), and there is insufficient evidence to indicate that the biological effects observed below 40 dBA $L_n$ are health hazardous. Adverse health effects (e.g., self-reported sleep disturbance, insomnia, and increased use of medications) are observed above 40 dBA $L_n$. Levels exceeding 55 dBA $L_n$ present a major public health concern.

5. Cardiovascular Health

Noise can trigger emotional stress reactions from perceived discomfort as well as physiological stress from interactions between the auditory system and other regions of the
central nervous system. Exposure to noise can increase systolic and diastolic blood pressure, create changes in heart rate, and cause the release of stress hormones. Studies have found positive correlations between chronic noise exposure and elevated blood pressure, hypertension, ischemic heart disease, and cerebrovascular accident. Systematic and quantitative reviews have collated and synthesized evidence of the relationship between noise exposure and cardiovascular disease, and some meta-analyses have developed exposure-response curves that are used to quantify human health risks in health impact assessments.

6. Epidemiological Literature Specific to the Oil and Gas Industry

There is currently no peer-reviewed literature related specifically to noise levels and potential adverse health effects from noise exposure related to oil and gas development.

The main sources of noise from oil and natural gas operational activities can be grouped into the following two categories: (1) construction and preparation (e.g., road construction, site preparation, and truck traffic), and (2) production and completion (e.g., flaring operations, drilling, hydraulic fracturing, and compressor stations). The report summarizes noise measurements and estimates from environmental impacts statements and other reports; however, the review acknowledges that the measurements are not necessarily commensurate because of the heterogeneity of sources of noise, measurement distance, measurement methodologies, nature of oil or gas operations, etc., and that many of the reported data are estimates – not actual measurements.

The report references McCawley (2013), a report prepared for the West Virginia Department of Environmental Protection, which monitored noise levels during various states of development from a few sampling sites situated 625 feet from the center of the well pads. Pad preparation was typically noisier than other activities, principally because earthmoving equipment was observed to frequently pass directly adjacent to the noise monitors. Because of this phenomenon, “site setbacks do not necessarily provide the expected attenuation if the source is not located solely at the center of the pad.”

7. Compressor Station Noise

A 2014 pilot study conducted as part of a report prepared for the Maryland Department of the Environment and the Maryland Department of Health and Mental Hygiene monitored resident exposures to noise associated with natural gas compressor stations in West Virginia. The study found an average $L_{eq}$ (equivalent continuous sound pressure level) for the combined compressor stations of 60.2 dBA (range 35.3 to 94.8 dBA) and an average short term (period unspecified) $L_{eq}$ of 61.4 dBA (range 45.3 to 76.1 dBA). Both average $L_{eq}$ and the average short term $L_{eq}$ decreased with distance from the compressor stations.

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30 Outliers facially influence the reported averages, and it would be informative to determine the central tendency of the data.

31 This observation is approximately consistent with the rule of inverse square – for every doubling of distance an ~ 6 dBA reduction in noise level ordinarily occurs.
8. Potential Health Outcomes from Unconventional Oil and Gas Development Noise

The health literature on noise exposure considered, together with noise levels associated with oil and gas operations, suggests that noise from UOGD presents a risk for potential adverse health outcomes. This finding is consistent with other studies and reports that consider potential health threats of noise exposure in the context of oil and gas development. Oil and gas operations produce sound level measurements and estimates that could lead to all three of the non-auditory health outcomes considered in this review.

There is a more significant risk for annoyance and sleep disturbance because these outcomes generally occur at lower noise thresholds. Although hypertension and cardiovascular diseases are associated with higher average noise levels than annoyance and sleep disturbance, many sources of noise from oil and gas operations produce noise levels known to be associated with these outcomes. Most oil and gas activities are not permanent, so there may be less of a risk for cardiovascular health outcomes, which are associated with chronic and continuous noise exposure; however, some sources do generate chronic noise post-completion (e.g., compressor stations).

9. Co-Morbidity and Co-Exposures

“Light pollution” resulting from nighttime UOGD may constitute an additional stressor and potential health hazard. Evidence suggests that light at night may impact health by disrupting normal circadian rhythms and altering melatonin and other hormone releases.

10. Low Frequency Noise

Some oil and gas operations generate low frequency noise (LFN) (e.g., compressor stations), but few data are available. LFN is not clearly defined and presents challenges for regulation based on conventional methods of assessing noise. LFN is generally described as noise below 100 Hz and at “infrasound” frequencies (< 20 Hz). Humans may complain about “pressure” or describe, “feeling the noise” as a consequence of infrasonic exposures.

According to the WVU-PSE article, the association between exposure to LFN and adverse health outcomes has not received as much attention in the scientific literature as compared to higher frequency noise measured by traditional A-weighted bands. However, the WHO has suggested that LFN may considerably increase the adverse effects of noise exposure. Exposure to LFN has been associated with sleep disturbance, annoyance, and other secondary health effects. Residential exposure to LFN may even be a greater problem than noise measured in the normal frequency range given that most walls in buildings and homes do not attenuate LFN. Some evidence suggests that A-weighting may underestimate the level of annoyance experienced by exposed populations.

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32 Infrasonic noise is noise below the human auditory threshold – optimally 20-20,000 Hz in a young, healthy person.

33 This is a correct and important observation that applies equally to noise countermeasures such as noise barriers, enclosures, and acoustically insulated building curtain walls.
11. Limitations

The report acknowledges the following significant limitations:

a. Noise data from actual oil and gas operations are very limited and most are based on *estimations* rather than actual field measurements.

b. It may be difficult to assess the potential health outcomes associated with LFN from oil and gas operations due to a lack of data and because traditional A-weighting may underestimate the prevalence of particular adverse health outcomes (e.g., annoyance) that may be related to LFN.

c. Some noise level thresholds tabulated in Table 2 of the report may not adequately reflect the current science on health outcomes associated with environmental noise exposure.

d. Due to the psychological dimension of noise exposure, the relationship between the source and the exposed individual can vary dramatically. Individual variation presents a high degree of uncertainty for most potential health outcomes associated with noise exposure.

12. Research and Policy Considerations

The report proposes the following “research and policy initiatives”:

a. There are a number of factors that should be taken into account when assessing health risks from oil and gas operations noise. These include the distance of populations from oil and gas operations, mitigation techniques, and subjective differences in noise sensitivity among individuals.

b. The majority of populations living in communities with active oil and gas development may not experience noise levels commensurate with those referenced in the report, depending on the siting of oil and gas operations, topography, and infrastructure.

c. There is some evidence that oil and gas operations produce noise levels that may adversely impact community health. Policies aimed to protect the health and wellbeing of human populations should consider noise levels when determining minimum surface distances between residents and sensitive receptors because noise levels decrease with distance from the source.

d. Some evidence suggests that current setback distances may not be adequate to reduce public health threats.

e. Policies should also require noise mitigation techniques, which are well known and already used by many oil and gas operators. These may include perimeter sound
walls, sound control systems, acoustical enclosures and buildings, and the use of
sound absorbing materials. Natural terrain can also play a role in mitigation and
where possible pads may be sited to make use of hills, trees, and other natural objects
to reduce exposure. Significant restrictions on nighttime operations should be put into
place in order to minimize sleep disruption.

f. Maximum allowable noise levels should take into account location and sensitivities of
surrounding populations. Both the nature and duration of noise are relevant to
potential health outcomes. Many of the noise levels associated with unconventional
oil and gas development are transient and only occur during certain development
activities.

g. Certain adverse health outcomes usually only result from long-term noise exposure
and may be less of a concern with most development activities; however, some
sources, such as compressor stations, produce chronic noise that will continue for
years after wells are in production.

h. More research is needed to clarify noise exposure from unconventional oil and gas
development as a potential health risk. Campaigns to measure noise levels from
unconventional oil and gas development activities should be undertaken to inform
policies and to protect public health. Cohort or longitudinal studies should be
developed to address the question about causal links between unconventional oil and
gas development noise and adverse health outcomes.

13. Assessment of the Quality of the Methodology of the WVU-PSE Literature Review

The review is not a systematic literature review, as that term is used in the science of
epidemiology, but rather, essentially a recapitulation of the conclusions of the original research
cited. No generally accepted criteria for the identification and evaluation of the quality of the
relevant literature are described,\textsuperscript{34} including, but not limited to, evaluation of the following
parameters:

- Detailed description of search criteria;
- Description of inclusion/exclusion criteria;
- Evaluation of whether the original research is contemporary;
- Evaluation of the quality of study design;
- Study quality (\textit{i.e.}, methodology and execution);
- Evaluation of study populations and controls;
- Evaluation of the quantification of exposure;

\textsuperscript{34} E.G., Higgins, J.P.T., Green, S. (Eds.). \textit{Cochrane Handbook for Systematic Reviews of Interventions}, Vers. 5.1.0
[updated Mar. 2011]. \textit{The Cochrane Collaboration}, 2011; GRADE (Grades of Recommendation, Assessment,
10.1136/bmj.328.7454.1490; Shea, B.J., Grimshaw, J.M., Wells, G.A., \textit{et al.}, Development of \textit{AMSTAR}: a
measurement tool to assess the methodological quality of systematic literature reviews, BMC Medical Research
• Evaluation of the case definitions (i.e., description of adverse health outcomes of interest according to generally accepted diagnostic criteria);
• Recognition and accounting for confounding variables;
• Recognition of and accounting for actual and potential sources of bias;
• Evaluation of statistical rigor and study power (numbers);
• Assessment of homogeneity of studies (Is a meta-analysis possible or does study heterogeneity preclude meta-analysis?); and
• Application of generally accepted guidelines for the inference of causal associations (i.e., determination of causation).  

H. Conclusions

The referenced noise abatement literature describes numerous engineering interventions calculated to attenuate the noise emissions associated with natural gas transmission compressor station noise emissions. These references may constitute evidence of industry standards of reasonable care for the design and construction of natural gas compressor stations to control community noise. The principal noise countermeasures currently implemented by midstream operators include noise barriers, equipment enclosures, exhaust and decompression silencers, noise attenuating intake ductwork, and acoustical insulation of compressor station structures, typically retrofitted at compressor stations in response to noise claims. Vulnerabilities include site selection, facility orientation, “reactive” implementation of noise abatement technology, nominal isolation/decoupling interventions, and potential materials selection for noise barriers and acoustic insulation.