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Noise control
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BLAST NOISE STANDARDS AND INSTRUMENTATION

by

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Bureau of Mines Environmental Research Program

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BLAST NOISE STANDARDS AND INSTRUMENTATION

by

David E. Siskind[1] and Charles R. Summers[2]

ABSTRACT

A Bureau of Mines survey of noise from quarry production blasting was conducted at seven crushed-stone quarries, providing information on close-in noise generation, comparative instrumentation, and evaluation of the sound levels as related to blasting parameters and existing State and local noise standards. The results from this preliminary survey will be useful in the design of a complete investigation of the problem of noise from blasting. There exists an immediate need for technical guidelines for noise pollution control agencies presently working on the regulation of impulsive noise sources. This survey and results from previous work by other researchers are used to derive interim recommendations on weighting scales, generated sound levels, and instrumentation. These recommendations are based on the limited data presently available and may be modified with subsequent investigation of noise generation, propagation, structural damage, and human tolerance.

INTRODUCTION

Air vibrations from blasting are being investigated as Federal, State, and local agencies consider legislation to control general noise pollution, and the Bureau of Mines has received numerous requests for assistance from State governments and explosive users' associations. Previous work, including Bureau of Mines Bulletin 656, established thresholds of damage applicable to glass breakage and residential structures (5-6).[3] However, the surface mining and quarrying industries consider their minimum impulsive damage threshold of 0.75 psi overpressure (168 db re 20 $\mu N/m^2$) and the recommended safe standard of 0.50 psi (165 db) unreasonably high. In addition, environmental protection agencies are presently considering legislation based on factors of human tolerance, and are suggesting maximum noise levels considerably lower than the structural damage threshold.

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[1] Geophysicist.

[2] Physicist.

[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

The general problem of airblast damage and annoyance involves many physical and psychological factors, including those of sound generation, propagation, and incidence. This preliminary investigation was limited to close-in noise generation from seven quarry production blasts at six quarries with known blast design parameters. Measurements were made within line-of-sight of the blast and near the property line or on the property of each quarry.

Recommendations made in this report are based on the results of this survey and previous airblast work. They are intended to provide realistic interim guidelines for blast noise standards and standardized measurement techniques, pending a complete study of the airblast problem.

ACKNOWLEDGMENTS

The authors wish to acknowledge the very capable assistance of the agencies, consultants, and quarry operators who contributed to this survey. Equipment and technical expertise were provided by Dennis A. Clark and Bill Kennedy of Vibration Measurement Engineers, Edward J. Walter, Jr., of Vibra-Tech Associates, Greg Zak of the Illinois Environmental Protection Agency, and Dennis C. Lyngass and Dan Bakk of the Cook County Department of Environmental Control (DEC). Valuable assistance was also given by Don Simpson and Lester Glynn of the Illinois State Department of Mines and Minerals, and George Svec of the Pittsburgh Mining and Safety Research Center.

PREVIOUS INVESTIGATIONS

The Handbook of Noise Measurement (7) lists continuous sound levels that cause public reaction, with 45-55 dbA[4] giving sporadic complaints and 50-60 dbA causing widespread complaints. Corrections are added to these values including +5 db for working hours only, -5 db for impulsive character, +25 db for very short duration (less than 15 sec), and +10 db for neighborhood classification (urban near some industry). The complaint threshold and widespread discontent values thus become 80-90 dbA and 85-95 dbA, respectively. The handbook notes that the Department of Labor through OSHA (Occupational Safety and Health Administration) allows noise levels of 90 dbA for an 8-hour day and a maximum of 115 db for up to 15 minutes, for hearing conservation. OSHA regulations also specify a maximum impulsive noise level of 140-db peak for hearing conservation.

A Ballistic Research Laboratories paper by Perkins and Jackson (6) describes an extensive examination of the blast noise problem, including long-range propagation as related to weather conditions, effect of confinement (charge burial), and damage thresholds for plate glass:

Properly mounted strainless glass.....0.75 psi (168 db)
Poorly mounted glass under stress.....0.10 psi (151 db)
Noise from window sash.....0.03-0.05 psi (141-145 db)

[4]All sound level measurements should specify the weighting scales used. Where wide-band recording was made with a flat frequency response over the range of frequencies of the noise, equivalent sound levels (in db) with no weighting-scale designation are given. These are usually called "overpressures" and are sometimes designated dbL, with L signifying linear frequency response.

Large plate glass windows are the structural component most sensitive to airblast damage.

Nicholls, Johnson, and Duvall (5) recommend a safe overpressure level of 0.50 psi (165 db) based on Perkins' highest damage threshold of 0.75 psi for "good quality properly installed glass." Because of the wide range of existing structural conditions in the field, and Perkins' lower damage threshold of approximately 0.10 psi, maximum value of 0.50 psi is unquestionably too high for continuous operation in urban areas for avoidance of both structural damage and widespread annoyance complaints.

Reed (9) examined long-range airblast propagation from nuclear shots and observed an overpressure of 0.24 psi (158 db) which produced much glass breakage. A very low damage threshold of 0.028 psi (140 db) overpressure was postulated from three incidents of breakage of large, single-strength, aged glass panes. Reed notes that in laboratory and limited field exposure tests with sonic booms, it was impossible to break a window pane with less than 0.145 psi (154 db). Other sonic boom investigations have examined glass strength in detail (4) and concluded that there is a low damage probability at the recommended design unit for supersonic flights of 5 lb/ft^2 or 0.035 psi (142 db).

Current investigations of airblast damage are presented as damage probability versus overpressure (9-10, 15), in place of single-value damage thresholds used previously. These analyses presume that, in a large sampling of structures, there exists a wide range of susceptibilities to damage, owing to variations in construction, geology, age, transmission, and generation of both airblast overpressures and ground vibrations. Reed (10) presents a summary of data from large blasts and plate glass laboratory breakage tests, indicating approximate window breakage probabilities of 4×10^{-5} and 3×10^{-3} at 140 and 150 db overpressures, respectively. Another study by Reed (9) examines damage probability versus pane area for a single event (the Medina blast) which resulted in claims for 3,644 broken window panes. Wiggins (15) presents maximum safe overpressures for glass of various thicknesses and sizes. Figure 1, after Wiggins (15) and Reed (10), is a graph of glass damage probability versus overpressure plotted on a log-normal distribution scale. Confidence in the damage prediction below about 0.02 psi is limited because of the small amount of data available. This approach to the airblast and ground vibration problems suggests a finite though small possibility of damage from even infinitesimal blasts.

Many other investigations of the airblast problem have been made, including intensification of sound by topographic channeling (16), structural damage potential resulting from temperature inversion sound refraction (8), wind intensification (2), noise from detonating cord (12), effects of overpressure on human ears (3), relationships between charge confinement (burial) and airblast levels (9, 13), close-in measurement (14), and long-range airblast prediction (6, 11). Much of this work is applicable to the general airblast problem, but incidental to the establishment of interim noise level standards.

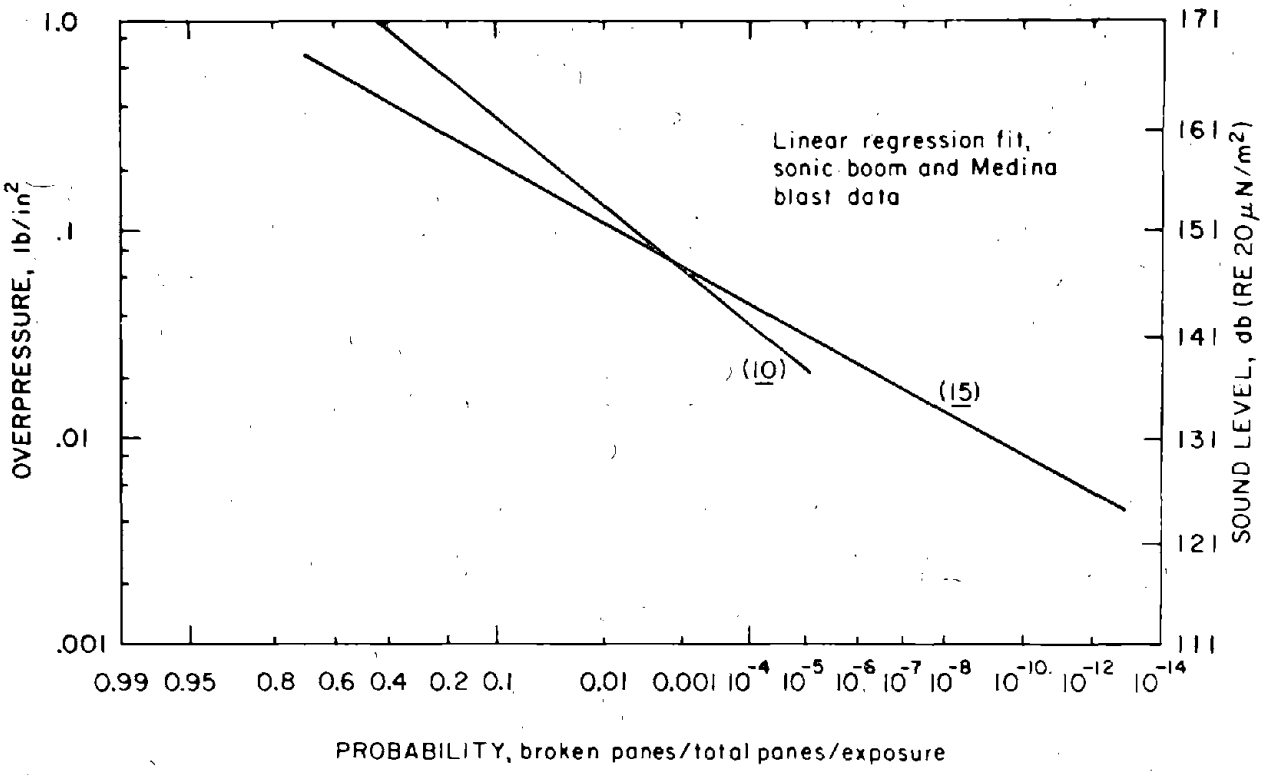

FIGURE 1. - Glass breakage probability, after Wiggins (15) and Reed (10).

INSTRUMENTATION FOR SOUND MEASUREMENTS

Sound level recording techniques and instrumentation are described in detail in two handbooks (1, 7) published by the two major sound equipment manufacturers. Noise-measuring instrumentation should be designed to meet specifications ANSI-S 1.4-1961 (American National Standards Institute) for general sound level meters, IEC - 179 (International Electrotechnical Commission) for precision sound level meters, and the proposed amendment to IEC - 179 for impulse measurement. Recording options include weighting scales (A,B,C,D), linear frequency response, fast and slow time response, and peak sound level and impulse. All sound level readings except those designated "peak" are RMS (root mean square) values. Broch (1) describes the relationships between RMS, average, and peak values. For sinusoidal signals the RMS value is (0.707) times the peak, or lower by 3 db.

Weighting Scales

Figure 2 shows the standardized weighting scales (A, B, and C) for sound level meters designed for steady state as opposed to impulsive sources. Recording can be done with either fast or slow response. The commonly used A scale approximates normal human hearing sensitivity at a sound level of 40 db (re 20 $\mu N/m^2$), and the B scale acts similarly at 70 db. The C scale is occasionally called "flat," but is down 3 db at approximately 35 and 7,000 Hz. "Linear frequency response" of a sound level meter depends on both amplifier

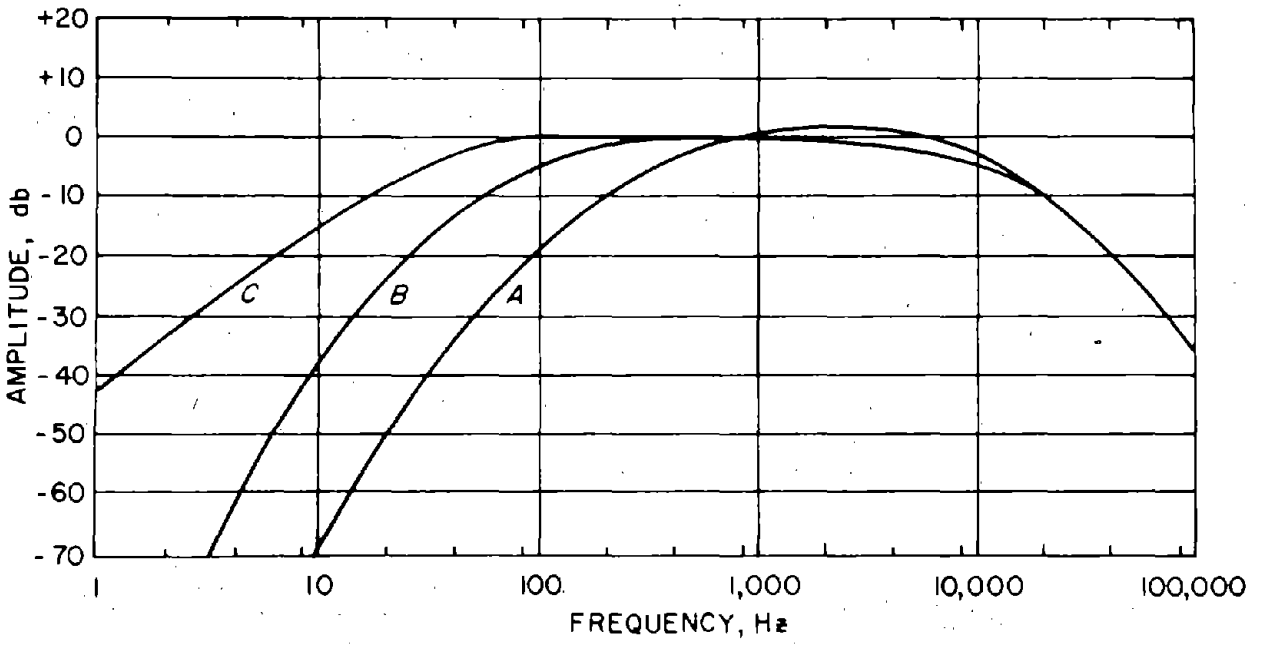

FIGURE 2. - Sound level weighting scales.

and microphone characteristics and is typically 5 Hz to 50 kHz. Some meters have a 20-kc band which is essentially flat from 20 Hz to 20 kHz. The A and B weighting scales were designed to simulate human sensitivity, approximating the 40- and 70-db equal-loudness contours, respectively. For airblast noise of over 100 db (linear), human sensitivity is probably better represented by the C scale.

Frequency Response

Characterization of a sound requires sufficient band width to include all the frequency components of that sound. Airblast usually contains considerable energy below 20 Hz, owing to the large source dimensions. While this low-frequency energy is below the audible range for humans, it cannot be ignored in evaluating damage risk to humans and buildings. These components of blast noise can directly damage structures, also generating higher frequency secondary vibrations in the structure by shaking panels, windows, doors, and anything not firmly attached. Additionally, the low frequencies are noticeable by humans and can cause hearing damage even though the human hearing system does not register the sensation as audible "sound." Consequently, it is necessary to use measuring techniques that are sensitive to all the sound energy present as an alternative to arbitrarily ignoring a large component of the energy. This essentially eliminates the three common weighting scales for blast noise measurements, since they all strongly discriminate against low frequencies.

Impulsive Sounds

Impulsive-type noises cannot be properly measured by simple sound level meters, but require an impulse detector circuit with rapid rise time and microsecond response. Some instrumentation of this type is designed to hold a peak value. In investigations of human response to impulsive noise, it was found that bursts of noise shorter than the ear averaging time (of approximately 50-100 milliseconds) appeared to be less "loud" than steady-state noise of the same overpressure (1).

Wind Effects

Sound level meter microphones must be shielded from high winds, which can produce turbulence and spurious high-level readings. Manufacturers provide spherical foam windscreens which typically reduce wind effects by 20 db; however, low noise level measurements made outdoors are meaningless without wind

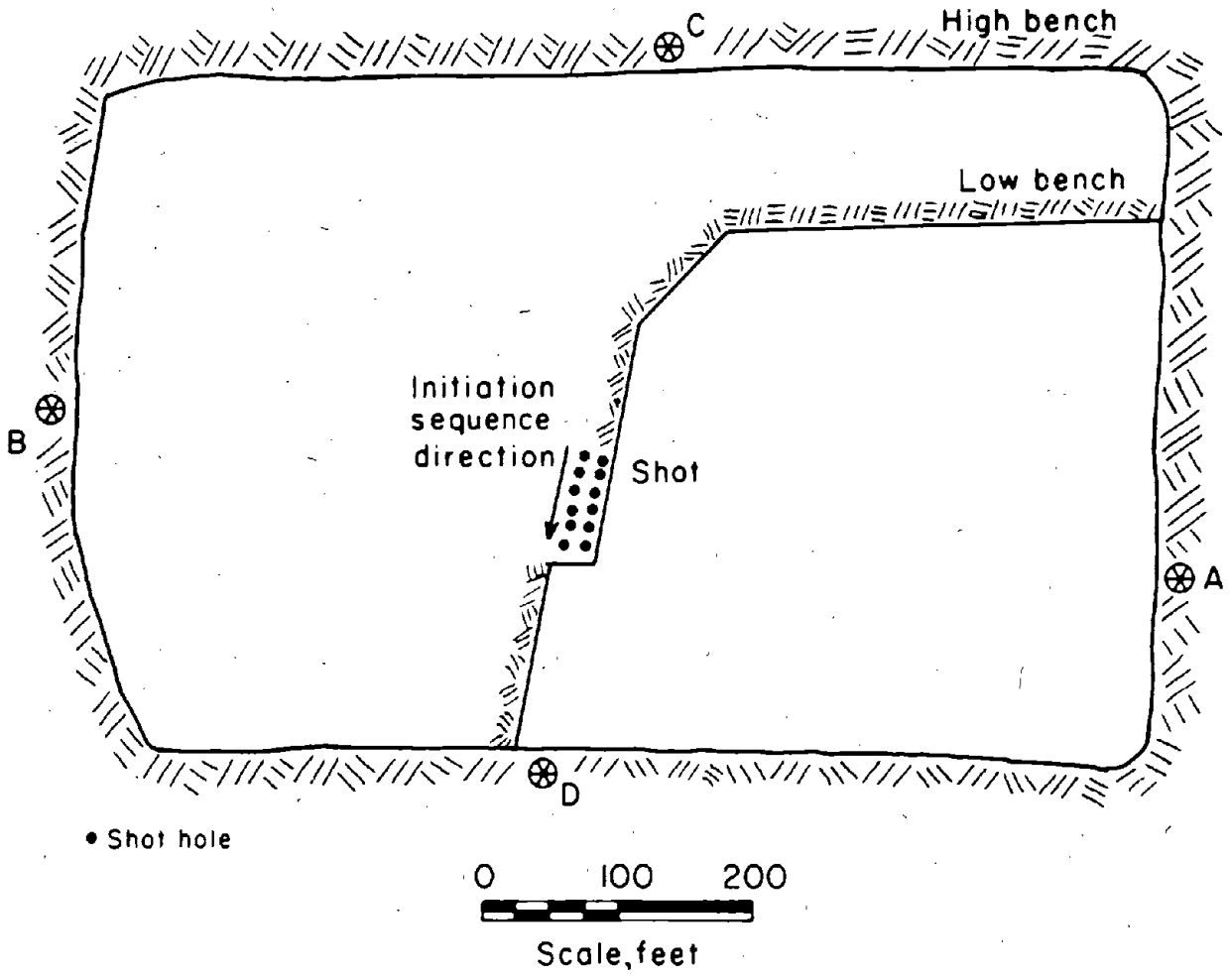

FIGURE 3. - Airblast survey instrument locations, typical quarry.

velocity and direction considerations. An examination of windshielding by one manufacturer found an apparent "sound level" using a 20-Hz to 20-kHz bandwidth of between 92 and 98 db from a 25-mph wind (1). The exact value found was related to the orientation of the microphone and the wind. Using a 5-inch foam sphere on the 1-inch microphone reduced the "sound level" to 73 to 77 db. Outdoor sound level measurements below about 70 db are questionable except under calm wind conditions.

AIRBLAST SURVEY

Sites

Airblasts were measured from seven production shots in six limestone quarries. Four locations were monitored in each quarry, A being directly in front of the face, B behind the face, and C and D away from, and in the direction of, the initiation sequence, respectively. Wherever possible, line-of-sight was maintained between the shot and the recording instrument, with the recording done on the high bench overlooking the quarry pit.

Results

Figure 3 shows the typical experimental setup. Table 1 summarizes the sound level measurements and a few blast parameters. Additional sound level values were obtained from the Bureau of Mines linearly recorded signals at station A, and are discussed in the section on frequency analysis. Shot-to-gage distances were not surveyed and are accurate to approximately ±10 percent. The sound level meter used for each measurement is specified for identification purposes, owing to differing instrument characteristics.[5] A geometric effect was noted from the shot at site 5 with a corner reflection arriving approximately 1 second after the initial blast, and at an 8-db-greater sound level (linear). Both arrivals were felt and measured. The values in table 1 are the highest measured. All the sites, except one, used blastholes between 4-1/2 and 6-3/4 inches in diameter (the exception was 12-1/4 inches) and had either one or two rows of blastholes. Shotholes were decked, and delays were at least 9 milliseconds. Bench heights ranged from 30 to 120 feet. Generally, care is used at these quarries to limit flyrock, vibration, and noise. General wind conditions were noted; however, local topography influenced both wind direction and speed. On-site weather measurements were not made.

[5]Reference to specific brand names is made for identification only and does not imply endorsement by the Bureau of Mines.

TABLE 1. - Sound level measurements, airblast survey

Instrument location	Instrument (B+K:Brüel+Kjaer GR:General Radio)	Agency	Scale used	Reading	Distance, shot to instrument, ft
SITE 1: TOTAL CHARGE WEIGHT, 15,500 LB; CHARGE WEIGHT PER DELAY, 640 LB; WIND TOWARD STATION C AT 15 MPH					
A	B+K 2204/S	BuMines	Linear-peak	124	1,500
	B+K 2204/D	BuMines	C-peak	110	
	GR 1551A/1556	BuMines	A-peak	>90	
B	B+K 2209	BuMines	Linear-peak	119	900
	B+K 2208	Illinois EPA	A-fast-max	79	
C	Vibra-Tape	Vibra-Tech	Linear-peak	123	900
	GR 1933	VME	A-peak	>100	
D	B+K 2204	Cook Co. DEC	Linear-peak	116	1,150
	Model F	VME	C-peak	104	
	GR 1933	VME	A-peak	105	
SITE 2: TOTAL CHARGE WEIGHT, 2,000 LB; CHARGE WEIGHT PER DELAY, 250 LB; WIND TOWARD STATION A AT 25 MPH					
A	B+K 2204/S	BuMines	Linear-peak	133	930
	B+K 2204/D	BuMines	C-peak	125	
	B+K 2208	Illinois EPA	A-fast-max	89	
B	GR 1933	VME	C-peak	No values, due	600
	GR 1551/1556	VME	A-peak	to wind blast	
C	Vibra-Tape	Vibra-Tech	Linear-peak	119	930
	Model F	VME	C-peak	98	
D	B+K 2209	BuMines	Linear-peak	123	780
	B+K 2206	Cook Co. DEC	C-fast	103	
	GR 1551/1556	BuMines	A-peak	85	
SITE 3: TOTAL CHARGE WEIGHT, 2,900 LB; CHARGE WEIGHT PER DELAY, 130 LB; WIND TOWARD STATION B AT 7 MPH					
A	B+K 2204/S	BuMines	Linear-peak	129	420
	B+K 2204/D	BuMines	C-peak	>110	
	B+K 2208	Illinois EPA	A-fast-max	96	
B	GR 1933	VME	C-peak	103	630
C	Vibra-Tape	Vibra-Tech	Linear-peak	127	400
	Model F	VME	C-peak	112	
	GR 1933	VME	A-peak	98	
D	B+K 2204	Cook Co. DEC	Linear-peak	124	200
	B+K 2209	BuMines	C-peak	>100	
SITE 4: TOTAL CHARGE WEIGHT, 8,400 LB; CHARGE WEIGHT PER DELAY, 700 LB; WIND TOWARD STATION C AT 15 MPH					
B	GR 1933	VME	C-peak	117	530
C	Vibra-Tape	Vibra-Tech	Linear-peak	132	2,300
	Model F	VME	C-peak	118	
	GR 1933	VME	A-peak	102	
D	B+K 2204	Cook Co. DEC	Linear-peak	122	1,400
	B+K 2209	BuMines	C-peak	>110	
	GR 1551A/1556	BuMines	A-peak	87	

TABLE 1. - Sound level measurements, airblast survey--Continued

Instrument location	Instrument (B+K:Brüel+Kjaer GR:General Radio)	Agency	Scale used	Reading	Distance, shot to instrument, ft
SITE 5: TOTAL CHARGE WEIGHT, 1,900 LB; CHARGE WEIGHT PER DELAY, 170 LB; WIND TOWARD STATION D AT 20 MPH					
A	B+K 2204/S	BuMines	Linear-peak	>130	670
	B+K 2204/D	BuMines	C-peak	>130	
	B+K 2208	Illinois EPA	A-fast-max	>100	
C	Model F	VME	C-peak	107	670
	GR 1933	VME	A-peak	110	
D	B+K 2209	BuMines	Linear-peak	>120	1,310
	B+K 2206	Cook Co. DEC	C-fast	105	
	GR 1551/1556	BuMines	A-peak	103	
SITE 6: TOTAL CHARGE WEIGHT, 1,357 LB; CHARGE WEIGHT PER DELAY, 100 LB; WIND TOWARD STATION C AT 17 MPH					
A	B+K 2204/S	BuMines	Linear-peak	125	1,760
	B+K 2204/D	BuMines	C-peak	118	
	B+K 2208	Illinois EPA	A-fast-max	86	
B	GR 1933	VME	C-peak	<100	530
	GR 1551/1556	VME	A-peak	84	
C	Vibra-Tape	Vibra-Tech	Linear-peak	136	200
	Model F	VME	C-peak	116	
	GR 1933	VME	A-peak	106	
D	B+K 2209	BuMines	Linear-peak	<120	1,510
	B+K 2206	Cook Co. DEC	C-fast	<110	
	GR 1551/1556	BuMines	A-peak	100	
SITE 7: TOTAL CHARGE WEIGHT, 1,900 LB; CHARGE WEIGHT PER DELAY, 250 LB; WIND TOWARD STATION C AT 25 MPH					
A	B+K 2204/S	BuMines	Linear-peak	120	980
	B+K 2204/D	BuMines	C-peak	108	
	B+K 2208	Illinois EPA	A-fast-max	<81 ambient	
B	GR 1933	VME	C-peak	102	730
	GR 1551/1556	VME	A-peak	75	
C	Vibra-Tape	Vibra-Tech	Linear-peak	120	880
	Model F	VME	C-peak	113	
	GR 1933	VME	A-peak	106	
D	B+K 2209	BuMines	Linear-peak	115	650
	B+K 2206	Cook Co. DEC	C-fast	98	
	GR 1551/1556	BuMines	A-peak	97	

Sound Level Measurements

Figure 4 summarizes all available wide-band airblast measurements, including the current airblast survey. All the points represent peak linear values (with frequency response down to at least 5 Hz) and are scaled to the cube roots of the charge weights in pounds per delay. Much of the data of figure 4 is from a previous

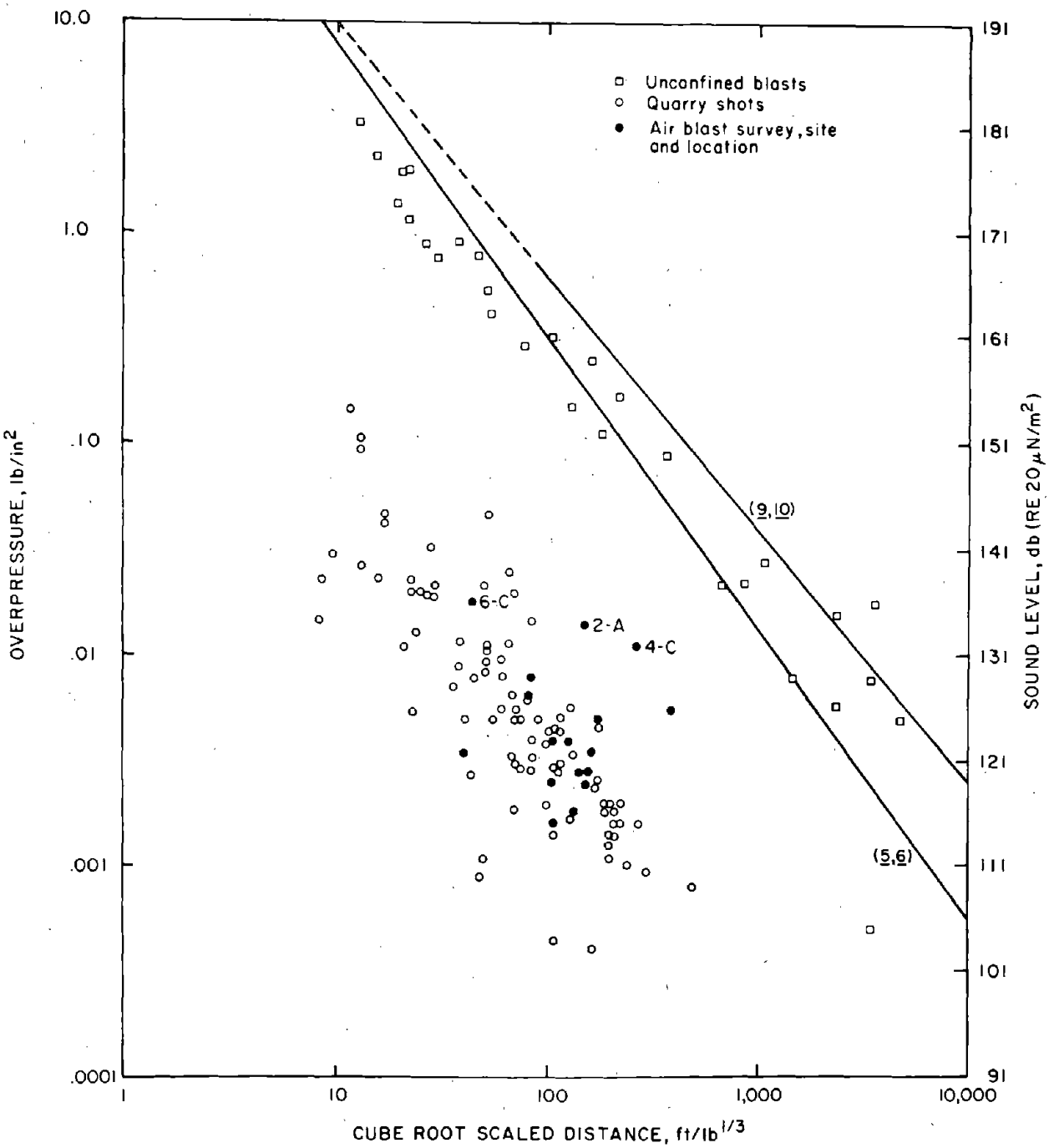

FIGURE 4. - Combined data, airblast sound level measurements.

Bureau of Mines study where airblast measurements were made for 26 blasts detonated at 8 crushed-stone quarries (5). The straight lines represent noise from surface or "unconfined" blasts (5-6, 9-10), with individual surface blast data points from other sources also shown. The airblast data show relatively high scatter. This is due to variable blast design, weather, and topographic conditions, which are not considered by the simple charge weight-distance-sound

level analysis represented by figure 4. Three of the current airblast survey measurements are labeled in figure 4, and represent sound levels greater than 130 db. These relatively high values are partly the result of brisk winds blowing from the shot to the sound level meter, as indicated in table 1. Generally, sound levels were higher in the direction of the wind, although topography (for example, reflections from very high quarry walls) occasionally dominated the propagation effects.

Frequency Spectral Analysis

Airblasts were recorded on tape by the Bureau of Mines at station A for six out of seven of the blasts. These recordings were analyzed in the laboratory for frequency content and the filtering effects of the weighting scales for comparison with the direct measurements. A wide-band seven-channel FM tape deck was used having a dynamic range of 20 db. Input was through a

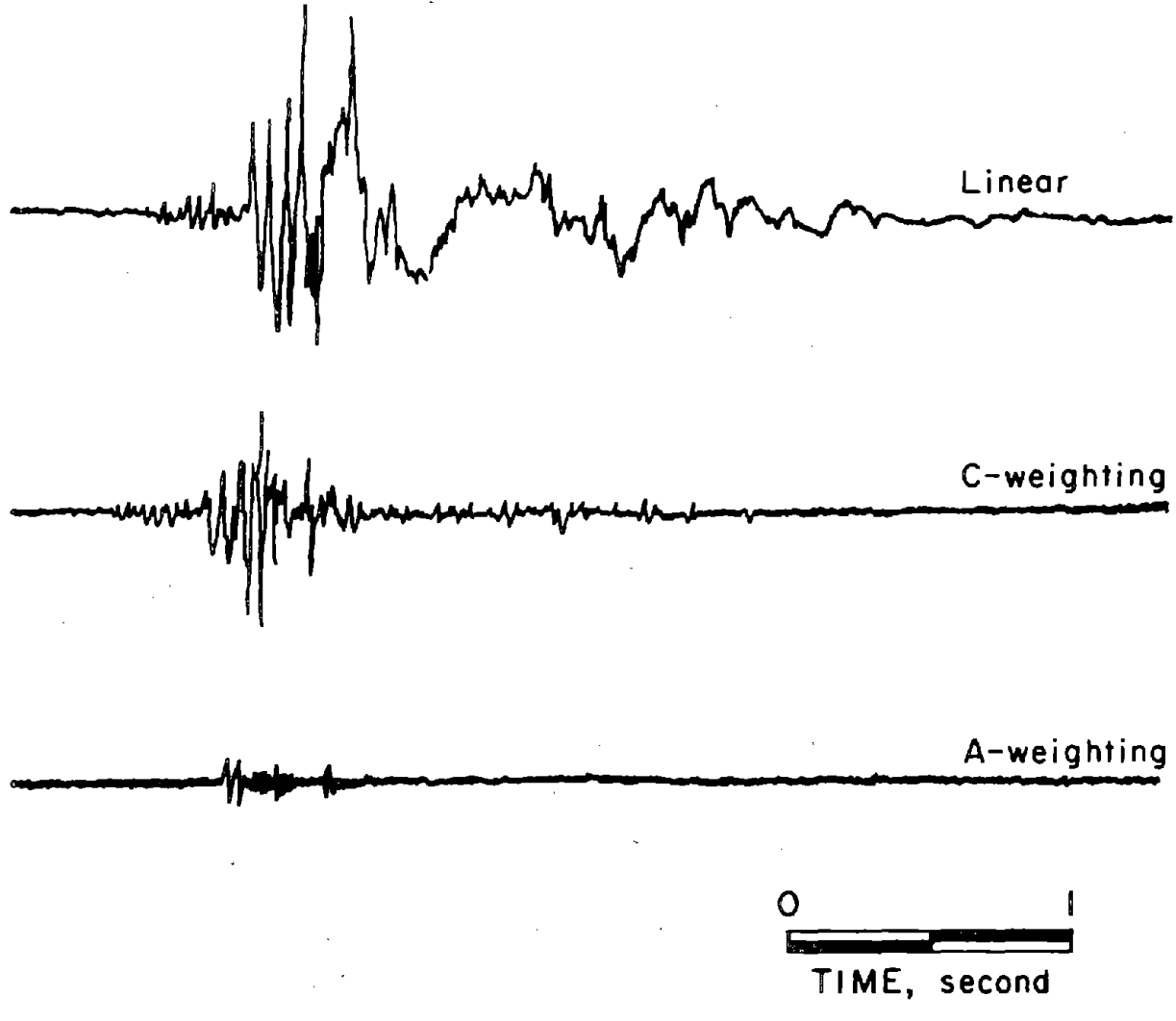

FIGURE 5. - Overpressure traces from site 3 blast, position A.

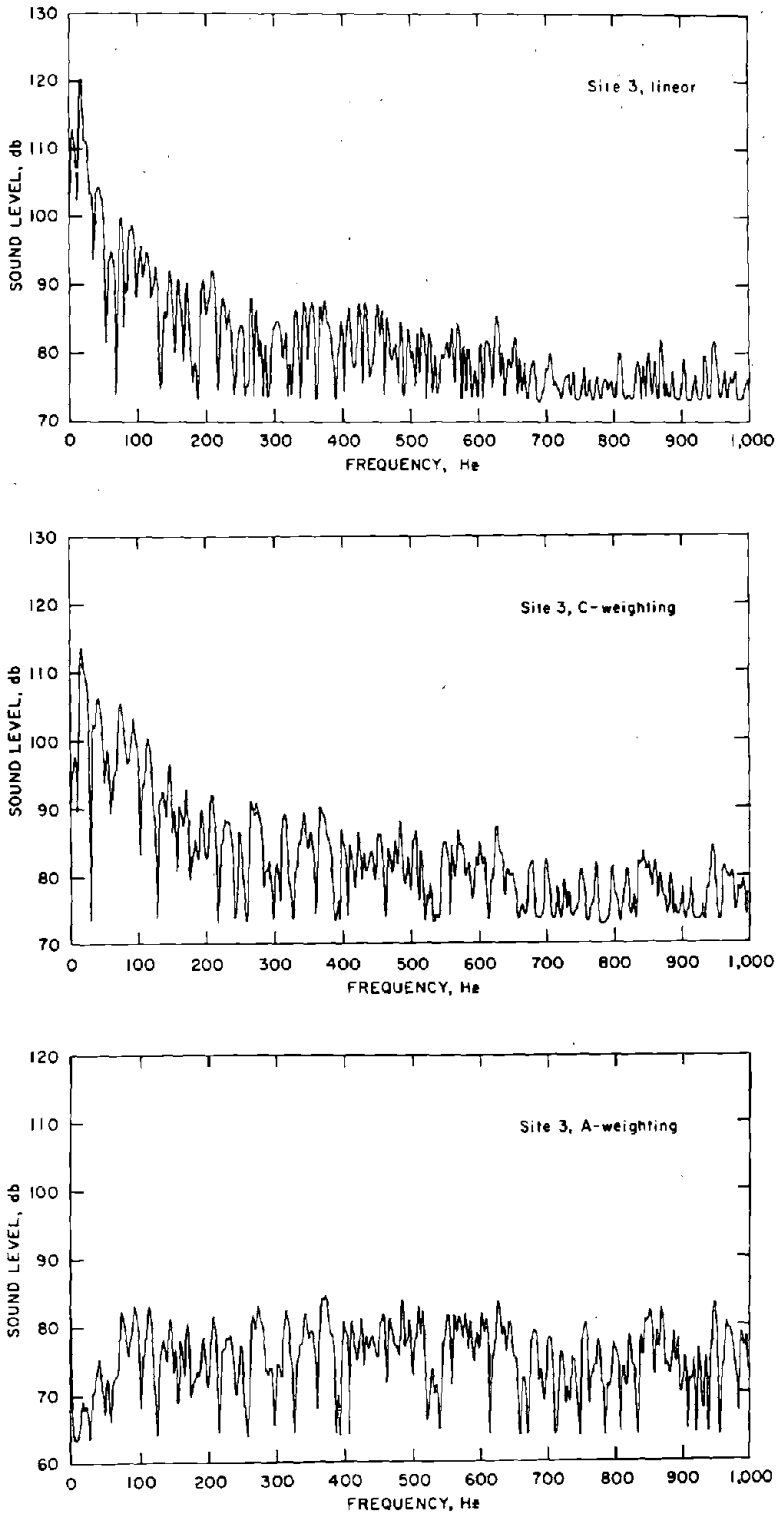

FIGURE 6. - Frequency spectra for site 3 blast.

B+K 2204/S sound level meter measuring linear-peak values and having a bandwidth of 2 Hz to 16 kHz. Figure 5 shows the blast overpressure from site 3, position A, as a typical example of the six measured airblasts. Shown is a trace of the linearly recorded sound level and the same blast noise after filtering through a B+K 2205/S weighting network. Obvious is the reduction in the amplitudes of the C- and A-weighted sound levels as compared to the original noise trace, with the same vertical scale applying to all three traces.

Figure 6 shows the frequency spectra for the site 3 blast as recorded linearly and after weighting for C and A sound levels. These spectra graphically show the cause of the reduction of amplitude of the C- and A-filtered signals, with a significant amount of the signal energy below 100 Hz and a dominant frequency of 27 Hz. The A scale has been shifted up 10 db for clarity, with much of the trace shown sufficiently reduced in amplitude to be predominantly electronic system noise, particularly below 100 Hz. An attempt was made to A-filter the original linear signal for an A-peak spectrum for comparison with other measurements; however, the signal strength was very low upon A filtering and outside the lower end of the 20-db recorder dynamic range. Table 2 lists the dominant frequencies and filtered

sound levels as derived from the Bureau of Mines station A linear recordings and compares these sound levels with directly measured weighted values taken from table 1.

TABLE 2. - Laboratory analysis of location A airblast survey measurements

Site	Scale used	Measurement made on site (from table 1)		Recorded as linear and laboratory filtered, db	Dominant frequency, Hz
		Instrument B+K	Reading, db		
1	Linear-peak	2204/S	124	124	12
	C-peak	2204/D	110	114	12
	A-fast (RMS)	-	-	94	50
2	Linear-peak	2204/S	133	131	19
	C-peak	2204/D	125	120	
	A-fast (RMS)	2208	89	93	
3	Linear-peak	2204/S	129	128	27
	C-peak	2204/D	110+	122	
	A-fast (RMS)	2208	96	93	
5	Linear-peak	2204/S	130+	[1] 136	24
	C-peak	2204/D	130+	[1] 131	
	A-fast (RMS)	2208	100+	[1] 112	
6	Linear-peak	2204/S	125	124	26
	C-peak	2204/D	118	116	
	A-fast (RMS)	2208	86	82	
7	Linear-peak	2204/S	120	118	32
	C-peak	2204/D	108	108	
	A-fast (RMS)	2208	[2] <81	[2] <84	

[1] Saturation of recorder, readings are approximate.
[2] Values listed are ambient, which exceeded blast noise.

An evaluation of the airblast traces and spectra by Du Pont personnel working on blast effects has suggested that the recording system has insufficient low-frequency response (2-Hz cutoff) and has caused the "ringing" in the traces, uncharacteristic of ultra-wide-band recording systems. It is likely that a reliable scientific examination of airblast effects will require such a wide-band system, although equipment of this type would probably not be available to most noise control agencies.

Comparison of Weighted Measurements

Table 3 summarizes the sound level measurements of the airblast survey as given in tables 1 and 2. Averages do not include the off-scale measurements. Generally, A-fast-maximum and C-fast appear to be lower than A-peak and C-peak, respectively, by approximately 8 db, although the very few reliable data values make this statement less than conclusive. As expected, linear-peak values

are the highest, C-peak intermediate, and A-peak sound levels the lowest measured. This results from the character of the airblast itself, which contains considerable energy below 20 Hz, to which the C and A weighting scales are increasingly insensitive. Additionally, there is a wide range of values and lack of consistency from shot to shot and, to a lesser degree, from station to station for any given shot in comparing the sound levels with the different weighting scales. This indicates that the frequency character of the blast noise varies between shots and in different propagation directions. All sound level measurements and comparisons between measured values are very general owing to differing site, blasting, and propagation conditions.

TABLE 3. - Weighting scale comparison, airblast survey measurements

	Average, db	Range of values, db	Number of measurements
Linear-peak	124	115-136	17
C-peak	113	89-131	20
C-fast (RMS)	102	98-105	2
A-peak	95	75-110	13
A-fast-max (RMS)	92	79-112	9
Difference between linear-peak and A-peak	29	11-38	8
Difference between linear-peak and C-peak	11	5-20	17
Difference between C-peak and A-peak	18	(-3)-27	8
Difference between linear-peak and A-fast-max	32	24-44	9

STANDARDS

Instrumentation

Realistic measurement of noise from blasting requires sound level meters with impulse capability and linear frequency response down to at least 5 Hz. Use of steady state (RMS) meters with limited frequency response and A, B, or C weighting scales simply ignores much of the blast noise energy which can damage structures and annoy and injure people. The impulse precision sound level meter should be set to measure noise on "peak-linear-hold" (B+K 2204/S, 2204/D, 2209) or "impulse-flat" (GR 1933) settings. Some old GR 1551 and impulse attachments (GR 1556) are still in use and would have to be set to the 20-kHz band, giving a flat response between 5 Hz and 20 kHz. The amount of airblast energy represented by frequencies below 5 Hz is yet to be determined, as well as its effects on people and structures.

There is a current tendency to base noise control standards on A-weighted sound levels (usually RMS values); however, this practice is totally unappropriate for blast noise measurement. Not only does the A scale fail to detect most of the noise energy, but it approximately simulates human sound sensitivity only at low noise levels. Measurements made close to quarry, surface mining, or excavation blasts would probably be in the 100- to 140-db linear-peak range. The corresponding C-peak values would be about 10 db lower, and at these levels the C-weighted scale would be superior to the A or B scales in

simulating human sensitivity to noise. (See previous discussion.) Most important, these weighting scales only represent how humans detect noise as perceived sound, while noise outside human frequency limits can still be felt, cause injury, damage structures, and break glass. Particular values adopted for sound level standards would depend on the weighting scales specified. For sounds between about 600 and 6,000 Hz, the A, B, C, 20 kHz, and flat scales will give approximately the same sound levels within 3 db; however, noise containing frequency components outside this narrow range will give lower sound level values on the weighted scales relative to flat response.

Damage and Annoyance

These two factors may not be as different as they appear, since most complaints of noise (and also ground vibration) result from incidents of damage, alleged damage, or fears of damage. Annoyance levels themselves are highly subjective and complicated by the fact that mines, quarries, and construction projects may not be popular with the general public. Most operators are aware of the problems and take steps to minimize the damage risk and annoyance probability, in the design of their operational procedures. Some of these measures include--

1. Minimizing the blast size (by the use of multiple delays, decking, and limiting the number and size of the blastholes) and the frequency of blasting, subject to production restrictions.

2. Timing the blasting to coincide with the periods of high ambient noise (for example, 12 noon).

3. Using audible warning devices.

4. Consideration of prevailing weather conditions, particularly wind and temperature inversions.

Some of these measures are costly and the degree of effort to control blast noise is a function both of past complaint history and of local regulation.

A great number of observations of blast damage have indicated that window glass is the part of a household structure most susceptible to damage from airblast overpressures. There has been some evidence for damage to plaster from repeated loading at levels comparable to window glass breakage thresholds. However, the relative effects of structural fatigue and surface corrosion for these cases are not known.

Table 4 gives recommended sound level standards for blast noise based on damage probabilities from previous studies and measurements as described in this report. The 136-db and 128-db linear-peak values represent maximum allowable levels and caution thresholds, respectively. These sound levels are compromises between the previously recommended high values of safe overpressure and the low levels desirable for protection of the rights of the general population. While 136 db is the recommended maximum value, there is a

likelihood that annoyance complaints will be received at this level, and it would be desirable for blasting operators to stay below this value.

TABLE 4. - Interim sound level standards, property line or receiver's property

	Linear-peak			C-peak or C-fast	A-peak or A-fast
	Db	Mb	Psi		
Safe level.....	128	0.48	0.007	120	95
Caution range, measures may be applicable to reduce annoyance	128 to 136	0.48 to 1.24	0.007 to 0.018	120 to 130	95 to 115
Limit of allowable impulsive noise	136	1.24	0.018	130	115
	Recommended technique			The use of these weighted scales is not recommended	

The maximum noise levels of table 4 are less than the design limits for sonic booms (4) of 142-db linear peak, Reed's (9) minimum glass damage threshold of 140-db linear peak, Reed's generally recommended maximum safe overpressure of 2 mb (0.028 psi, 140 db), and the OSHA occupational limit peak linear value of 140 db (5). The probability of glass damage to a single window at the maximum allowable noise level of 136 db is between 10^{-5} and 10^{-7}, based on figure 1.

Implicit in the recommended values of table 4 are the asssumptions that blasting is done infrequently, that the measures previously described to minimize annoyance are employed, and that special factors such as the close proximity of schools, hospitals, etc., are not involved. Adjustments for these other factors could be made, resulting in lower standards. Except for situations requiring adjustments in the recommended standards, these sound level standards could be used as thresholds for annoyance and noise pollution.

The recommendations herein are tentative and subject to revision as new studies produce more directly applicable measurements and analyses. It is not realistic to expect new excavation techniques to replace hard rock blasting in the foreseeable future, and unrealistically severe controls could make it technically and economically impossible for many mining and quarrying operations to continue.

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