U.S. DEPARTMENT OF LABOR MSHA
00033849

Copy 2

BOLT BERANEK AND NEWMAN INC

CONSULTING • DEVELOPMENT • RESEARCH

Report No. 2827

Bolt, Beranek & Newman

COAL CLEANING PLANT NOISE AND ITS CONTROL

U. S. Bureau of Mines
Minneapolis, Minn.
LIBRARY

E.E. Ungar
G.E. Fax
W.N. Patterson
H.L. Fox

Contract No. H0133027

May 1974

Submitted to:

U.S. Bureau of Mines
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213

Attention: Mr. Charles Summers

OFR
74-44

CAMBRIDGE WASHINGTON, D.C. CHICAGO HOUSTON LOS ANGELES SAN FRANCISCO

Report No. 2827

COAL CLEANING PLANT NOISE AND ITS CONTROL

E.E. Ungar
G.E. Fax
W.N. Patterson
H.L. Fox

Contract No. H0133027

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or the U.S. Government.

May 1974

Submitted to:

U.S. Bureau of Mines
4800 Forbes Avenue
Pittsburgh, Pennsylvania 15213

Attention: Mr. Charles Summers

FOREWORD

This report was prepared by Bolt Beranek and Newman Inc., 50 Moulton Street, Cambridge, Mass. 02138, under USBM Contract No. H0133027. The contract was initiated under the Coal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Charles R. Summers acting as the technical project officer. Mr. Joseph A. Herickes was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June, 1973 to April, 1974. This report was submitted by the authors on 15 May 1974.

ABSTRACT

Criteria applicable to noise in coal cleaning plants are presented, and the generally applicable noise control principles and approaches are discussed. The operating characteristics and equipment of coal cleaning plants are described. Considerations entering in the selection and design of noise control means are delineated, and specific means for equipment noise reduction are described.

The limited utility of acoustically absorptive materials in plant spaces is indicated, administrative means for reducing worker noise exposure are pointed out, and ear-protective devices are described briefly. The reduction of plant noise reaching nearby communities is discussed. Programs leading to quieter machines and coal cleaning plants are suggested.

EXECUTIVE SUMMARY

The noise produced by coal cleaning plants must be considered in relation to (1) hearing damage to plant personnel (in view of standards prescribed in the Coal Mine Health and Safety Act of 1969) and (2) annoyance to nearby communities.

Noise Control Principles and Approaches

Noise is unwanted audible sound. Noise problems may best be approached by considering three basic elements: the sound sources, the paths along which sound travels to personnel affected by the noise, and the affected personnel. A given noise may be characterized by the frequency components it contains and by the *levels* of these components. Levels usually are expressed in *decibels* or *dB*; the corresponding numbers provide an approximation to the perceived loudness. The effect of all frequency components is usually summarized in a single number, the *A-weighted noise level*, expressed in *dB(A)*, which accounts for the frequency-dependence of human hearing.

Outdoors, or wherever there is nothing to reflect the sound or to provide shielding, one hears less noise as one moves further away from a source. Indoors, where sound is reflected from walls, etc., one may reach a point where reflected sound dominates, and where moving away from the source results in no reduction of noise. The distance beyond which no decrease in noise is observed increases with increasing acoustical absorption in the space.

Noise control usually can be achieved most efficiently by reducing the source of the noise. This may involve (1) replacing a noisy machine by a quieter one, (2) reducing the basic noise-generating mechanisms (e.g., impacts, vibrations, air or fluid pulses) in machinery, (3) obstructing sound radiation from

machine surfaces, and (4) muffling of aerodynamic noise sources, such as intakes and exhausts of fans, blowers, air compressors, and valves.

Noise control in the source-to-hearer path involves: (1) obstruction of the path and (2) absorption of sound energy. Obstruction is obtained by means of total or partial enclosures for the source, barriers (such as walls or partitions), and total or partial enclosures for personnel. Acoustical absorption (in the form of acoustical tile or blankets) reduces noise due to reflected sound and thus is useful only where reflected sound is important. Control of hearer exposure may be obtained by use of total or partial personnel enclosures, by means of ear-protection devices (ear plugs, ear muffs, helmets), or by limiting the noise exposure duration of personnel (e.g., by rotating job assignments between quiet and noisy areas).

Preparation Plants and Their Noise

Cleaning plants perform two basic functions: separation of coal from other materials and classifying coal by size. Since all plants must move and store coal, essentially all have conveyors, bins, feeders and chutes. The vast bulk of classifying work is done by means of screens; these and crushers may be found in virtually all plants.

However, coal cleaning is principally by three different processes, requiring different equipment. Nearly half of all plants use the heavy media process, about 30% use jigging, 9% use air tables (considered obsolete by the industry), the rest use combinations of these processes. Primary cleaning machinery includes heavy media vessels, jigs, heavy media cyclones, air tables. Secondary equipment includes cyclones, concentrating tables, centrifugal dryers, filters, flotation cells. Not all of these constitute significant noise sources.

The number of workers present in a coal cleaning plant depends on its size, age, and primary process. Modern heavy media plants employ per shift an average of about 0.7 workers per 1000 tons/day input capacity; for an older jigging plant the corresponding number is about 1.2. In relation to noise exposure, workers may be characterized as stationary (always in the same location and continuously exposed to the same noise level) or mobile (moving between areas of different noise levels). A typical work force is divided about evenly between the two groups.

The machinery found in coal cleaning plants may be classified in terms of the basic noise-producing mechanisms, and noise control may be approached in relation to these mechanisms. The primary mechanisms are: impacts, fluid flows, and structural vibrations. Impacts of coal on coal or coal on steel dominate in screens, chutes, hammer mills, hoppers and bins; impacts of steel on steel are responsible for the noise of car shakeouts and for the gear noise of crushers. Fluid flow noise dominates in blowers, fans, vacuum pumps, valves, and air blasts. Structural vibrations contribute to the noise of screen shaking mechanisms, blowers, gear drives, pumps, centrifugal dryers, conveyors, feeders, and the snubbing tanks of vacuum pumps.

The following table presents a rank-ordering of machinery in terms of need for quieting, taking account of both the noise levels and the worker exposure. All items except those in the last group must be quieted if it is desired to provide a plant noise environment that is below the 8 hour per day allowable 90 dB(A) level.

RANK-ORDERING OF EQUIPMENT IN TERMS OF NOISE

Rank	Equipment	Typical Sound Level at Worker Position (dBA)	Typical Worker Proximity
1	Car Shakeout	110-120	2 workers, full time
2	Screens	95-105	Predominant in-plant noise source; many workers, often near full time
3	Picking Tables	90-95	1 worker, full time
4	Blowers, Dryers, Air Pumps, Fans, Crushers, Air Valves, Feeders, Flighted Conveyors, Chutes	90-105	Maintenance and Operational Support Workers
5	Motors, Gear Drives, Liquid Pumps, Hoppers	85-95	Maintenance and Operational Support Workers
6	Belted Conveyors, Deister Tables, Flotation Cells, Water Falls, Rotary Pumps, Heavy Media Vessels, Cyclones	75-85	Maintenance and Operational Support Workers

Reduction of Preparation Plant Noise

Any economical noise control approach must not interfere significantly with plant operations and maintenance, must not constitute a safety hazard, and must find worker acceptance. It must also not involve large penalties in direct and indirect initial and operating costs.

Cost-effective noise control measures for the various items of equipment commonly found in coal cleaning plants are listed in the following table, together with estimated typical initial costs and the associated potential problems. Use of sound-absorbing materials in plant spaces should also be considered, but only if the reflected portion of the noise is known to be significant. Rotation of work assignments and/or ear-protective devices may be used where the aforementioned "mechanical" noise control measures cannot be implemented.

For any given plant, the most cost-effective overall noise control approach is likely to consist of a mix of machinery-related noise reduction means and worker-related exposure control. The most suitable mix will vary from plant to plant and can be selected only after the total costs associated with alternative, acoustically sufficient, mixes have been evaluated.

MACHINERY NOISE REDUCTION MEANS

Equipment	Noise Reduction Means and Unit Cost		Potential Problems
Screens	Rubber decking	$1500	wear, material movement
	Slow shaking mechanism	$ 300	material flow rate
	Better gearing for shaking mechanism	$ 300	
	Enclosure for shaking mechanism	$ 200	cooling, maintenance
	Improved supports	$ 300	
	Screen enclosure	$8000	working access, inspection
Chutes	Interior ledges	$ 100	material flow obstruction
	Rubber linings	$ 100	wear, repairability
	Concrete liners	$ 100	wear, repairability
	Exterior damping	$ 200	wear, repairability
Hoppers, Bins	Keep nearly full	-	interferes with operations
	Rubber linings	$ 300	wear, repairability
	Exterior mass	$ 500	weight, supports
Crushers	Better gearing	$ 300	
	Enclosure	$2000	access for inspection, repair

MACHINERY NOISE REDUCTION MEANS (Cont'd)

Equipment	Noise Reduction Means and Unit Cost	Potential Problems
Car Shakeouts	Replace with rotary dump $150,000	compatibility with plant and cars
	Operator enclosures $ 15,000	working convenience
Picking Tables	Replace with rotary breaker $ 70,000	compatibility with plant; community noise
	Partial enclosures for workers $1500	work convenience
Blowers, Fans, Valves	Mufflers on intakes $ 500	
	Duct to plant exterior $ 500	exterior noise
	Enclose casing $ 700	
Vacuum Pumps	Mufflers on exhaust $ 500	
	Duct to plant exterior $ 500	
	Enclosure for snubber tank $ 100	
Air Blasts	Replace nozzler $ 200	reduced efficiency
Liquid Pumps, Dryers, Motors	Enclose body $ 700	
Feeders	Replace electromechanical with mechanical	compatibility
	Add noise barriers $2000	access

Control of Plant Noise Intrusion into Nearby Communities

Noise intruding into communities is usually due to a few readily identified items of equipment that are much noisier than others, located outside of buildings or near openings, and/or located near a sensitive community area.

Once these items have been identified, one may quiet them by any of the means discussed for in-plant noise reduction. For items located near openings, it is usually useful to close these openings, or to provide them with barriers or mufflers. Where building walls are of lightweight construction, adding heavier or secondary walls may be useful to contain the plant noise.

Walls or earth berms need to be close to the noise sources to be effective. They typically do little good for communities at considerable distances from the plant. Ground cover, vegetation, bushes, or trees have no appreciable effect on the noise propagated to nearby communities.

Additional Recommendations

It is recommended that designers of new plants keep the requirements in mind; they should then be able to achieve notably quieter plants at no significant cost increase.

Recommended investigations that would be beneficial to the industry include: (1) development of quiet screens, (2) studies of chute noise reduction means, (3) review of noise control means employed in related industries and other countries, (4) demonstration design of a new quieter coal cleaning plant. All of these investigations need to consider not only noise, but also wear life and cost.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

Recent years have seen in the United States an increased public concern with the prevention of occupational hearing damage of the nation's work force. This concern has led to the passage of a number of noise-related laws, including the Federal Coal Mine Health and Safety Act of 1969, which prescribes the maximum permissible exposure of mine personnel and places primary responsibility for compliance on the mine operators.

In most currently operating coal cleaning plants (where coal is separated from rock), there are numerous work stations where the noise levels exceed those permissible for long-term exposure of personnel. The industry thus faces the need of providing its workers with cost-effective noise protection that will be acceptable to the work force and that will result in no decrease in production efficiency.

This report is intended to serve as a guide toward solution of the problem of noise exposure reduction in coal cleaning plants. Its objective is not only to provide technical guidelines towards the control of noise in cleaning plants, but also an assessment of the associated costs.

The first of the following sections, Section II, delineates the noise standards that apply to coal cleaning plants. Section III provides a general description of the applicable noise control principles and approaches. Section IV discusses coal cleaning plants in terms of their noise characteristics and noise-producing equipment, Section V presents specific approaches to the reduction of noise in plants and corresponding cost estimates, and Section VI discusses the control of plant noise intruding into nearby communities. Section VII, which provides illustrative examples of plant noise control strategies, is followed by a concluding section that suggests noise control efforts that should be pursued.

That part of the information presented here that is specific to coal cleaning plants was obtained by Bolt Beranek and Newman Inc. as the result of extensive field measurements made in several cleaning plants and on the basis of interviews with plant personnel, equipment manufacturers, plant design engineers, and mining industry consultants. A list of cooperating organizations appears in Appendix A; their cooperation is gratefully acknowledged.

II. NOISE STANDARDS

Two considerations are of importance in relation to the noise produced by coal cleaning plants:

1. Hearing damage of personnel employed in such plants,
2. Annoyance of people in communities near such plants.

The maximum permissible noise exposure of plant personnel is delineated by the Federal Coal Mine Health and Safety Act of 1969. There exist as yet no federal guidelines concerning the permissible intruding noise levels in communities; however, some communities have passed their own noise control ordinances, and levels to which intruding noises in communities should be limited are suggested in the technical literature.

The noise standards applicable to coal cleaning plants are described in the following paragraphs.

Provisions of Federal Coal Mine Health and Safety Act of 1969

In the Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173), Congress declares that "...there is an urgent need to provide more effective means and measures for improving the working conditions in the Nation's coal mines in order to prevent death and serious physical harm, and in order to prevent occupational diseases originating in such mines..." and that "...the operators of such mines with the assistance of the miners have the primary responsibility to prevent the existence of such (unsafe and unhealthful) conditions and practices in such mines..." Among the stated purposes of this act is "to establish interim mandatory health and safety standards" and to require compliance.

The noise standard under the aforementioned act is delineated in its section 206, where it is stated that "...the standards of noise prescribed under the Walsh-Healey

Public Contracts Act...shall be applicable to each coal mine...", and where it is indicated that operators shall not require use of any protective device or system deemed to be hazardous or to cause a hazard.

Noise Standards Prescribed by Walsh-Healey Act

The "occupational noise exposure" portion of this act delineates the requirements described below (paraphrased from the original language).

(a) Protection against the effects of noise exposure shall be provided when the sound levels, measured on the A scale of a standard sound level meter at slow response,* exceed the permissible exposure shown in Table I.

(b) When employees are subjected to sound levels exceeding those of Table I, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce the sound levels to the values listed in the table (or to lower values), personal protective equipment shall be provided and used to reduce sound levels within the levels of the table.

(c) If the noise is unsteady and involves maxima that occur at intervals of one second or less, the noise is to be considered as steady.

---

*By this means one obtains the so-called "A-weighted" overall sound level. If sound level data are available in octave bands, one may obtain the corresponding equivalent A-weighted sound level by plotting the octave band data on the graph of Fig. 4; the highest "A-weighted sound level" curve penetrated by the octave band data gives the equivalent A-weighted sound level.

(d) In all cases where the sound levels exceed the values specified here, a continuing, effective hearing conservation program shall be administered.

TABLE I - PERMISSIBLE NOISE EXPOSURES PRESCRIBED BY WALSH-HEALY ACT[1,2]

Duration, (hours per day)	8	6	4	3	2	1 1/2	1	1/2	1/4 or less
Permissible sound level (dBA, slow response)	90	92	95	97	100	102	105	110	115

For impulsive or impact noise, the maximum permissible sound pressure level corresponds to a measured instantaneous peak value of 140 dB.

Notes:

1. Tabulated values are graphed in Figure 1 below:

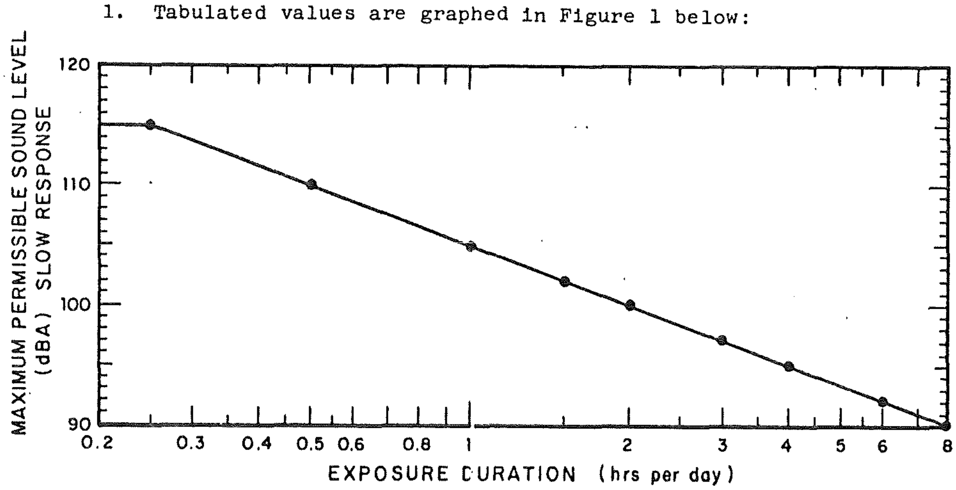

FIG. 1 - PERMISSIBLE NOISE EXPOSURES

2. If a person's daily noise exposure involves periods in which he is exposed to different sound levels, his exposure may be considered acceptable if the sum

$$S = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots$$

is less than 1.0. If this sum exceeds 1.0, his exposure is unacceptable. Here C_n represents the total time the person is exposed to the *nth* noise level, and T_n represents the total time of exposure permitted at that level, as tabulated above. The sum must account for all exposure periods.

Example: Exposure for 5 hours per day to 90 dB(A), and 2 hours per day to 92 dB(A), and 1 hour per day to 95 dB(A) gives

$$S = \frac{5}{8} + \frac{2}{6} + \frac{1}{4} = 0.625 + .333 + .250 = 1.208.$$

Since sum is greater than 1.0, exposure is unacceptable.

Community Noise Criteria

Most existing statutes governing industrial noise prescribe maximum permissible A-weighted levels of 50 dB(A) for nighttime (10 p.m. to 7 a.m.) and 55 to 65 dB(A) for daytime, as measured at the boundaries of surrounding residential areas.* These values assume that the noise level fluctuates little with time; more stringent restrictions may apply for fluctuating noise levels.

Since the noises emanating from coal cleaning plants tend to be essentially non-fluctuating, one may take 50 dB(A) for nighttime and 60 dB(A) for daytime operation - as measured at the community boundary nearest the plant - to be reasonable criteria.

*Beranek, L.L., "Criteria for Noise and Vibration in Communities, Buildings, and Vehicles" Ch. 18 of *Noise and Vibration Control*, ed. by L.L. Beranek. McGraw-Hill Book Co., New York, 1971.

III. NOISE CONTROL PRINCIPLES AND APPROACHES

Basic Components of Noise Problems

Noise is defined as unwanted audible sound. Audible sound is essentially a disturbance (or vibration) of air sensed by people's ears. Anything that causes air to vibrate - or anything that sets something else into motion, which, in turn causes air to vibrate - may be considered a *source* of sound.

Sound typically propagates from a source to a *receiver* (i.e., to a person or item of equipment whose noise exposure is of concern) via diverse *paths*. These paths can be very complicated, involving not only reflections but also conversions between vibrations of air and vibrations of structural components. For example, a noise source in an enclosure causes the enclosed air to vibrate, the air vibrations set the enclosure walls into motion, and the wall vibrations, in turn, produce vibrations of the air outside the enclosure. Before arriving at a receiver, vibrations may be reflected from several walls of a room housing the noise source.

Virtually every noise problem may be approached conceptually in terms of three basic elements: sources, paths, and receivers. Noise control then in essence involves reduction of noise generation by the significant sources, reduction of the propagation of noise from the sources to the receivers along the important paths, and/or rendering the receivers more tolerant to noise. For example, one may use rubber liners to reduce noise-producing impacts of coal on steel chutes (to reduce noise generation at the source), one may construct an enclosure around a noisy machine (to obstruct the noise propagation path), or one may limit the amount of time a worker can spend in a noisy location, thus enabling him to accept a higher noise level without suffering hearing damage.

In most realistic plant noise situations, many sources and paths act simultaneously to expose many receivers. Therefore, many noise control approaches tend to be potentially useful. The problem of selecting the best approaches is one that involves both engineering and economical considerations. The present section is intended to provide a guide to the relevant noise control engineering concepts; a later section is addressed to the associated economics.

Noise Characterization

The noise one measures in a given location in a plant generally is complex. Not only does this noise consist of contributions from many sources, but even the noise from a single machine is made up of many frequency-components (tones) and may vary with time.

Frequency Components

The noise levels that correspond to the various frequency-components which make up the noise that is present at a given observation location may be determined with the aid of suitable instruments called "filters". Usually, there are present so many components that accounting for each individual one would be impractically tedious; therefore, one generally only considers the noise distribution in "frequency bands" - in effect grouping together the contributions from tones that have nearly the same pitch. The frequency bands used for noise analysis have been standardized, and virtually all instruments sold today make use of these standard bands.

"One-third octave bands" usually are most useful for characterizing the frequency-content of machinery noise. Thirty-two of these bands cover the entire audible frequency range (from about 15 Hz to about 22,000 Hz). Each band is commonly designated by its "center frequency" - i.e., by the frequency at its mid-point (on a logarithmic scale).* A plot of noise level (or, more precisely, sound pressure level) in one-third octave bands versus the center frequencies of these bands is called a "one-third octave band spectrum". Such a plot permits one at a glance to note the frequency-distribution of a noise.

Machinery noise often is also reported in "octave bands". Each octave band extends over three contiguous one-third octave bands; eleven octave bands cover the entire audible frequency range. The upper bounding frequency of any octave band is twice its lower bounding frequency; the center frequencies of adjacent octave bands differ also by a factor of 2. (Minor deviations from this factor occur for the standard octave bands, in order to have the center frequencies of all bands come out to be convenient simple numbers.) A plot of noise level in octave bands against the center frequencies of the bands is called an "octave band spectrum".

---

*The upper bounding frequency of any one-third octave band is $\sqrt[3]{2} \approx 1.26$ times its lower bounding frequency. The center frequency (the root-mean-square value of its bounding frequencies) of any given one-third band differs by a factor of $\sqrt[3]{2}$ from that of the next band. The center frequencies of the standard bands are chosen so as to be simple numbers, and the aforementioned factor generally differs slightly from $\sqrt[3]{2}$.

Decibels

It is common practice to express noise levels in terms of decibels (dB). The decibel is a logarithmic measure, which takes some account of the way people judge loudness - e.g., very approximately, people judge an 80 dB sound to be noisier than a 70 dB sound by as much as a 50 dB sound is noisier than a 40 dB sound. Because of their logarithmic nature, noise levels in decibels do not add like simple numbers.* Figure 2 is a chart for combining two sound levels. For example, an 80 dB noise added to an 86 dB noise produces a total noise of 87 dB - not 166 dB.

Human Hearing and dB(A) Levels

The human hearing system does not respond equally to all frequencies. It typically is most sensitive in the 1,000 to 5,000 Hz range, has limited sensitivity above 20,000 Hz, and can sense little below about 20 Hz. In order to account for this frequency-dependence of human hearing, "weighting factors" often are applied to measured noise levels. These factors, which consist of decibel numbers to be added to or subtracted from measured one-third octave-band levels, convert a measured

---

*The sound pressure level L_p - somewhat colloquially called the noise level - is defined as L_p (dB) = 20 $\log_{10}$ (p/p_{ref}), where p denotes the root-mean-square sound pressure and p_{ref} is a reference value of pressure, standardly taken as 2×10^{-5} N/m^2 $\approx 2.90 \times 10^{-9}$ psi. The total sound pressure level L_{comb} that results from the combination of levels L_1, L_2, L_3, ...is $L_{comb} = 10 \log_{10} [10^{L_1/10} + 10^{L_2/10} + 10^{L_3/10} + \ldots]$.

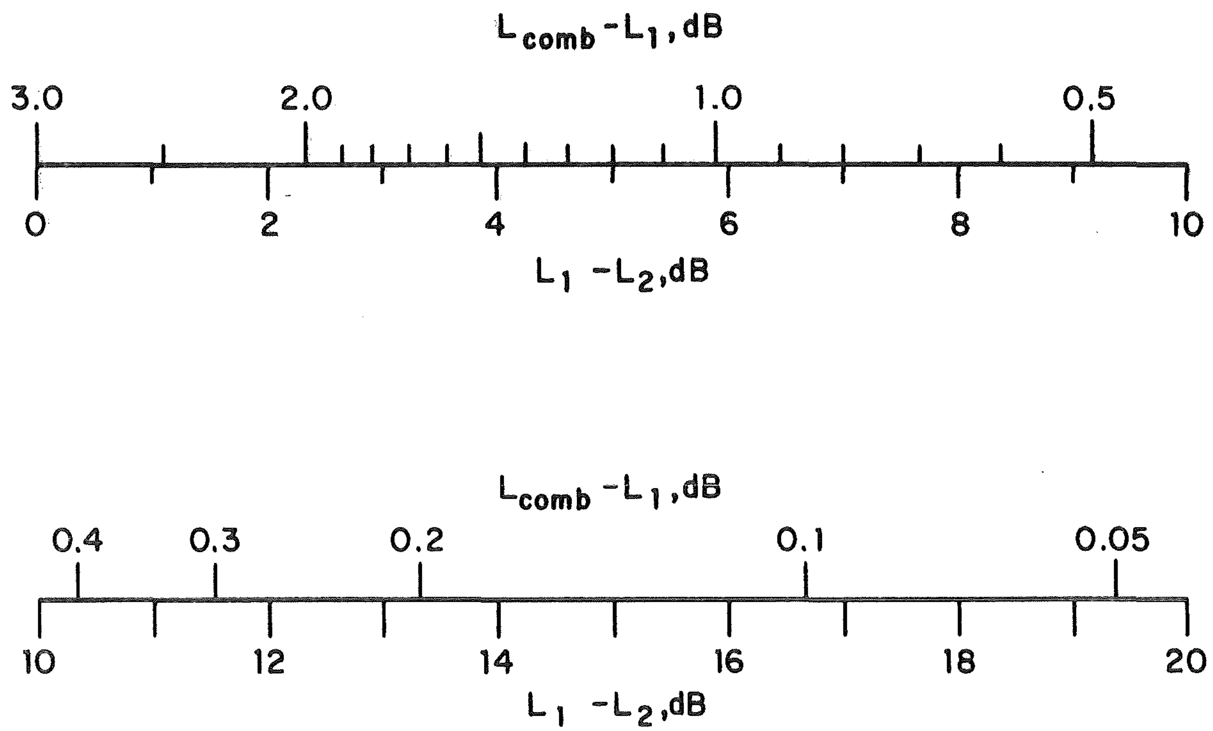

FIGURE 2 CHART FOR COMBINING TWO UNCORRELATED ACOUSTIC LEVELS, L_1 and L_2

EXAMPLE: L_1 = 90 dB, L_2 = 86 dB.
$L_1 - L_2$ = 4 dB.
From the chart, $L_{comb} - L_1$ = 1.5 dB.
Thus, $L_{comb} = L_1 + 1.5 = 91.5$ dB.

spectrum into a weighted spectrum, in which the different levels correspond to different audible loudnesses. The "A-weighting" is the most commonly used weighting; the corresponding weighting factors are shown in Fig. 3.

Although spectra are preferable for noise source analysis because they provide considerable information about a noise, they tend to be too complicated for simple designation of its total noisiness. Single-number measures have been devised for this purpose; of these, the "overall A-weighted level", often called simply the "dB(A)" level, has come into widest use. This level is determined by combining the A-weighted levels obtained in all one-third octave bands in the entire audible frequency range. Instruments are available which permit one to read the overall A-weighted [dB(A)] levels directly.

Plotting of octave band noise levels on Fig. 4 and noting the highest dB(A) contour penetrated by the data constitutes an alternative means for determining the overall A-weighted level corresponding to the data. The "equivalent dB(A) level" obtained in this manner may differ - though for most practical cases not significantly - from the dB(A) level obtained by the two more precise means described above.

Sound Fields Around Noise Sources

In Absence of Sound Reflectors (Outdoors)

The farther one moves from a single source of noise, the less noise one hears from that source. Outdoors, or wherever there is nothing to reflect the sound or to provide shielding,

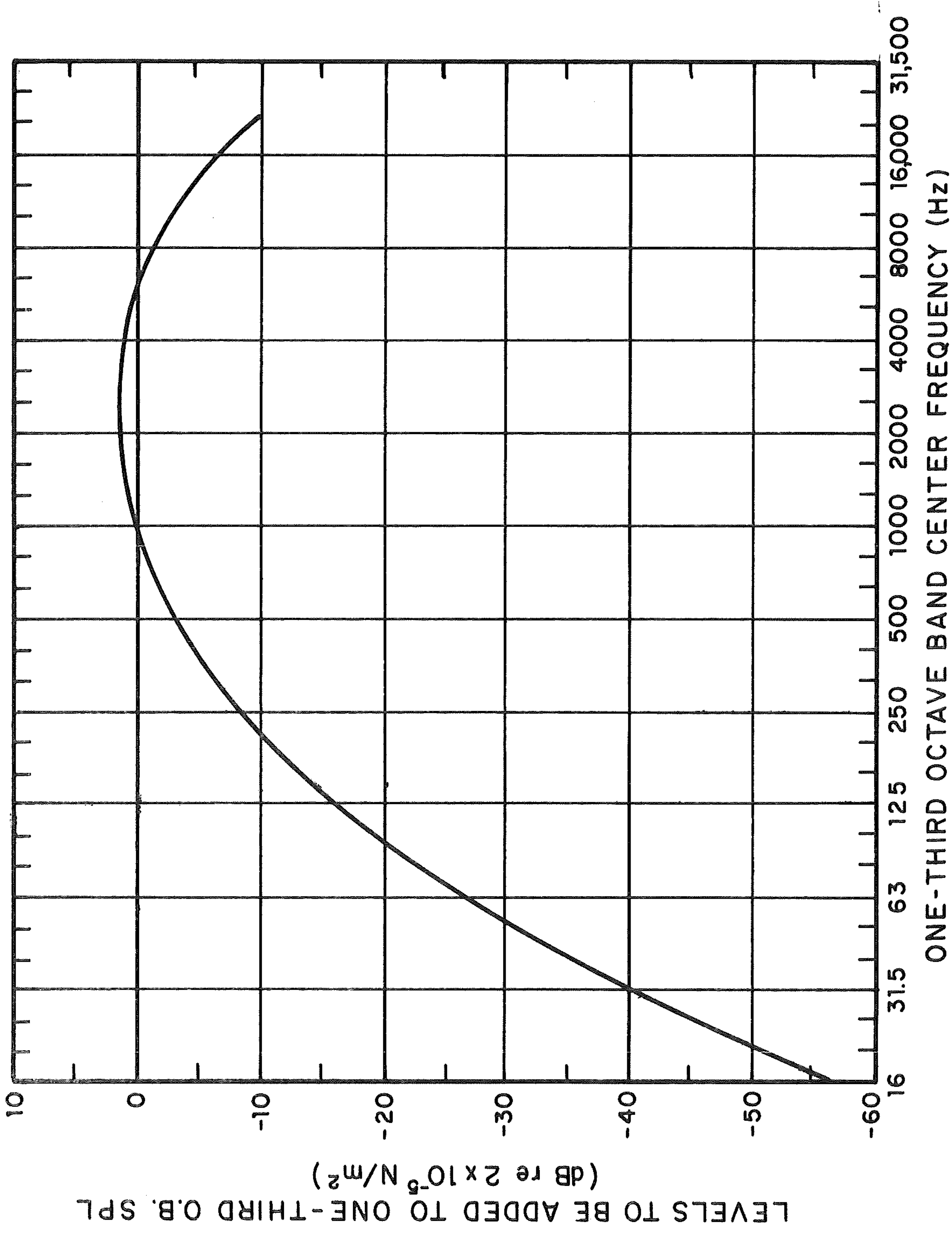

FIG. 3. A-WEIGHTING FACTORS

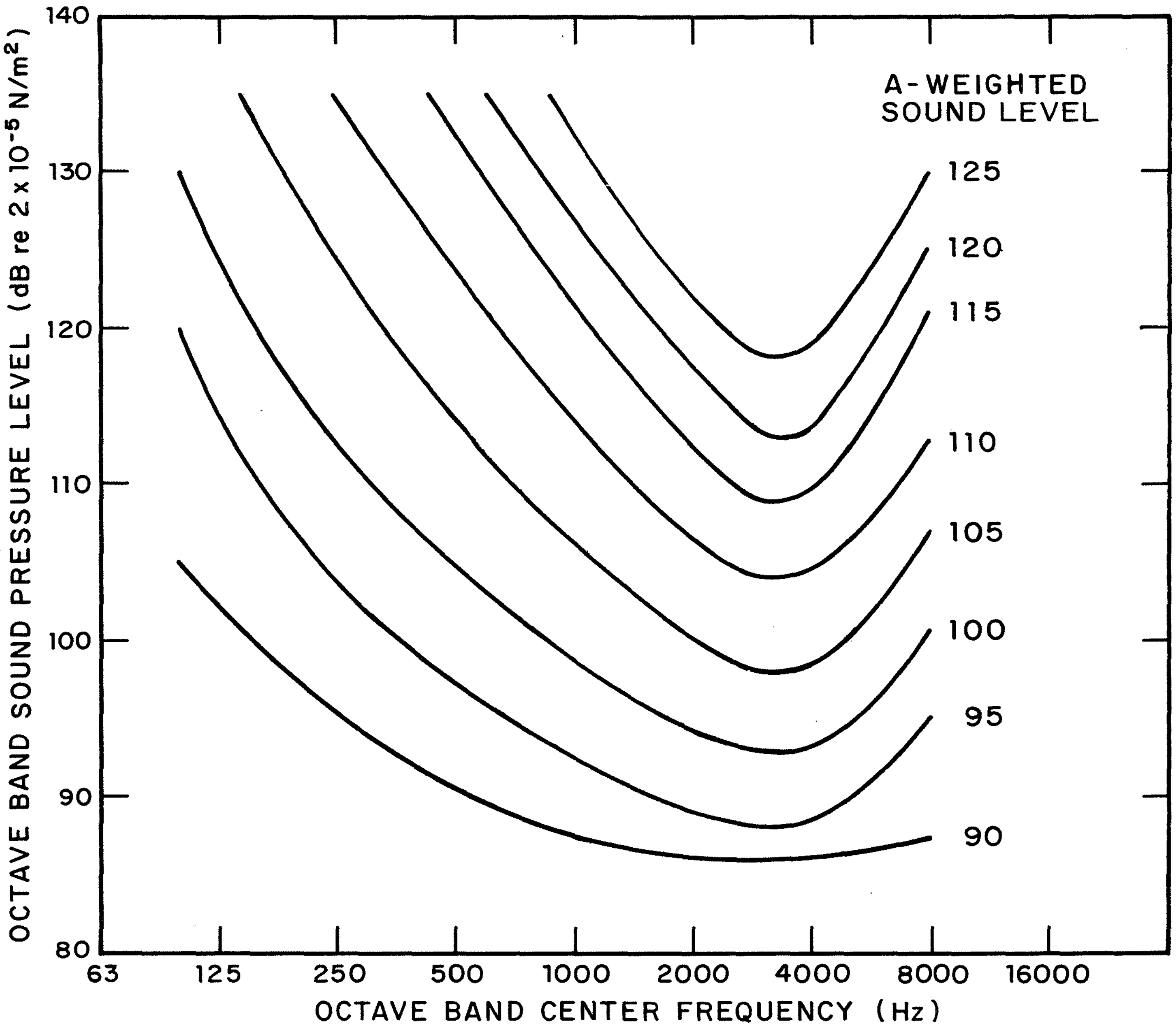

FIG. 4 - GRAPH FOR DETERMINATION OF A-WEIGHTED LEVELS FROM OCTAVE BAND DATA

the noise level beyond some minimum distance* decreases by 6 dB for each doubling of source-to-observer distance. For example, if one measures 100 dB(A) at 400 ft (in a given direction) from a motor outdoors, one may expect to measure 94 dB(A) at 800 ft (in the same direction) from the motor, 88 dB(A) at 1600 ft from the motor, etc., until one reaches a point where the background noise in the measurement area no longer permits one to measure the motor noise.

A source rarely radiates the same amount of noise in all directions, so that the direction along which one measures must be specified.

For distances up to several thousand feet, all frequency components typically decrease by the same amount (i.e., 6 dB per doubling of distance), regardless of atmospheric conditions (wind, air temperature, humidity). At greater distances these conditions may have some effect, primarily on the higher frequency components.

In Presence of Sound Reflectors (Indoors)

When sound reflectors are located around sound sources, the sound fields one observes in the vicinity of the sources are due both to the sound that comes directly from the sources and to the reflected sound. Consequently, as one moves further away from a sound source in a building (where the floor, roof,

*This minimum distance typically is several times greater than (1) the wavelength of the lowest frequency component of importance and (2) the largest dimension of the noise source.

walls, and machinery surfaces constitute sound reflectors), one observes the outdoor-like 6 dB decrease per doubling of distance only over a very limited distance from the source. As one moves farther away from the source, one soon reaches the distance at which the noise due to the reflections dominates over that arriving directly from the source. For greater distances from the source, there occurs then no further decrease in noise level with increasing distance.

This distance r beyond which no further decrease in noise is observed depends on the effectiveness of the reflectors: good reflectors provide stronger reflected fields and decrease this transition distance, whereas reflectors that absorb sound provide lesser reflected fields - increasing the transition distance - and approximating more nearly the outdoor reflection-free environment. The transition distance obeys

$$r \approx \sqrt{A\alpha/16\pi} \approx \sqrt{A\alpha}/7.1$$

where A represents the total area of the interior surfaces of the building (or room) housing the noise source and α denotes the average value of the acoustical absorption coefficients of these surfaces, with the averaging being done over all the surfaces.*

---

*If the total interior area A is made up of component areas A_1, A_2, A_3, ..., with different absorption coefficients α_1, α_2, α_3, ..., respectively, then $A\alpha = A_1\alpha_1 + A_2\alpha_2 + A_3\alpha_3 + \ldots$.

Some typical absorption coefficient values (largely taken from C.M. Harris "Architectural Acoustics" Sec. 3j of *American Institute of Physics Handbook*, McGraw-Hill Book Co., New York, 1957) are given in Table II.

The absorption coefficients α of most materials vary considerably with frequency, so that one needs to consider one frequency band at a time in order to determine the effect of distance on noise level. Nevertheless, one often may obtain a useful idea of the transition distance by dealing only with the band in which the highest A-weighted level occurs.

For example, consider a 20 x 50 x 100 ft building with an α of 0.10 (corresponding to considerable absorption of sound at the walls or - equivalently - sound leakage through windows, doors, etc.) in the mid-frequency range of primary concern. The total surface area here is 2(20 x 50 + 20 x 100 + 50 x 100) = 1600 ft^2, so that $r \approx \sqrt{1600(0.1)\ ft^2} \approx 13$ ft. Thus, beyond 13 ft from a noise source in this building one would obtain no further decrease in the observed noise - and because of the predominance of the reflected sound, one generally could not determine the location of the source by using only one's ears.

TABLE II

Some Typical Absorption Coefficient Values

Material	α at 500 Hz
Openings (open doors, windows)	1.0
Porous glass fiber board	0.8
Textured acoustic tile	0.7
Carpet and drapery	0.1-0.5
Plaster, gypsum; rough finish	0.06
Wood paneling	0.06
Plaster, gypsum; smooth finish	0.03
Wood floors	0.03
Glass	0.027
Brick wall, unpainted	0.03
Brick wall, painted	0.017
Concrete floor	0.015
Glazed tile	0.01

Multiple Sources

The discussions of the foregoing paragraphs dealt with cases where only one source is active at a time. In most practical circumstances, however, the noise field at a given observation position results from a number of sources simultaneously.

Where there exist multiple sources in absence of reflectors (e.g., in open areas outdoors), the observed noise field is due to the contributions resulting directly from the individual sources. Where there exist multiple sources in the presence of reflectors (e.g., in buildings), the observed noise field results from both direct and reflected contributions from each source.

In any case, the total noise level obtained at any observation position may be found by combining the noise levels due to the individual sources - again using the rules for combining decibels, and not simple addition.

It is instructive to note that combination of n equal noise levels L_1 results in a total level L_{comb} that obeys

$$L_{comb} = L_1 + 10 \log n.$$

Thus, for example, the level resulting from the simultaneous occurance of two noises of equal level is 3 dB greater than that from one of these components; for 5 simultaneous noises of equal level, the combined level exceeds that for a single component by 7 dB. Therefore, eliminating the contributions produced by 3 of 5 equal-level components produces a reduction of only 4 dB.

Noise Control at the Source

Noise problems usually can be solved most efficiently by reducing or eliminating the primary causes of the noise or - if modification of the primary sources is not feasible - by dealing with the noise-producing mechanisms as near to the primary sources as possible.

Replacement of Noisy Machines

Conceptually, the simplest means for reducing the excessive noise contributed by a given machine consists of replacing that machine by a quieter one that performs the same function - e.g., replacing electromagnetic feed vibrators by mechanical ones, replacing piston-type air compressors by screw-type compressors, or by replacing car unloading systems using extremely noisy shake-outs with rotary dumping systems requiring no shaking.

Unfortunately, such replacement of machinery is most often not feasible operationally or economically, so that one usually needs to consider what one can do to quiet an existing machine. Quieting of any item of equipment usually can best be accomplished on the basis of how and where this item generates and radiates noise.

Attack on Internal Causes of Noise

The primary noise-producing mechanisms in coal cleaning plant equipment are impacts, mechanical vibrations, and aerodynamic and hydrodynamic sources. Of these, impacts are most prevalent - including impacts of coal, rock, etc., against steel (as in chutes, screens, rotary breakers), impacts of steel against coal, etc. (as in some crushers and breakers), impacts of coal on coal (as in screens and some chutes), and impacts of steel on steel (as in shake-outs). Mechanical vibrations that are not the results of impacts occur, for example, due to feed vibrators and screen shakers, or due to unbalanced rotating equipment or imperfect gearing. Hydrodynamic or aerodynamic sources occur in pumps, compressors, and valves, and in essence consist of fluid pulsations or oscillations.

Clearly, one may reduce the noise associated with these mechanisms by reducing their strengths. One may reduce the noise associated with impacts by reducing the severity and/or the number of impacts per unit time - for example, by reducing the distance through which material falls before landing in a chute, by tightening rattling parts, or by slowing down screens, crushers, or breakers. One may also lessen the severity of impacts by providing some cushioning - e.g., providing soft gaskets between rattling parts, or by having coal impact against a rubbery material, against a layer of coal, or into a liquid layer, instead of against steel surfaces.

One may reduce noise due to mechanical vibrations generally by reducing the amplitudes of these vibrations (e.g., by eliminating mechanical imperfections in gears, improving the balancing of rotors) or by changing their frequency so as to avoid resonances of nearby components.

Fluid pulsations usually are caused by unsteadinesses or irregularities in the flow. These disturbances may be generated by the inherent action of a machine (e.g., by pistons and valves or by the siren-like flow chopping in axial flow compressors), or by side-effects, such as vortex-shedding (from fan blades, guide vanes, valve lips, or duct edges), flow and boundary layer turbulence, and cavitation.

Reductions in these irregularities may be expected to result in reduction of the associated noise. Some of these flow irregularities can be reduced only by modification of major items of the equipment; however, many may be reduced by changing some of the operating parameters (speeds, pressures) and making minor modifications - such as, adding flow-straighteners and smooth transition sections, streamlining struts, increasing distance of upstream struts and guide-vanes from fan intakes, or adding pulsation absorbers (or tuned dampers) in the flow circuits.

Reduction of Noise Radiation

Of all of the previously discussed noise-generating mechanisms, only aerodynamic disturbances produce vibrations of the surrounding air - i.e., audible noise - directly. All others produce oscillations of solid or fluid surfaces, which in turn make the air vibrate. This production of air vibrations by oscillating surfaces is called sound radiation; obviously, inhibition of this radiation reduces the associated noise.

The noise radiated by a vibrating surface varies as the surface area (perpendicular to the direction of the vibratory motion) and the amplitude of the vibration. Thus, one important technique for reducing radiation consists of reducing the vibrating surface area, either by removing material (cutting holes into plates, replacing sheet metal by rod-truss structures) or by adding stiffeners that reduce the areas that participate in the vibration.

Reduction of radiation may also be accomplished by any scheme that reduces the vibration amplitudes of radiating surfaces. Thus, attenuating vibrations generated inside a machine before they reach its exterior surfaces (e.g., by use of isolation) reduces radiation. For radiating surfaces that vibrate at one or more of their resonances, the vibration amplitudes and the attendant radiation can be reduced by the addition of structural damping (e.g., in the form of viscoelastic layers). The addition of mass is useful for reducing the vibrations of radiating surfaces at frequencies above their resonance frequencies, whenever the exciting force does not increase to compensate for the increased mass.

Finally, one may reduce the radiation from a vibrating surface also by "decoupling" this surface from the adjacent air. Such decoupling may be accomplished by placing an enclosure around the surface, so that this surface no longer communicates with the surrounding air. Alternatively, one may achieve decoupling by attaching to the radiating surface a soft layer (e.g., of foam rubber) topped by a heavy layer (e.g., a lead or steel plate) - so that the heavy layer essentially stands still as a result of its inertia, while the erstwhile radiating surface vibrates. Again, vibrations of this surface then no longer set the adjacent air into motion.

Muffling of Aerodynamic Sources

One may reduce the noise of such aerodynamic sources as compressor intakes and exhausts, and fans and valves, by providing them with appropriate mufflers.

Mufflers for sources that emit broad-band noise (i.e., noise that has significant components at many closely spaced frequencies) typically are ducts lined with acoustically absorbent materials and configured so as to permit no "line of sight" sound propagation path from the source to the surroundings.

The ducts' lengths must be at least of the order of the wavelength of the lowest-frequency sound of concern. Since such mufflers of necessity also impede the flow, a prime consideration in their design is the pressure drops they produce and the attendant reductions in the flow or equipment performance.

The duct linings that may be used for such mufflers must have adequate acoustical absorption over the frequency range of interest. In addition, they must not become clogged by dust, they must be able to withstand the environment in which they are to operate, and they must not produce any safety hazards (e.g., in terms of flammability). The design of appropriate linings appears feasible, for example, using pads of glass or fine metal fibers, covered with a thin plastic coating for dust protection, and placed behind a perforated metal abrasion and impact shield - or using finely perforated metal liners mounted essentially parallel to the duct wall, a short distance (of the order of one or several inches) from these walls.

Mufflers for sources that emit only a few tones may be of the "tuned resonator" type. These typically consist of several volumes connected to the source and to each other via pipes of appropriate lengths - as in automobile engine mufflers. It is not necessary for the gas to flow through such a volume, the volume must merely be connected to the flow in a manner in which it can sense the fluid pulsations. A great many geometric configurations are possible; one with little detrimental effect on the flow or equipment performance can usually be obtained by careful design and development.

Although significant amounts of noise reduction can often be obtained by cut-and-try methods, the design and development of optimized mufflers of both types is a specialized art requiring considerable experience.

Noise Control in the Source-to-Hearer Path

Where reduction of noise at the sources is not feasible, or where such reduction as can be accomplished by dealing with the sources is insufficient, one needs to consider how one may achieve noise reduction along the path from the sources to the hearers. Noise control along the sound propagation paths involves two concepts: (1) obstruction of the paths, and (2) absorption of sound energy.

Barriers

A barrier, such as a solid wall or earth dam, permits relatively little sound to pass through it. Placement of such a barrier between a source and a hearer in effect blocks the direct transmission path. At "high" frequencies, at which the acoustic wavelengths* are much smaller than the height and width dimensions of the barrier, sound propagation is analogous to light propagation. At such frequencies there result quiet "shadow regions" behind barriers, and even relatively lightweight walls that obstruct the source-to-hearer line of sight can result in up to about 20 dB of attenuation.

The amount of attenuation that barriers can provide is limited by sound "leaking" around the barrier - generally due to reflections from structures or topographic features to the side of the direct source-to-hearer path or due to refraction by wind and turbulence in the atmosphere. Any openings (e.g.,

---

*The wavelength L of sound at frequency f (Hz) obeys L(ft) = 1100/f. For example, at the frequency of 400 Hz, the wavelength is 2.75 ft. Therefore, 400 Hz may be considered a high frequency in relation to a 30 ft high wall of any length greater than about 30 ft.

vents, windows, doors) that may be present in the barrier present leakage paths that reduce the barrier effectiveness. However, openings do not affect the barrier effectiveness appreciably, if these openings constitute only a small percentage of the barrier surface area and if all of their dimensions parallel to the barrier surface are considerably smaller than a wavelength.

At "low" frequencies - that is, at frequencies at which the sound wavelengths are of the same order as the barrier heighth and width dimensions (or are longer than these dimensions) - a barrier does not produce a "dark" (silent) shadow region, because of the diffraction of sound around the barrier edges. In terms of the light analogy, the shadow regions behind barriers here are grey and diffuse, rather than black and sharply defined. In short, barriers provide relatively little attenuation at low frequencies, even in absence of reflections from other nearby structures.

Barriers are useful primarily for outdoor applications in areas where no reflecting features are present that can serve to provide an efficient sound path around the barrier. Where a sound source and hearer are in the same room, barriers tend to be ineffective, because walls, ceilings, floors, and machinery, etc., generally are good reflectors which help the sound pass around the barrier. However, if all these reflecting surfaces are treated acoustically so that they reflect little sound, then barriers can provide useful amounts of attenuation.

Enclosures Around Noise Sources

An enclosure may be visualized essentially as a barrier that is wrapped entirely around a source, so that there is no path for sound leakage around the barrier. Thus, the amount of noise reduction that an enclosure can provide is not limited by the sound that is transmitted around it, but rather by the sound transmitted through it. Therefore, full enclosures as a rule can provide considerably more attenuation than partial enclosures or barriers.

Because of this relatively large amount of attenuation provided by enclosures, openings tend to reduce the performance of enclosures more than that of barriers. Openings in enclosures should therefore be avoided to the greatest possible extent; where openings are unavoidable, they should be provided with mufflers (labyrinthine lined ducts).

Enclosures may consist of sheetmetal structures built around all or part of a machine (the latter case in essence using a portion of the machine housing as part of the enclosure), or they may be in the shape of boxes, rooms or buildings housing one or more noisy pieces of equipment. In all cases, enclosures provide their noise-reducing effects by preventing direct communication of the vibrating air (sound) inside the enclosure with the air outside it. Sound reaches the outside of well-designed (essentially air-tight) enclosures only because the interior air vibrations cause the enclosure surfaces to vibrate, and because these surface vibrations set the external air into motion.

The effectiveness of an enclosure depends primarily on the extent to which the vibrations of its surfaces can be limited. In designing an enclosure, it thus is imperative that one avoid mechanical contact between the enclosed item and the enclosure walls, in order to avoid direct vibration transmission. Where fastening of enclosure surfaces to the enclosed item is required, this fastening should be "soft", - i.e., via vibration isolators (e.g., rubber isolation mounts, foam rubber gaskets).

The plate and shell components of sheetmetal enclosures generally need to be stiff in order to resist being set into motion by the vibrations of the interior air. Sheetmetal components usually vibrate considerably at their resonances, and thus provide poor sound isolation, unless some damping is provided. Such damping can be obtained, for example, by coating the metal surfaces with a damping mastic (many such are commercially available), or by making the enclosure surfaces out of sandwich materials incorporating viscoelastic adhesives.

On the other hand, enclosures in the form of rooms or buildings generally require walls that are as heavy as possible - i.e., that have large weights per square foot - if they are to resist excitation by sound in the frequency range of usual interest.

Use of acoustical absorption inside enclosures enhances their performance because this absorption decreases the sound level in the enclosure and thus reduces the sound's capability for vibrating the enclosure walls. Added absorption is particularly effective in enclosures that have little acoustical absorption to begin with (e.g., whose interior surfaces are entirely of brick and/or steel).

One may also reduce the radiation from an enclosure surface, and thus improve the acoustical performance of the enclosure, by "decoupling" the surface from the air outside the enclosure. One means for accomplishing this decoupling consists of placing a second enclosure around the first, in effect constructing a double-wall enclosure. Such enclosures tend to be very effective, particularly if the two walls have different masses per unit area and different flexural stiffnesses, if the air space between the walls is of considerable thickness, and if some acoustical absorption is provided in that air space.

One may also obtain a decoupling effect much like that of a double-wall configuration by fastening a secondary wall to the primary one via a soft layer (e.g., of fiberglass or foam rubber). For all double-wall configurations, care must be taken to avoid direct mechanical contact between the interior and exterior walls.

Acoustical Absorption

In situations where a listener's noise environment contains a significant component that reaches him via reflections from walls, ceilings, etc., acoustical absorption that reduces these reflections is useful for reducing the listener's noise exposure. On the other hand, added acoustical absorption in spaces where reflections are not significant can produce no measurable reduction in the observed noise.

Reflections are likely to be important in locations where sound sources are enclosed in rooms or buildings with surfaces that have little acoustical absorption (e.g., walls, roofs, and ceilings of concrete, brick, steel, glass) and no large openings. In such spaces, sound bounces back and forth - and one can usually hear many echoes of impulsive noises such as footsteps, hand claps and pistol shots, provided these noises are intense enough to be audible above the general background. Because a listener in such a space is exposed to reflected sound that arrives from many directions simultaneously, he usually cannot tell where a given noise originates. Thus, acoustical absorption is likely to be useful wherever echoes can be heard and wherever one cannot localize a sound source (that has a characteristic different from the background noise) using only one's ears.

In order to be effective, acoustical absorption - for example in the form of acoustical tile or fiberglass batts - should be placed on several nonparallel surfaces of a space, e.g., on two adjacent walls and the ceiling of a room. (If only the walls were treated, for example, sound could still bounce back and forth between floor and ceiling.) It is usually convenient to attach such acoustical treatments to walls and ceilings, but suspending panels of absorptive material - vertically, horizontally, or at any angle - anywhere is also acceptable acoustically, and often preferable.

Acoustically absorptive materials perform their function by virtue of the multitude of small openings they contain. Sound waves impinging on these materials set up minute air flows through these openings, and the friction these flows experience produces energy losses, which drastically reduce the amount of acoustical energy that is reflected. Thus, anything that closes off the "pores" in acoustical absorbers reduces or destroys their effectiveness; for example, acoustical mats or tiles that are painted, clogged with dust, or full of water cannot absorb much sound. However, sealing absorptive materials in bags of thin plastic (e.g., 1 or 2 mil thick mylar) has been found to preserve their acoustical properties while preserving their cleanliness. Such thin plastic films evidently move with the impinging sound and do not appreciably obstruct the pumping of air through the pores, provided these films have some freedom to move. In order to assure this freedom, some kind of netting should be placed between the plastic layers and the porous materials; it usually is necessary also to place some protective cover - e.g., of perforated metal - on the outside of the plastic film, to help preserve its integrity.

Control of Hearer Exposure

Personnel Enclosures

One may reduce the noise to which a person is subjected by providing him with an enclosure. The same principles apply to such enclosures as apply for machinery enclosures. However, personnel enclosures must be carefully designed to permit people to use them and to perform their required work in reasonable comfort. Thus, room-sized personnel enclosures typically must have doors and observation windows. Care must be exercised to ensure that the doors and windows are heavy enough and tightly enough sealed, so that they constitute no excessive sound leakage path. Windows usually should be double-glazed, consisting of two panes of different thicknesses separated by an air space. Care must also be taken to treat ventilation ducts and other utility penetrations of the walls acoustically, so that also they permit no excessive sound leakage.

In some work or observation positions, where personnel need to enter and leave often and without obstruction, one may use partial enclosures. Such enclosures may be essentially like phone booths, but with the doors removed; some enclosures enclose only the upper half of a person and are open on the bottom. Partial enclosures in all cases are less effective than full enclosures; their effectiveness depends strongly on how well they are lined with acoustically absorbent material.

Numerous designs of both full and partial enclosures for personnel are commercially available, including some in modular form. Full enclosures can be expected to yield noise reductions (at a listener's ear) of about 20 to 25 dB(A), whereas partial enclosures typically result in reductions of 10 dB(A) or less.

Ear-Protective Devices

Where enclosures are impractical, one may need to resort to noise-attenuating devices worn over or in the ears of exposed personnel. Such devices are of three types: ear plugs, ear muffs, and helmets.

Ear plugs are made of soft nonporous material and are designed to fit into the ear canal. Properly designed plugs can provide as much as 25 dB(A) attenuation in typical coal cleaning plant noise environments. However, their effectiveness is greatly reduced if they are poorly fitted or placed. They also present a cleanliness problem, unfortunately, and many workers refuse to wear them continuously.

Dry cotton or similar material stuffed into the ear canal is not an adequate substitute for well-designed ear plugs. Such materials offer no appreciable protection from noise, contrary to popular belief. However, wax-impregnated cotton and some similar commercially available materials work almost as well as good ear plugs, if carefully inserted into the ear.

Ear muffs are devices that surround the external ear completely. If they fit well and allow no leakage, good ear muffs can provide as much attenuation as good ear plugs. Unfortunately, leak-free fitting is difficult, particularly if the wearer has much facial hair or is also wearing eye-glasses with ear-pieces; the face-to-ear muff seal also often is broken by jaw motions associated with chewing, swallowing, or talking. Because muffs have much less of a cleanliness problem than ear plugs, muffs tend to be more easily accepted by workers. Because of the greater visibility of ear muffs, their use also can be supervised more easily.

Experience has shown that the percentage of employees misusing ear protective devices - or not using such devices, even if they are made available - is alarmingly high. Effective use of such devices by workers generally requires convincing them of the desirability of such devices (by means of an indoctrination program that spells out the hazards of excessive noise exposure) and a program of supervision and enforcement. Acceptance of ear protective devices by workers is usually greater if they are allowed some choice in the selection of the devices, and if care is exercised in keeping the devices clean, comfortable, and irritation-free.

Limitation of Exposure Duration

Since people can stand high noise levels for short periods of time without suffering hearing damage, one can protect workers from the adverse effects of intense noise by limiting the time these workers are exposed to intense noise. The permissible exposure durations are specified in the Walsh-Healey Act and are given in Table I of this report.

Figure 5 has been prepared to permit one to determine easily how much time a worker is permitted (according to the Walsh-Healey Act specifications) to be exposed to a given noise level, if he needs to work at a specified noise level for a specified period of time. The example indicated in the figure shows that if a worker is required to spend 1.5 hours per day in 100 dB(A) environment, then he is permitted to spend at most 2 hours per day in an area where he is exposed to 90 dB(A); the remainder of his working day he would presumably be permitted to work only in much quieter locations (perhaps where the noise level is no greater than 80 dBA).

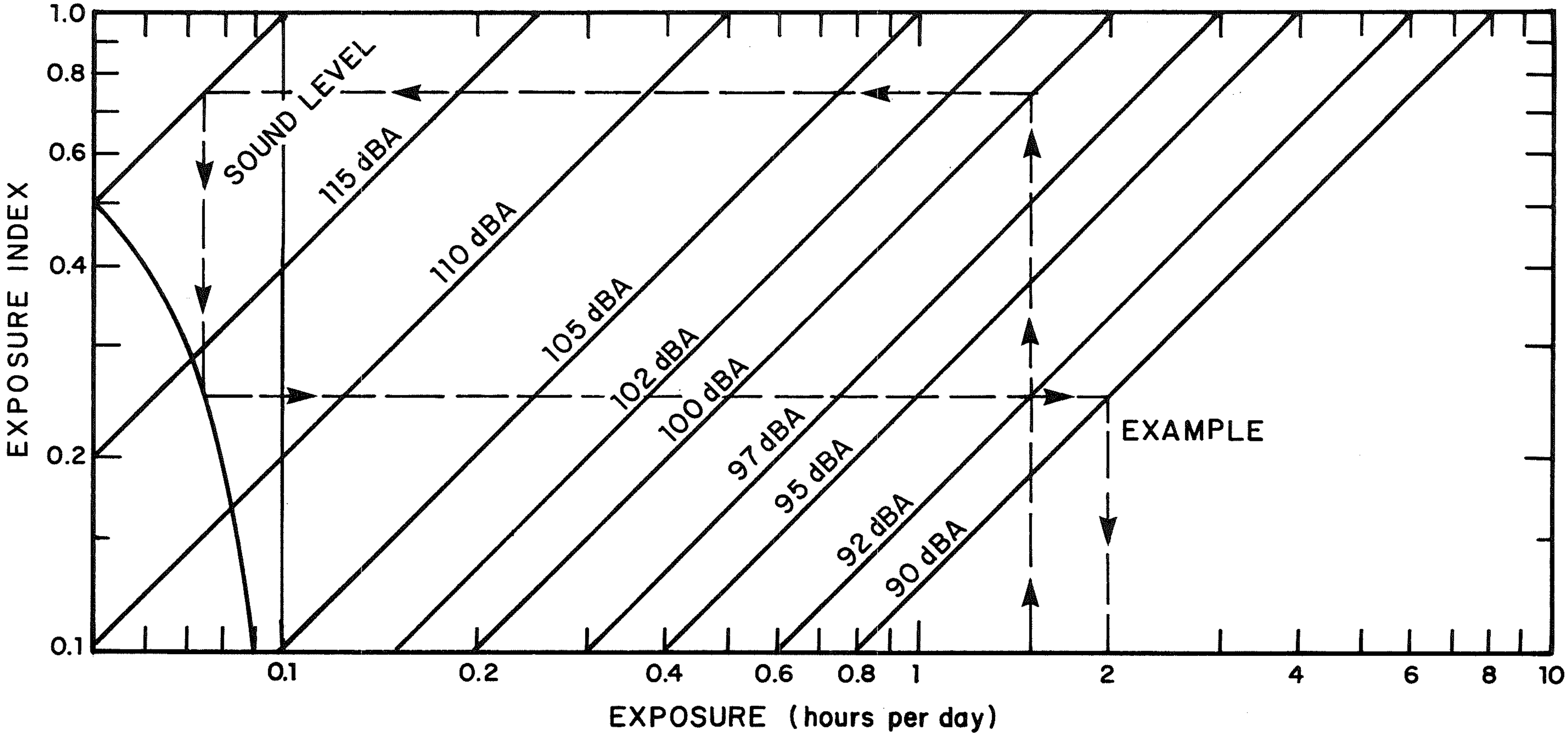

FIG. 5 - CHART FOR DETERMINATION OF ADDITIONAL ALLOWABLE EXPOSURE

EXAMPLE: Find exposure to 90 dB(A) allowed in addition to 1 1/2 hour/day exposure to 100 dB(A). Answer: 2 hours/day.

Careful supervision and administration are required in plants where this type of exposure control by rotation of work locations and/or assignment is required. "Dosimeters" - commercially available devices that are worn by individuals and that record their total noise exposure - can be useful for monitoring and administrating this rotation process.

IV. PREPARATION PLANTS AND THEIR NOISE

Plant Characteristics

Raw coal must be processed before it can be used. About half the coal produced in the United States (595 million tons in 1972) requires only a modest amount of crushing and screening; this is done in low-capacity facilities which may be called "raw coal plants". The remainder of the coal requires further treatment to remove impurities; this is done in mechanical cleaning plants, of which approximately 408 were operating in 1972 (U.S. Bureau of Mines, 1972). The present study is concerned primarily with the noise in these cleaning plants, and the term "preparation plants" here is used in that sense.

Mechanical cleaning plants perform two general functions: (1) removing impurities such as rock, ash, and sulfur from the raw product, and (2) classifying the coal according to size. Since all plants must store and move coal, they all have a basic set of components in common; these include conveyors, bins, feeders, and chutes. The vast bulk of classifying work is done by means of screens, and these also are common to virtually all plants, as are crushers. However, different processes are used for cleaning, depending on the composition of the raw product and the end use for which the coal is intended.

Processes

There are three principal methods by which most coal is cleaned: jigs, heavy medium baths, or air tables.*

*These three processes constitute the primary coal cleaning methods; they account for 80% of the mechanically cleaned coal. Other processes (flotation, classifiers, concentrating tables, etc.) are typically used in series with the three primary processes in order to recover fine particles and thus enhance overall plant efficiency.

About 85% of all plants use only one of these processes; the remainder combine processes. The distribution of plants by type is shown in Table III. One may note that heavy media plants account for almost half of the total, with jigs the next most common type of plant. Plants with air tables are relatively scarce; this technique is fairly obsolete, for a variety of technical and economic reasons. The fact that air tables are commonly found in conjunction with other processes probably reflects the trend of plant conversions from air to wet cleaning techniques.

The relation between primary cleaning process and plant size is evident from Figure 6, which shows the distribution of plants by output capacity for each process. (The figure includes only plants that use a single primary process.) Jig and heavy media plants have average output capacities of 4.3 and 5.1 thousand tons per day, respectively; air table plants, on the other hand, average only 2.0 thousand tons per day. The small contribution of air table plants to the mechanical cleaning industry is also evident from Table III, where pure air table plants are shown to account for only 4% of the total cleaning capacity.

Machines

As has been mentioned, almost all preparation plants contain conveyors, feeders, bins, chutes, crushers, and screens. A 1969 survey of 90 plants yielded an estimate of the average numbers of these types of equipment (except for bins and chutes) installed in plants of different sizes. This estimate is shown in Table IV.

Primary coal cleaning equipment varies from plant to plant. No complete survey information is available, but Table V presents

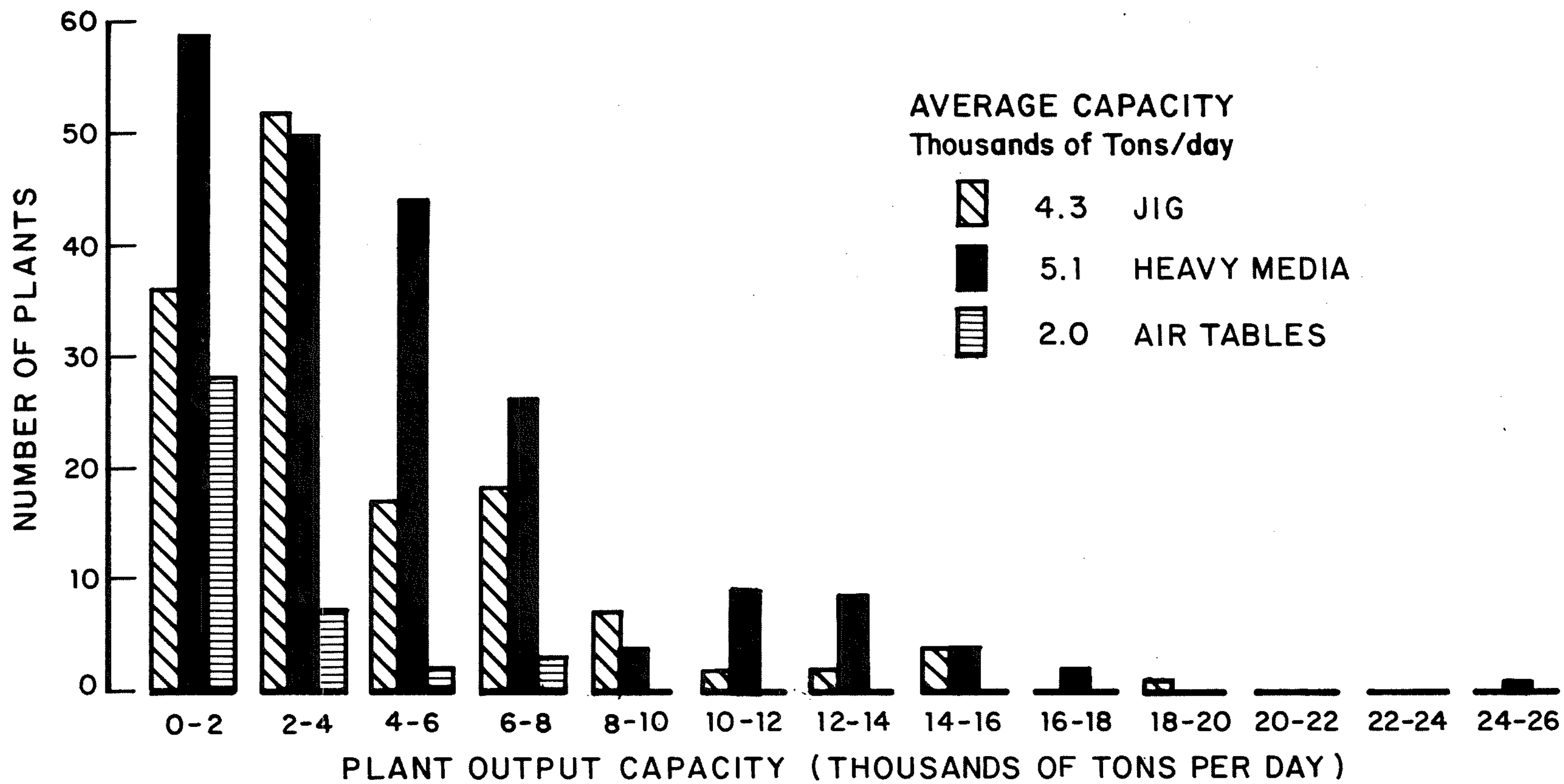
AVERAGE CAPACITY
Thousands of Tons/day
4.3 JIG
5.1 HEAVY MEDIA
2.0 AIR TABLES
NUMBER OF PLANTS
0
10
20
30
40
50
60
0-2
2-4
4-6
6-8
8-10
10-12
12-14
14-16
16-18
18-20
20-22
22-24
24-26
PLANT OUTPUT CAPACITY (THOUSANDS OF TONS PER DAY)

FIG. 6

Table III

Distribution of Mechanical Cleaning Plants
by Primary Cleaning Process*

Process	Number of Plants	Percent of Plants	Percent of Total Output Capacity
Jigs	130	29%	29%
Air Tables	40	9%	4%
Heavy Media	210	47%	54%
Jigs and Air Tables	9	2%	2%
Jigs and Heavy Media	22	5%	4%
Air Tables and Heavy Media	36	8%	6%
Jigs, Air Tables, and Heavy Media	2	<1%	<1%
	449	100%	100%

*Figures based on a 1972 survey conducted by Theodore Barry Associates.

Table IV

Average Numbers of Coal Classification Equipment Items in Plants of Various Sizes*

Equipment	Plant Output (tons per day)		
	Under 2000	2000-5000	Over 5000
Conveyors	14.6	11.2	8.0
Feeders	4.8	3.3	7.0
Crushers	2.8	2.1	2.4
Screens	8.7	10.0	6.9

*Source: Coal Age, 1969. Original study gave plant size in tons per year; this table assumes 250 production days per year.

typical numbers of primary equipment items noted during noise measurement field trips under the contract which led to the present report.

The distribution and average numbers of secondary and auxiliary equipment items found in plants of various sizes are given in Table VI.

Table V

Typical Numbers of Primary Coal Cleaning Machines in Plants of Various Types*

Process	Plant Input Capacity (tons per day)	Number of Machines
Jig	27,000	2
Jig	19,000	2
Heavy media vessel	29,000	14
Heavy media cyclone	24,000	18
Air table	2,400	3

*Source: Counts during plant noise survey.

Table VI

Average Numbers of Secondary and Auxiliary Cleaning Equipment Items in Plants of Various Sizes*

Equipment	Plant Output (tons per day)		
	Under 2000	2000-5000	Over 5000
Cyclones	5.3	8.1	6.25
Concentrating tables	7.5	7.3	21.3
Centrifugal dryers	3.3	2.9	2.8
Filters	.75	1.3	2.6
Flotation Cells	-	6.0	6.0

*Source: Coal Age, 1969. Numbers represent the average number of each item in those plants where the item is present.

The figures in Table VI do not tell the full story, for two reasons: (1) within any category there are several different types of equipment which may operate on different physical principles; (2) the unit capacities are much larger for larger plants. Nevertheless, the statistics do give guidance as to the potential magnitude of the noise control problem.

Workers

The number of production workers present in coal preparation plants varies, depending on the plant's age, size, and process. Industry-wide data are not available; the following discussion is based on limited field observations made in the course of the current contract effort.

The workday in most plants is divided into two operating shifts and one maintenance shift. Noise is of concern only in relation to the workers who are present during operation, because the plant is shut down during maintenance. The workers present during operation fall into two general groups: those inside the plant and those at exterior locations. The workers within the plant are of primary concern since they are the ones most exposed to noise.

Figure 7 indicates how the number of in-plant workers per shift varies with plant size, for those plants included in the survey. From this small a sample, one cannot derive a meaningful average number of workers per ton of plant capacity, especially since age of the plant and the nature and number of processes employed in the plant are contributing variables. It is worth noting that, of the two jigging plants included in the figure, the one built in 1951 uses .55 workers per 1000 tons/day of capacity while the one constructed in 1928 employs 1.2 workers per 1000 tons/day.

The workers within the plant can be characterized as either stationary or mobile. Again, statistics are unavailable, but observation indicates that a typical workforce is about evenly divided between the two groups. Stationary workers are usually associated with a particular piece of machinery or work station which requires full-time attendance. Examples of these are panel-board operators, pickers, and tipple operators. These people are exposed to a fairly constant noise environment. Mobile workers include men who operate several different pieces of equipment (each one needing only part-time attendance), mechanics, general laborers and clean-up personnel.

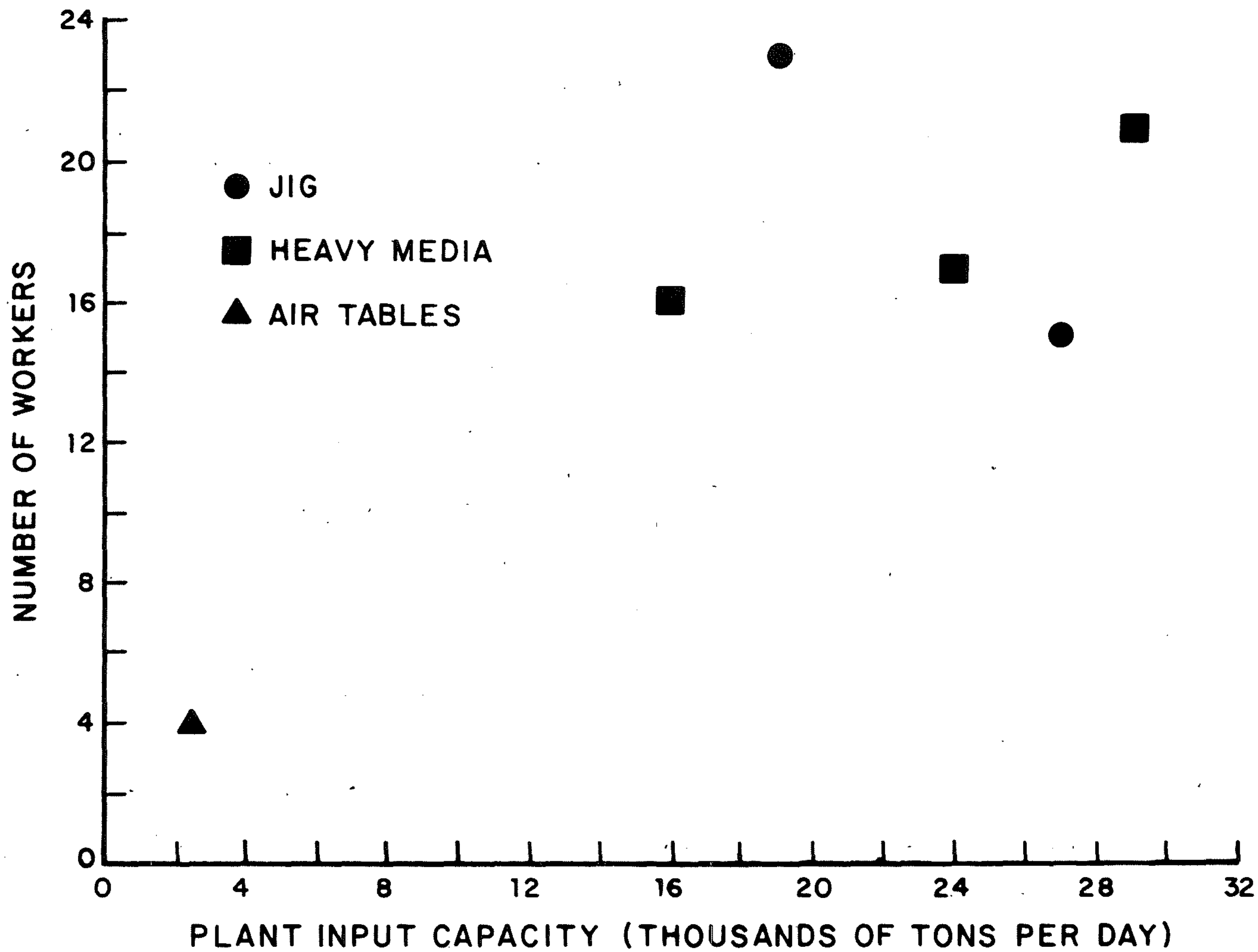

FIG. 7. NUMBER OF IN-PLANT WORKERS PER SHIFT VS. SIZE OF PLANT FOR SIX PLANTS

Because of the high variability in plant layouts and machinery lineups, general statements concerning workers' exposure to noise tend to be relatively useless. (For example, one plant that was surveyed was found to have very high levels in some machinery areas, but to have no workers actually exposed to noise in excess of the Walsh-Healey criterion.) However, it is possible to associate potential hazards with specific permanent work stations, where a permanent work station is defined as a station occupied more or less full time by one or more workers during the plant's operation. (Although all plants surveyed had screens, only two had a full-time operator's position.) The range of sound levels measured at each permanent work station is shown in Figure 8, along with the number of such stations found in the six plants surveyed. Figure 8 thus provides an indication of the severities of the noise exposure for the various work stations and of the frequency with which such work stations occur among plants.

Figure 8 shows that the most commonly found permanent work stations, listed in order of decreasing noise exposure, are: shake-out operators, pickers, conveyor operators, and control panel operators. The remaining work stations are found relatively infrequently, although some (such as vibrating feeder and screen operators) may have severe noise exposure problems when they do occur.

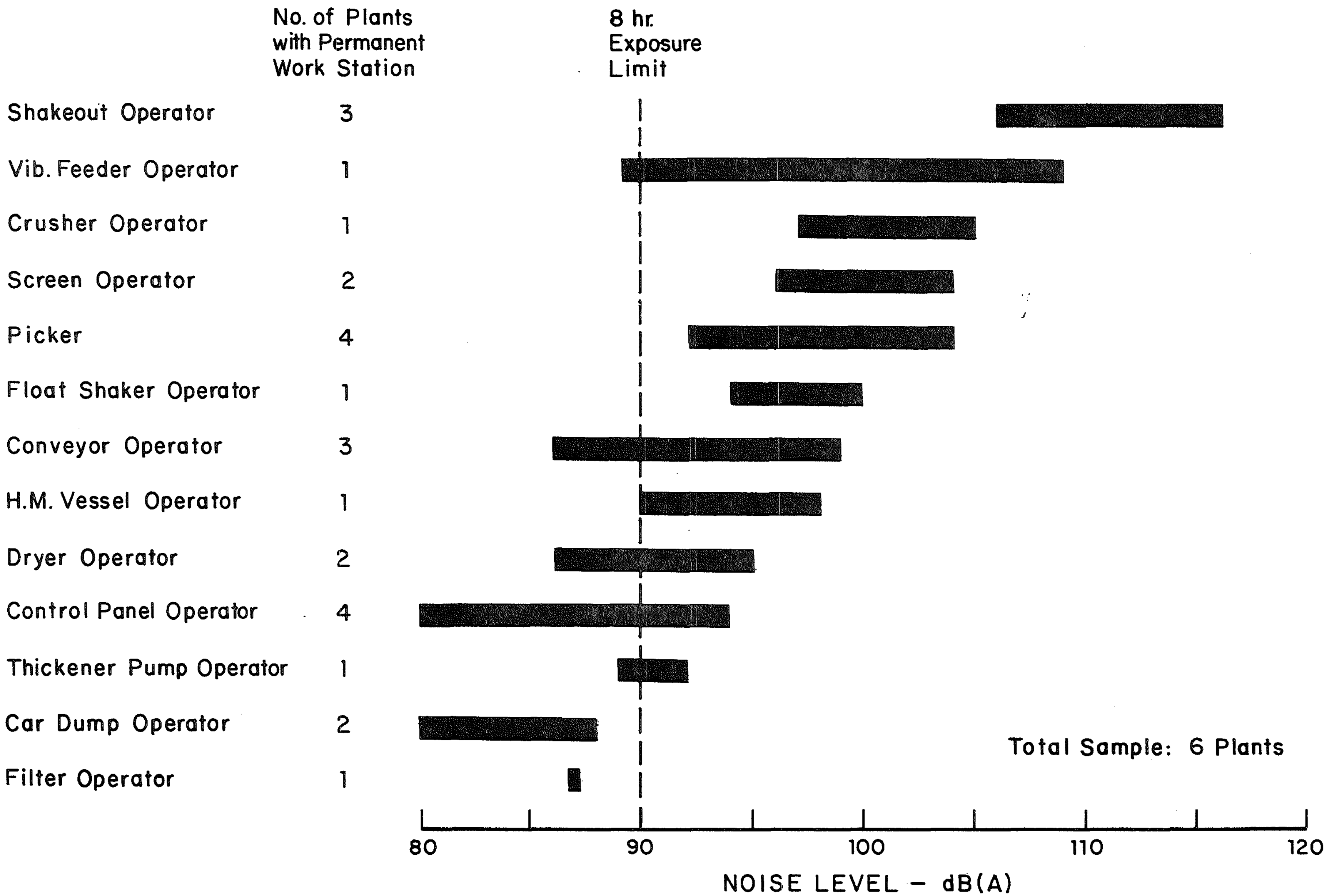

FIG. 8. RANGES OF NOISE LEVELS AT VARIOUS PERMANENT WORK STATIONS

V. REDUCTION OF PREPARATION PLANT NOISE

General Considerations

Operations

Most preparation plant functions are controlled from a central operator's position, with the operator at some distance from the equipment itself. With the exception of picking tables, few machinery items require that workers be able to have immediate physical contact with the machine or the coal. Thus, noise control enclosures would not directly impede the coal cleaning process. However, plant personnel want to be able to see the flow of coal through chutes and screens and to prevent sticking and jamming; this requirement complicates the design of close-fitting enclosures and may limit their utility.

Maintenance

Maintenance activities in preparation plants frequently include cutting and welding of worn or damaged parts. Treatments applied to any surfaces repaired by these means must not impede torch-cutting, either by being unsafe or by being prohibitively expensive to replace.

For maintenance purposes it is often necessary to move large pieces of machinery within the plant. This means that any noise control enclosures or partitions must have large doors or be removable.

Safety

The primary safety concern in cleaning plants is dust build-up and the consequent fire hazard. Thus, fibrous acoustical materials, which may tend to retain dust, cannot be used in coal preparation plants without special treatment. All installations should also be designed for easy cleaning, ideally by water hosing.

Worker Acceptance

From cursory interviews with workers and supervisors it appears that workers presently do not set a high value on quiet. Although workers are aware that some work stations are noisier than others, this does not affect their choice of assignments; work at picking tables, for example, tends to be popular. This attitude toward noise may change, however, as general noise consciousness increases.

Workers may object to some noise control techniques. Workers tend to value their ability to hear the equipment operating, claiming that this ability allows them to recognize irregularities and forestall trouble. To the extent that noise control treatments (such as operator enclosures) interfere with this ability, they will be disliked. Experience in other industries indicates, however, that the operators will become acclimated to the lower noise levels after some time, and objections to noise control treatments will wane.

The fact that workers in the mining industry generally are highly health- and safety-conscious can be expected to enhance their ultimate acceptance of noise control procedures. Virtually all workers currently receive annual instruction in various aspects of mine safety. If hearing loss is presented as a health hazard, like visual damage or lung disease, for example, worker cooperation with noise control efforts could be greatly facilitated.

Cost Considerations

The cost of noise control is reflected not only in the cost of materials and labor, but also in the impact on the firm's normal pattern of business. To account more fully for these impacts, one can define four general categories of cost within which the characteristics of proposed noise control treatments can be discussed:

1. *Direct Initial Costs*. These comprise the actual cost of installation, including expenditures for materials, labor, and shop capacity.
2. *Indirect Initial Costs*. This cost is the lost sales due to extra downtime required to install noise control equipment.
3. *Direct Operating Costs*. This includes increases in the required power consumption and operator's labor needed to clean a given amount of coal.
4. *Indirect Operating Costs*. These include changes in sales due to changes in the plant cleaning capacity, and any changes in inspection and maintenance effort.

The actual value of these costs vary from plant to plant for a given noise control treatment. Only some general considerations are discussed below.

Direct Initial Costs

Hardware modifications in existing plants are usually done by the plant's internal workforce, except in cases where a major process revision is being made. Major equipment items are purchased from the manufacturer and delivered in knocked-down form; the labor for assembly and installation is provided by the plant's maintenance staff. Minor items are frequently fabricated in the plant's own shops. In general, plant personnel have the skills and equipment which would be required to fabricate and install noise control treatments.

Most often, the maintenance shop and labor force capacity is large enough to sustain the normal preventive maintenance effort (which is quite substantial) plus a few "special projects". The ability of the normal maintenance staff to perform noise control work without hiring extra labor or adding more shop space depends on the rate at which the work must be performed. If enough time is allowed for compliance with a given reduced noise level, then most of the work can be absorbed into the normal maintenance routine. A quieting program consisting of enclosures, mufflers, vibration mounts, and similar hardware add-ons probably could be accomplished by most plants within the space of a year, without their having to hire extra workers or to obtain extra shop capacity. A crash program to obtain compliance within, say, three months would require substantial additions to the staff and shop facilities and might also result in considerable plant downtime (see below under Initial Indirect Costs). Some quieting items, such as application of wall treatments, are usually best done in a single effort rather than distributed out over time; accordingly, such work might be done by an outside contractor using his labor force.

Indirect Initial Costs

As with direct costs, the indirect cost associated with noise control retrofit depends largely on the allowed performance period. Coal preparation plants typically have a considerable amount of normal downtime built into their operation. A typical plant runs two shifts per day, the third being reserved for maintenance; six days a week; and fifty weeks per year, two weeks being used for vacation shut-down. This amounts to approximately 4000 plant-hours per year during which operating machinery can be accessed without interfering with production. With careful planning and enough lead time, it should be possible to do almost all the necessary work during these inactive periods. As stated before, a crash program would require extra downtime with a consequent loss of production.

The effect of lost production varies greatly, depending on the nature of the larger operation of which the plant is a part. If the plant is owned by a steel company that has many alternate sources of coal supply, then a week's shut-down would have little impact on the parent company's operation. An independent operator selling on the open market, on the other hand, might have a problem. If he is operating at less than full capacity prior to the shutdown, then he can presumably use the extra capacity to build up inventories sufficient to tide him over. If he is operating at full capacity, however, he cannot do this; a week's extra downtime is then a week's lost revenue. Current prices at the mine run from $26 to $36 per ton for good quality metallurgical coal (5-7% ash, .7% sulfur) to $20 a ton for steam coal.* If an operator who produces 6,000 tons of coal per day sells it at $25 per ton, a week's shutdown will cost him revenues of $900,000. Even when reduced costs are taken into account, this is a substantial impact. The incentive to complete the noise control work during normal downtime is obviously great.

*Prices obtained from a spot check of wholesale coal brokers. Prices current as of March 1974.

Direct Operating Costs

None of the noise control treatments considered in this report would require an increase in the amount of operating labor required to run the plant. It is possible, however, that power consumption may be increased by some of the measures. Enclosing motors, for example, may require the addition of ventilating fans. Replacing picking tables with rotary breakers will also require additional power, but with a savings of one man's labor.

Indirect Operating Costs

Some noise-control devices may add to the effort required to maintain plant machinery. Enclosures, for example, will, to some extent hamper access to parts of the enclosed machine. In addition, the devices themselves will require some inspection and repair. It is not anticipated, however, that the extra effort will require any significant expansion of the plant's maintenance staff.

Machinery Noise Reduction

As discussed in Section III, the overall noise control problem is best viewed in terms of the amount of noise reduction required by the receivers (workers), the paths that the noise travels from the sources to the receivers, and the source noise generation characteristics. General approaches to noise control are also delineated in Section III, and it is noted that noise reduction at the source is most effective wherever it can be implemented. The noise producing mechanisms and the noise levels associated with the various types of machinery were presented in the foregoing section; the present section deals with the specific available noise treatments applicable to the various items of coal cleaning plant machinery.

Screens

The simplest add-on method for reducing the noise generated by screens consists of building an enclosure around the screen. Noise reductions of 10 to 15 dB(A) may be realized with enclosures that also cover the driving mechanism, producing generally acceptable in-plant noise levels adjacent to screens. A few plants have actually installed enclosures on coal screens, but no general information is available on maintenance problems (access doors or covers must be removed for service), operational problems (improper flow of material over the screen or breakdown of the deck that cannot readily be observed) and on enclosure life and deterioration. The initial cost of rubber-covered decking is estimated to be $1,000 to $2,000 per screen greater than that of conventional decking.

Replacement of the steel deck with a rubber-coated or other resilient deck would reduce the severity of impacts and the associated noise. Reductions of the order of 5 to 10 dB(A) may be expected for the impact-related component of screen noise, but the total noise reduction would be only between 2 and 8 dB(A); the 2 dB(A) corresponds to screens processing clean bituminous (soft) coal, and the 8 dB(A) corresponds to screens handling refuse of anthracite (hard) coal.

The performance and economic advantages and problems of rubber-coated and similar decking are not clear. Although the initial cost of rubber-coated decking is about three times that of conventional decking, the estimated life of rubber-coated decking is about 3 to 5 times that of steel decks. Some operators state that rubber decking would not work for processing fine coal, that larger deck area is required to process the same flow rate, and the rubber-coated decking would require additional structural support. On the other hand, some plant experience has shown these drawbacks to be either minimal or absent, and has in at least one instance indicated achievement of an increased flow rate with the same surface area.

Reductions of impact severity and the associated noise may be obtained also by reducing the stroke and speed of the shaking mechanism. Noise reductions of 5 to 10 dB(A) are estimated to be achievable. The related direct costs would be minimal (corresponding only pulley and throw changes), but the process flow rate would be reduced, so that this approach is not likely to be acceptable economically.

It is recommended that rubber-coated decking be given first consideration and that an enclosure be used if rubber-decking will not reduce the screen area noise level to below 90 dB(A). If the noise produced by the empty screens is below 87 dB(A), rubber-coated screens may be expected to reduce the (full) operating noise level to below 90 dB(A). If the noise level produced in the screen area by the empty screens is above 87 dB(A), control of mechanical vibrations is required, as discussed below.

Reduction of the noise contributed by the eccentric weight driving mechanism may be achieved by use of gearing manufactured to closer tolerances and tighter bearings. Corresponding reductions of 5 dB(A) are possible, at a cost differential of about $100 for new screens or $300 for retrofit of old screens. Alternatively, one may consider covering the mechanism with a closely fitting enclosure that is acoustically lined and vibration-isolated from the case. Noise reductions of up to 10 dB(A) are possible, at an estimated cost of about $200 per unit; however, the associated cooling and maintenance problems are not known.

When noise is caused by a chattering of screen supporting spring against the mount pad or screen frame, one may insert a resilient pad between the spring end and screen structure to obtain perhaps 5 dB(A) of noise reduction at a cost of about $50 per screen. Alternatively, one may replace the steel springs with air bags. The cost is higher, of the order of $300 per screen, but field reports indicate that air bag supports produce a reduction of the total screen-related noise, which may be as high as 15 dB(A).

Where the foregoing noise reduction treatments are not feasible, one needs to consider enclosures. Enclosures for dust-control purposes are currently available for production-model screens. It would not be difficult to add acoustical absorption to the interiors of these enclosures, thus increasing their acoustic effectiveness. When purchased with the screen, a dust-control enclosure typically costs $7000 to $10,000; interior acoustic treatment would perhaps add another $300 to $600. There is some concern among operators that enclosures would prevent visual inspection of screen decks, thus hindering removal of refuse and clearing plugged holes; however, the dust-control enclosures presently in use in the coal cleaning industry seem to be quite acceptable.

Chutes

Impact noise reductions of about 5 dB(A) can be achieved by lining the chute with a rubber or similar covering. The availability, wear, repairability, and costs of suitable coverings is not known.

A widely employed useful approach consists of placing welded ledges or similar obstructions to the flow of material into the chute, so that a layer of material remains in the chute. This layer then shields the chute surface from the impacts. The expected noise reduction is about 5 dB(A). Utility of this approach is limited to cases where the flow obstructions created by the chute inserts can be tolerated.

The addition of mass to chutes, in the form of concrete liners on the inside (as are often used for wear reduction) or of metal plating or sandbags on the outside may also be expected to contribute several dBA of noise reduction at limited cost. Wear and repairability remain to be explored.

The same statements apply also to the use of structural damping materials adhered to the exterior surfaces, except that their safety and costs for coal preparation plant applications are also not known.

Hoppers and Bins

The noise problem associated with hoppers and bins must be attacked by reducing the vibrations of their panels. This may be accomplished by mass-loading the panels with material - most simply keeping the hopper or bin full or nearly full. Alternatively, additional mass (steel panels, sand, etc.) can be added to the outside. One may also consider rubber-linings on the insides, especially in the area where direct impact occurs. Noise reductions of 5 to 10 dB(A) should be achievable with any one of these approaches. The first, of course, implies an operational constraint, but no other cost. The other approaches imply potential structural (weight) problems, as well as unexplored maintenance complexities and costs estimated at $500 (for material) per hopper or bin.

Crushers

Noise radiation from double roll crushers may be reduced by keeping the material inflow uniform. Since most of the perceived noise from crushers is radiated by the external casing and gearing, noise control may be achieved by reduction of the gearing tolerances and backlash and by use of tighter bearings. If such modifications cannot be implemented or if the resulting noise reduction is insufficient, then an enclosure should be placed around the crusher and associated gearing. This enclosure would need to be provided with acoustically treated ducts at the inflow and outflow positions. The cost of improved gearing is difficult to estimate until the required tolerances are known; a complete crusher enclosure is estimated to cost $2,000 for labor and materials.

Car Shakeouts

The pounding of the shakeout mechanism against the railroad car side cannot be reduced without reducing its efficiency for unloading the car. Padding of the contacting surfaces or clamping the shaker to the car sides would reduce the noise, but also the efficiency of the unloading operation. The only practical means for dealing with the noise of shakeouts consists of providing an enclosure for the shakeout operator and his helper. This enclosure must provide at least 40 dB of noise reduction. Thus its walls and ceilings need to be built of massive panels, its door should be self-closing with air tight rubber seals, and its windows must be double glazed. The cost for each such room is likely to be between $10,000 and $20,000.

Replacement of an installation requiring car shakeouts with a rotary dump carloader is rarely feasible and also costly ($150,000 per rotary dump), but would eliminate the shakeout noise problem.

Picking Tables

In some plants, it is feasible to eliminate the inherently noisy jobs of pickers by replacing picking tables with a rotary breaker. However, such breakers are economical only for high throughput rates. Breakers are expensive, costing from $35,000 for a small unit (9' diameter x 12' length) to $100,000 for a large one (13'6" diameter x 32' length). They are heavy, weighing 45,000 to 143,000 lbs., and require considerable supporting structure. The cost of installation, including construction of supports and changing conveyor lines, is approximately the same as the purchase price of the unit.

Because of their size, rotary breakers are usually located outside the plant building. They therefore, may create a community noise problem. This can be overcome by purchasing dust-control hoods and treating them with interior acoustic absorptive material; adding about $7,000 to $10,000 to the cost of the unit.

It is estimated that a rotary breaker can be installed while the picking tables are still on line, with the changeover in operation taking place after the breaker is installed. Little plant downtime would therefore be required.

If rebuilding of the plant as discussed above is not feasible, one may construct a partial barrier between the picker and the table. This would have to be built to suit the local circumstances, and would have to be designed not to interfere with the picking action. Estimated cost for such a barrier, installed, is $1000 to $2000.

Blowers and Fans

The in-plant noise associated with blowers and fans that transport air into enclosed spaces comes primarily from the air inlets. This noise typically has dominant pure-tone (single frequency) components at frequencies that correspond to the rotor lobe or fan blade passage rates and harmonics of those.

Noise control can best be accomplished by means of mufflers or ducts affixed to the inlet port. Where the predominant noise is a single tone at a fixed frequency, mufflers tuned to this frequency can be quite useful. If the dominant noise consists of a multitude of pure tones and/or broadband noise, then a muffler consisting of a long, labyrinthine, acoustically lined duct is required for muffling purposes.

Alternatively, one may duct the inlet to the outside of the coal plant, thus removing the noise source from inside the plant. Either mufflers or ducts should provide about 10 dB of noise reduction if they are well designed acoustically; greater amounts of noise reduction are available if large mufflers and heavy-wall ducts are acceptable. Estimated costs for simple mufflers or ducts vary between $200 and $1,000 per unit, depending on the complexity of the system.

Pumps

Vacuum pumps are similar to blowers, they take air from an enclosed space and exhaust into the plant. Here the exhaust, rather than the intake, is the dominant noise source. The same muffler and ducting noise control approaches apply to the exhaust port of a vacuum pump as for the intake port of a blower, at similar cost. The noise radiated from the shell of snubber tanks that are used in conjunction with vacuum pumps may best be reduced by providing this tank with a sheet metal wrap that is isolated from the shell by a resilient material. Such a wrap might cost approximately $100 per unit and should provide about 10 dB(A) of noise reduction.

Liquid pumps are not significant noise sources, but if noise treatment should be needed, it can best be obtained by means of an isolated wrap around the casing, as discussed above for snubber tanks. Reductions of 10 dB(A) should be attainable at costs of a few hundred dollars per unit.

Valves

Water valves are not a significant noise source. Air valves have been found to produce significant noise levels; valves like the baum jig air valves tend to be extremely noisy due to the explosive and hissing noise associated with the venting process. The noise control methods applicable to air valves are the same as those for blower and fan inlets: the valve exhaust must either be muffled or ducted to the outside of the plant. The estimated associated cost is from $200 to $1,000 per valve.

Air Blasts

Air blasts that are used to aid the material flow in chutes and hoppers generate a loud hissing noise due to the high air exit velocity and impingement of the air stream on solid surfaces. Reduction of the noise of air blasts should be achievable by a redesign of the exit nozzle or fitting to provide a lower exit velocity. A velocity reduction by only 20% should result in little loss of material moving performance, but may reduce the noise by several dB. The associated cost should be minimal, perhaps $100 to $200 per unit.

Water Falls

Although the noise levels produced by water falls rarely are as significant as others, simple perforated deflection shields, introduced above the impingement locations to slow and split the flow, may be used to provide noise reduction of 5 to 10 dB(A) at relatively little cost.

Casing Noise of Blowers, Pumps, Dryers, Motors

The simplest means for reducing the noise radiated due to vibrations of surfaces of machinery consists of the addition of a close-fitting enclosure that is vibration-isolated from the machinery casing. Reductions of casing noise by 10 dB(A) are typical. The costs may be expected to vary according to the size and complexity of the casing to be enclosed; estimates range from $200 to $1,000 per unit. Enclosures must be designed to permit adequate cooling and any required access for maintenance, inspection and lubrication.

Gear Drives

Enclosures like those discussed above also apply for gear drive casings. Noise control at the source would involve use of closer tolerance gears and bearings. The latter approach should provide noise reductions in excess of 5 dB(A), with no changes in efficiency or maintenance requirements. The added cost is about 10% of the cost of conventional gears.

Conveyors

No simple means is available for quieting the noisy squeal of flighted drag conveyors. Lubrication of the rubbing surfaces (with water or oil) might work, but has not been tried. Where possible, drag conveyors should be replaced with rubber-belted conveyors for noise control purposes. Costs of such replacement are high, unless this replacement is made as part of a plant modification program undertaken for other reasons.

Other Equipment

Noise control of electro-mechanical vibrating feeders may be accomplished by replacing them with mechanical feeders; this would lead to a net noise reduction of 10 dB(A). Enclosing electro-magnetic feeders or isolating them from workers by acoustic barriers may provide up to 15 dB(A) of noise reduction, at a cost of about $2,000 per unit.

Rap sieve bins that are used to classify coal are constantly tapped by hammers; resulting in impact, noise, noise due to mechanical vibrations, and air exhaust valve noise. Since the rapping is required for proper machine function, one can only enclose the tapping hammers and provide mufflers for the air exhaust, or one may provide an enclosure for the entire machine. Costs would be about $2000 for up to 10 dB(A) noise reduction.

Acoustical Absorption in Plant Spaces

All of the noise control approaches discussed above have centered on quieting of machines or enclosing of the workers. The use of sound absorbing materials, placed on the walls and ceilings, should also be considered.

However, the addition of such materials is useful only if the sound field in the plant areas is reverberant - i.e., consists largely of reflections from the walls, ceiling, and floor. Measurements (Appendix B) have shown that this is not the case in most plants; thus, little would be gained by use of acoustically absorbent materials in these plant areas.

Noise Control Strategies

To provide a plant-wide worker environment that has a sound level below 90 dB(A), all of the machines or systems ranked 1 through 5 in Table III must be quieted. If a combination of engineering noise control and worker placement and/or scheduling is to be used, only those machines or systems ranked 1 through 4 need quieting. If acoustic barriers are placed between **all** the noise sources ranked 4 and the associated worker locations, then quieting only the machines ranked 1 through 3 should provide acceptable worker noise exposures. The latter represents the minimum noise control required to meet the letter of the required worker exposure limitations.

Machinery Characteristics

Noise in coal preparation plants typically results from numerous simultaneous noise sources. Although the noise producing machinery varies with the plant process and arrangement, the basic noise-generating mechanisms are the same for many different machines, and therefore the same noise reduction techniques apply. The noise-generating mechanisms normally found in coal preparation machinery are: impacts, fluid flows, and structural vibrations. In order to assess the noise reduction means suitable for various machines, it is useful to classify them according to their noise-generating mechanisms.

Impacts

In coal preparation plants there occur impacts of coal and refuse on plates, screens, panels, and each other. A multitude of simultaneous impacts typically produces broadband spectra. For sharp impacts the spectra have considerable high-frequency content; with duller impacts, there is more low-frequency content.

At present, it is not known how much of the noise of chutes and screens is due to impacts between lumps of material and how much due to impact of materials on structural components. Sound radiation may occur directly from the impacting lumps or from the plates and panels that make up the equipment. The hardness of the impacting bodies may have an effect,* as should the impact velocity. Resonances of the structural components may also be expected to affect the character of the noise.

Screens

Screens may be classified as either horizontal or inclined and as either driven by eccentric weights or by crank and rod mechanisms. A typical horizontal screen with eccentric weight drive produces near it a noise level of about 90 dB(A) when running empty. Comparison of noise spectra calculated from acceleration levels measured on the side panels of a screen and with sound spectra measured near these panels (Fig. 9) reveals little similarity above about 1000 Hz. This and other observations indicate

*Screens handling anthracite were observed to be a little noisier than similar screens handling bituminous coal.

that the side panels are not the only noise source. For empty screens, most of the higher frequency noise comes directly from the shaking mechanism; for full screens (whose noise typically is between 3 and 10 dB(A) greater than that of empty screens) the impacts of coal and refuse lumps constitute a noise source whose magnitude equals or exceeds that associated with the shaking mechanism.

Crank and rod-driven screens, like those often used in picking tables, operate at lower shaking frequencies (typically 6-10 Hz) than the typical 15 Hz for screens driven by eccentric weights. The primary noise generating mechanism in crank-driven screens clearly consists of impacts of the coal and/or refuse flowing over the screen. The noise levels of these crank-driven screens are similar to those of eccentric weight-driven screens, except that crank-driven screens are somewhat quieter when running empty.

Modern inclined screens, such as are used to classify coal, typically are driven by eccentric weight mechanisms. The motions of these screens generally are less vigorous than those of horizontal screens; consequently, the noise levels of inclined screens usually are lower than those of horizontal screens. The noise level at 3 ft from a typical empty inclined screen is about 85 dB(A) when the screen operates with coal.

In summary, individual screens produce sound levels of about 90 to 95 dB(A) during clean coal processing, and 95 to 100 dB(A) during refuse and anthracite processing. Since typical plant operation usually entails the use of multiple screens, noise surveys in screen areas usually indicate sound levels of 95 to 105 dB(A), with spectra similar to that shown in Fig. 10.

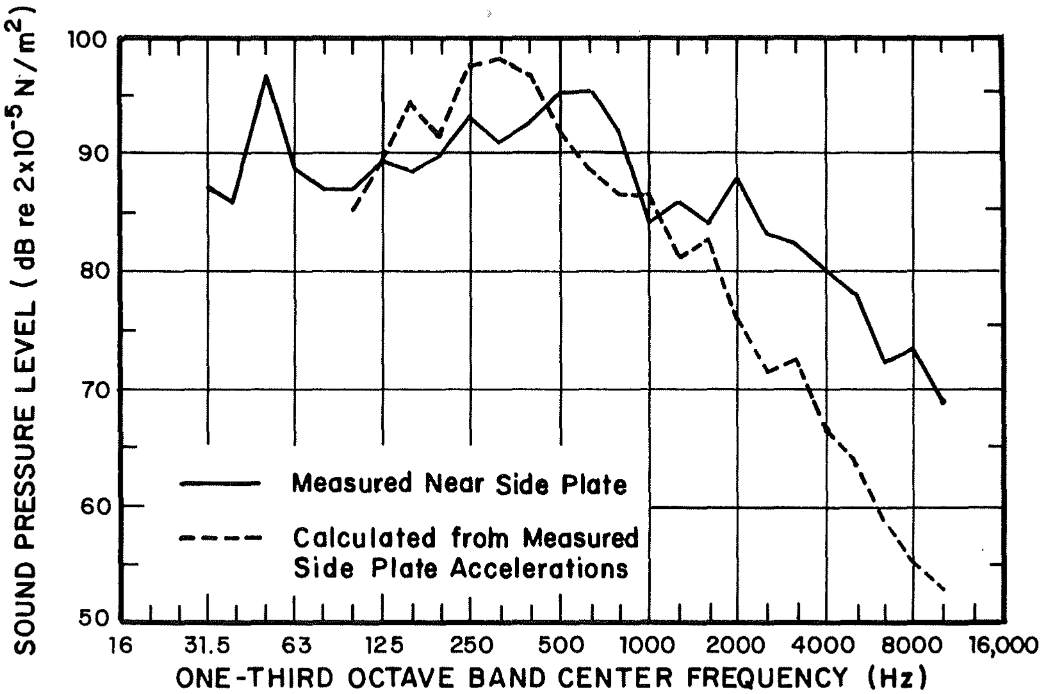

FIG. 9. NOISE NEAR HORIZONTAL SCREEN WITH ECCENTRIC WEIGHT DRIVE

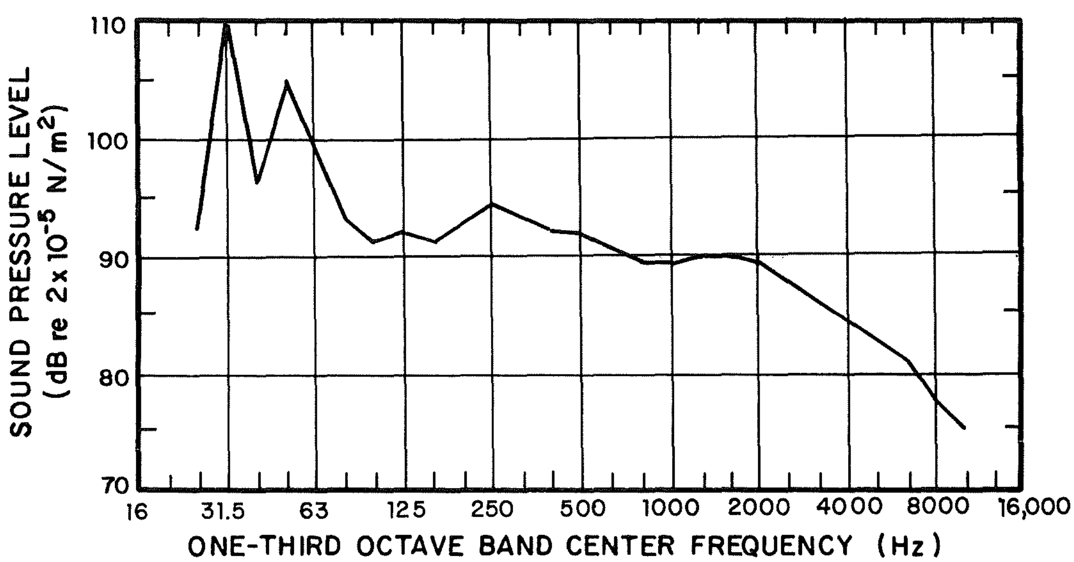

FIG. 10. NOISE IN TYPICAL SCREEN AREA

Chutes

Falling raw coal, processed coal or refuse is guided or carried by sheet-metal panel configurations called chutes. The noise emanating from chutes is generated primarily by the impacts of material lumps on the metal or on each other. Often auxiliary devices, such as tappers and air blasts used to maintain the flow, also contribute considerable noise. The impacting of coal and/or refuse on chutes produces sound levels comparable to those of screens; closed chutes handling wet material are somewhat quieter.

Partial or intermittent material flows are often noisier than full flows; this fact indicates that the primary noise radiation comes from the metal plates (whose motion is reduced if they carry more material). The noise generated by the auxiliary devices is often louder than that generated by the material flow; associated noise levels of 100 to 105 dB(A) at 3 ft have been measured.

Hoppers

Hoppers, such as are used to collect and store coal or refuse for subsequent operations, constitute a noise source similar to chutes. Noise radiation is primarily from the steel plates forming the sides and bottom of the hopper. Noise levels are highest during the initial filling period, when the hopper is almost empty; noise levels outside hoppers have been observed to decrease by 10 dB(A) as the material depth in the hopper increases. As with chutes, auxiliary devices, such as tappers and air blasts, often produce high noise levels.

Crushers

In crushers, noise is produced both by impacts and by mechanical vibrations; the actions are interrelated and difficult to separate. For example, the breaking of material in a double roll crusher exerts impact-like dynamic loads on the rolls. These vibrate, causing also the drive gearing to vibrate (perhaps losing contact and impacting against its backlash) and to generate noise at its resonance frequencies. Noise levels have been found to increase with the age and tolerances of the crusher gear train. Old gear trains or ones with excessive tolerances can generate sound levels of 100 to 105 dB(A) at 3 ft.

Clearly, impacts of the hammers of hammer mills against coal also are significant sources of noise. No detailed related information is available at the time of this writing.

Car Shakeouts

A car shakeout is a device that is placed on the top edges of the sides of railroad cars, and which literally pounds the top edges of the car to shake the coal down and out through the doors in the car bottom. Sound levels adjacent to the car during the shakeout operation are on the order of 105 to 120 dB(A). Typical spectra are shown in Fig. 11. As with hoppers, the greatest noise results when the railroad car is empty or almost empty, indicating that the car structure is the primary noise radiator.

Fluid Flows

The movement of water and air and the interaction of fluid streams with structures or with bodies of fluids produce noise in various ways. The specific noise generating mechanisms and sound levels depend on the particular machine or element; machines with similar functions are discussed here under a common heading.

Blowers

Blowers are used to provide moderate volumes of air under moderate pressure; in cleaning plants, blowers typically are of the Roots type, with two mated lobed rollers for pumping the air. Noise generation is related to fluid flow and also to mechanical vibrations. The fluid flow noise consists of (1) pressure pulses at a frequency corresponding to the rotational speed times the number of lobes on the rollers, and at harmonics of this frequency, and (2) broadband flow noise due to turbulence at intake ports. The noise levels associated with these blowers at 3 ft from the air intake port are 95 to 100 dB(A) with the spectrum, like the typical one, given in Fig. 12.

Fans

Fans are used to move large volumes of air with little pressure rise. Fans produce noise because of unsteady air loads on the blades, which unsteady loads are due to nonuniform or turbulent inflows. Nonuniformity in the inflow distribution gives rise to tones at a frequency corresponding to the rotational speed times the number of blades, and at frequencies corresponding to harmonics of that basic frequency. Inflow turbulence gives rise to broadband noise. Levels of 95 to 100 dB(A) at 3 ft are typical for fans encountered in coal preparation plants.

Pumps

Liquid pumps used for water or slurries in coal preparation plants are typically of the impeller type. The noise of such pumps is usually generated primarily by mechanical vibrations, rather than by the fluid flow. High velocity water flowing through pipes can generate shell vibration in the pipes due to

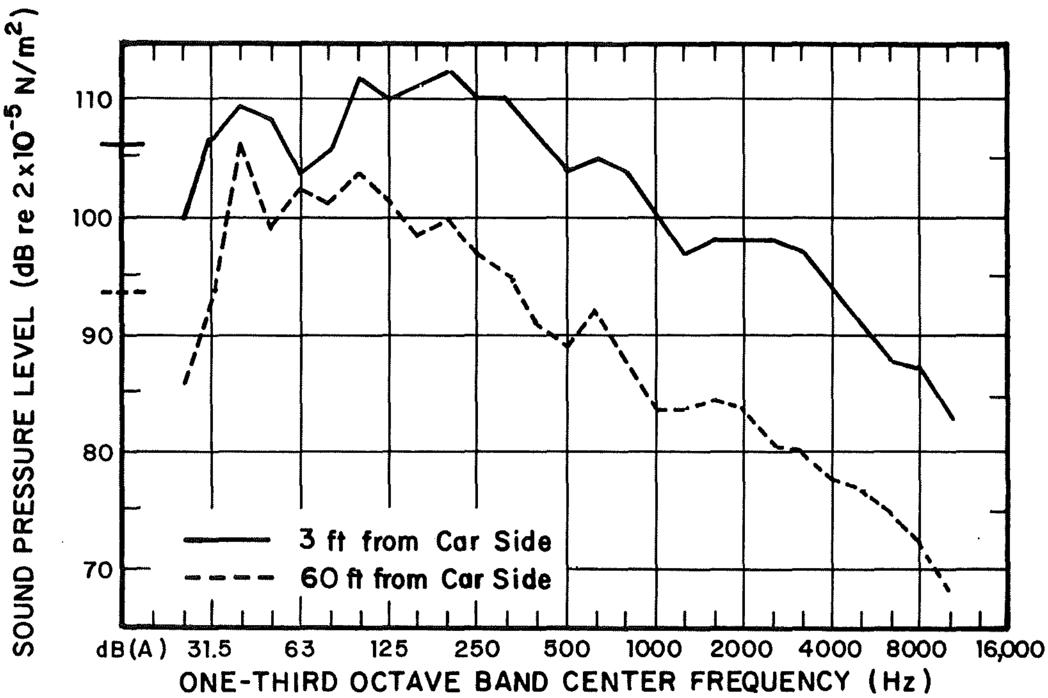

FIG. 11. CAR SHAKEOUT NOISE

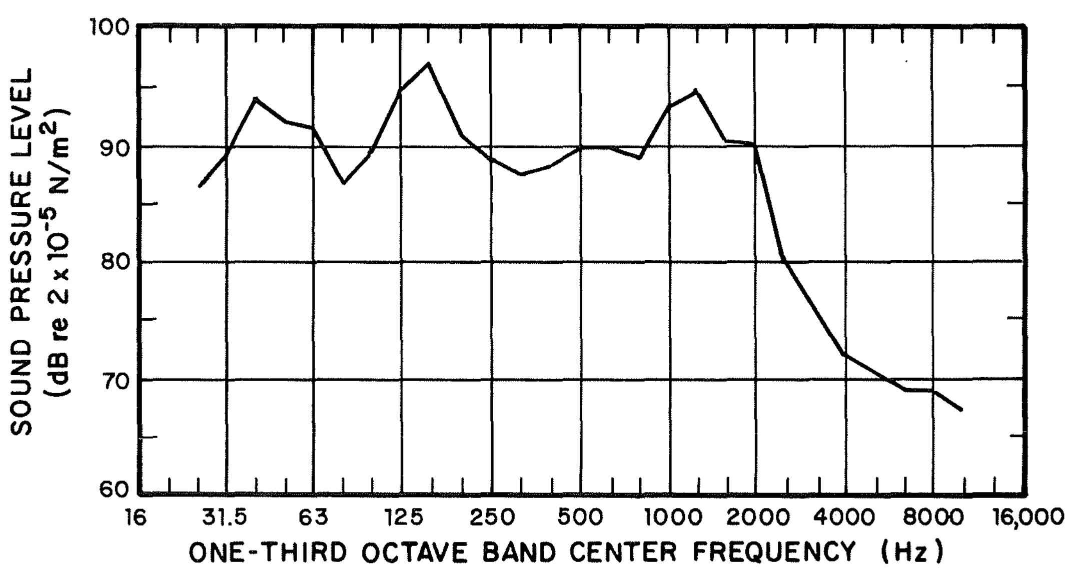

FIG. 12. NOISE AT 3 FT FROM BLOWER INLET

flow turbulence, with attendant noise radiation; however, the corresponding noise levels normally are relatively low.

Flows from the exhaust ports of vacuum pumps, as are commonly used in conjunction with large disk filters, tend to be very noisy. The primary sources are turbulence, jet interaction with quiescent air, and pressure pulsations. Unmuffled exhausts can produce 110 to 115 dB(A) at 3 ft. However, most vacuum pumps in use have mufflers or ducts installed to reduce the exhaust noise by 5 to 15 dB(A).

Vacuum pumps are generally used in conjunction with an air tank or receiver. These large tanks tend to vibrate in response to internal pressures and thus to radiate noise. As is evident from Fig. 13, tank wall vibrations dominate the noise spectrum at low frequencies.

Valves

The movement of high velocity fluid in pipes will generate noise due to turbulent pressure fluctuations setting the pipe walls into motion. Turbulence is particularly severe where there occurs a discontinuity in fluid flow, such as at valves. The sound level near a valve depends on the valve setting and the velocity of the fluid; noisy valves can generate a noise level of 90 to 100 dB(A) at 3 ft.

Air Blasts

Air blasts, such as are used to keep the material flowing through chutes and hoppers, or as occur when valves discharge, generate noise due to jet interaction with solid surfaces or with ambient air. Noise levels associated with air blasts were found to be about 100 to 105 dB(A) at 3 ft; Fig. 14 shows some related spectra.

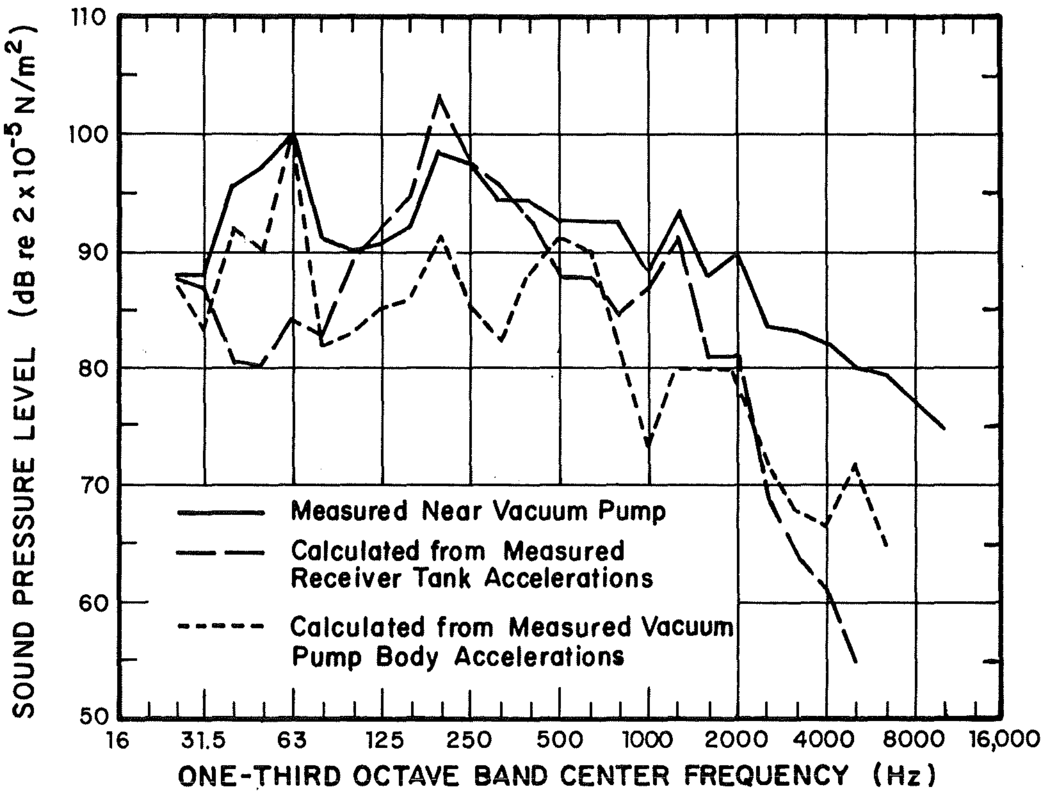

FIG. 13. VACUUM PUMP NOISE; CONTRIBUTIONS FROM PUMP BODY AND RECEIVER TANK

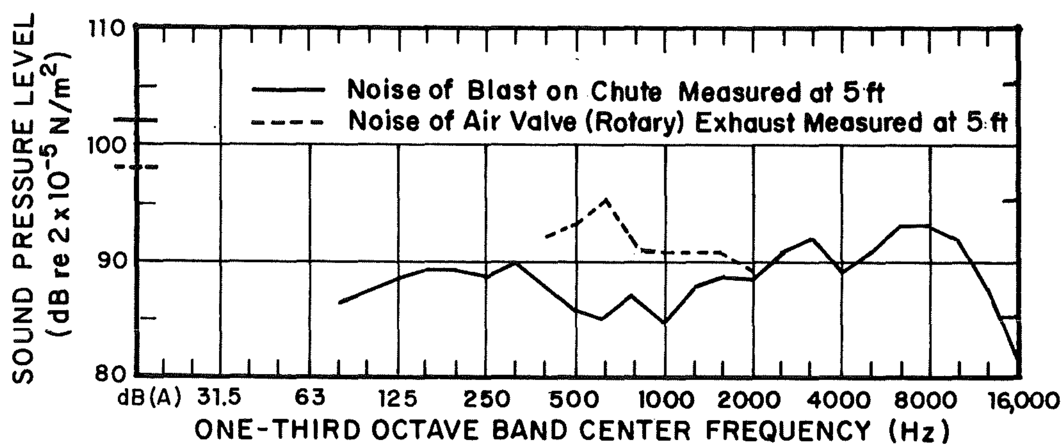

FIG. 14. AIRBLAST NOISE

Water Falls

The impact of water or slurry streams onto steel plates usually does not constitute a significant noise source. Such water falls may produce sound levels of about 75 to 85 dB(A).

Structural Vibrations

Vibrating mechanical devices can radiate noise directly; they also can set neighboring structures into motion, causing these structures to radiate noise. The noise control techniques one needs to use depend on the relative magnitudes of the direct and indirect radiation.

Screens

The primary source of mechanical vibrations in screens is the shaker used to provide the oscillatory motion necessary for screen operation. The eccentric weight driving mechanisms used on most modern screens are particularly noisy. The shaking forces generated by this device are nearly sinusoidal at the nearly inaudible rotational frequency (typically 15 Hz), but gear tooth mashing impacts (aggravated by manufacturing tolerances, wear, and bearing looseness) introduce high-frequency forces that act on the mechanism case. These forces cause this case to vibrate, to radiate noise directly, and also to set the screen structure into motion, resulting in secondary sound radiation. On the basis of the previously discussed data, the dominant contribution here is the direct radiation. The noise levels associated with empty screens, ascribable essentially to the shaking mechanism, are of the order of 90 dB(A).

Another mechanical vibration problem encountered with screens is associated with their spring supports. The spring ends tend to vibrate against the base pad and screen support, resulting in a "buzz" that can generate noise levels of about 85 to 90 dB(A) at 3 ft. Here noise is radiated from the screen structure and from the floor on which the screen is mounted; the latter is likely to dominate where steel decking is used.

Blowers

In addition to flow-related noise, blowers generate noise due to vibrations of the casing produced by the internal rotating parts. Figure 15 compares the noise spectrum obtained near a Roots blower to the noise level predicted from measured casing accelerations. The agreement of the measured and predicted spectra at frequencies below 1000 Hz indicates that casing vibrations play a significant role in low-frequency noise generation by blowers.

Gear Drives

The primary noise sources in large conveyor drives encountered in coal preparation plants are the gear reduction drives used to connect the electric motors to the conveyors. These gear boxes are quite large and rotate at a constant speed; the primary noise consists of a whine at the gear mesh frequency and its harmonics. The levels and frequencies may be expected to vary with the size of the unit and the speed of rotation. Figure 16 shows a typical spectrum measured in a conveyor drive area, showing peaks corresponding to discrete tones or narrow band noise.

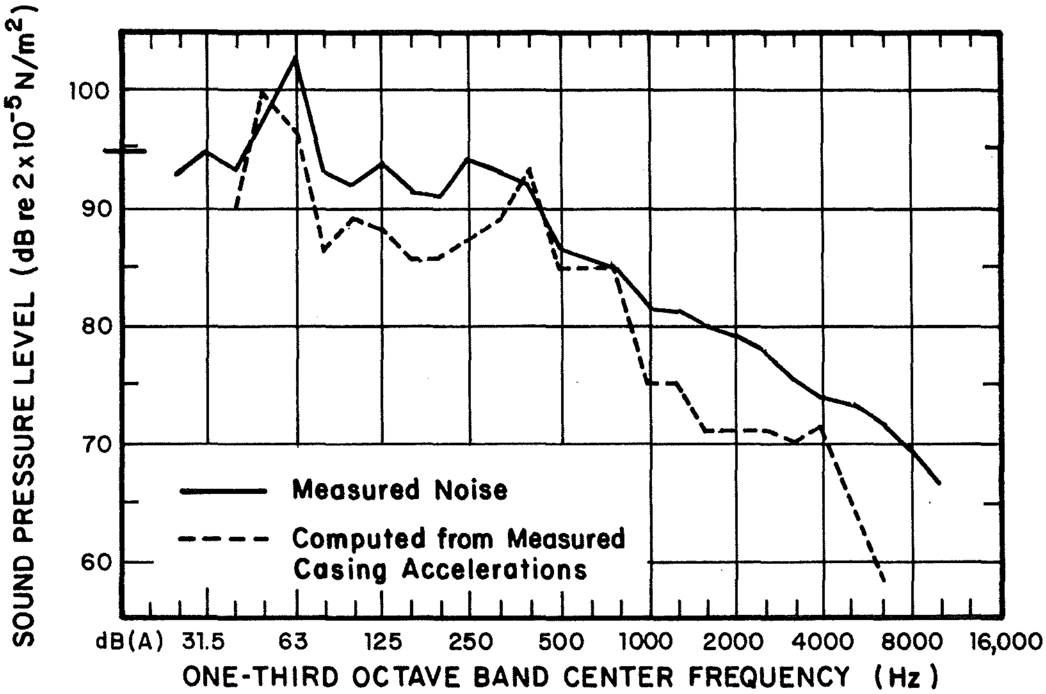

FIG. 15. NOISE AT 6 FT FROM ROOTS BLOWER; CASING CONTRIBUTION

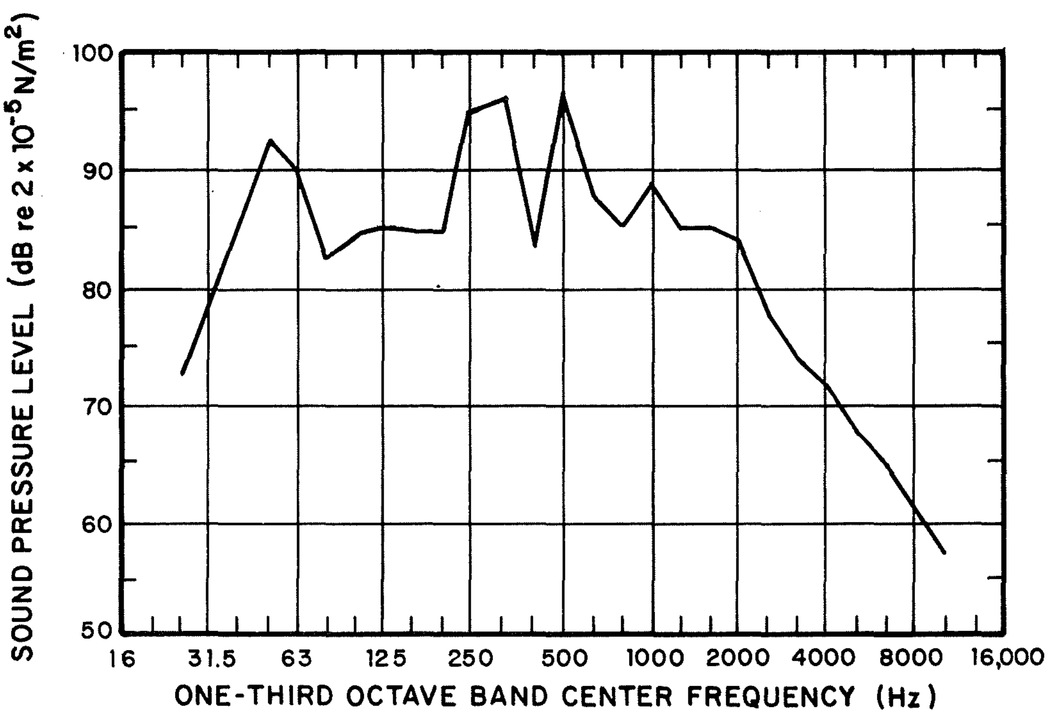

FIG. 16. NOISE IN CONVEYOR DRIVE AREA

Electric Motors

The electric motors found in coal preparation plants vary greatly in size and age, but no motors were found to be significant noise sources. Cooling fans are the primary source of noise, where these are used in conjunction with motors. Noise levels at 3 ft due to mechanical vibrations of motors are estimated (from acceleration measurements) to be less than 80 dB(A).

Pumps

Liquid and slurry pumps were found not to be significant noise sources. Maximum noise levels of 80 to 85 dB(A) were measured in liquid pump areas. These levels are due partly to pump casing vibrations, and partly to motor noise.

Centrifugal Dryers

Centrifugal dryers, where the fine coal slurry is passed through spinning cones to separate the bulk of the water from the coal, produce noise levels at 3 ft between 90 and 100 dB(A). New, tight dryers were quieter, and dryers with worn bearings or loose parts were noisier. Figure 17 displays the measured spectra for several different dryers.

Conveyors

Measurements on rubber-belted conveyors disclosed no significant noise sources besides the motor drive and occasional squeaky rollers. Flighted conveyors, where steel paddles are fastened to a drag chain, were found to be significantly noisy, on the other hand. The squeal of metal-to-metal slipping was observed to be the predominant noise-generation mechanism; levels of 90 to 100 dB(A) were observed in a room, at 10 ft from the conveyor. The squeal of a single conveyor was noted to be intermittent, but with many conveyors in use, the net effect was that of continuous squeal. Figure 18 shows the measured spectrum of a squealing flighted conveyor, for which the highest level noise level was 100 dB(A).

Feeders

Mechanically driven feeders that are used for moving coal over short horizontal distances were found not to constitute a significant noise problem. Electro-mechanical vibrating feeders were found to be noisier, largely due to a buzz, typically producing noise levels at 3 to 5 ft of 90 to 95 dB(A).

Rank Ordering of Equipment in Terms of Noise

An effective noise control program must first attach the noisiest sources. However, only those sources that contribute to worker exposure are important from the standpoint of industrial health. For this reason, the importance of quieting a noise source depends on both the noise level and the proximity of workers.

Table VII presents a rank ordering of machinery, taking account of noise levels and worker exposure. It indicates that the most severe hearing damage-risk problem is associated with car shakeout operations, where workers are positioned full time in high-noise areas. The second most significant problem is associated with screens, of which large numbers are used throughout every coal preparation plant; although plant workers are not normally stationed continuously in screen areas, operational support workers (lubricators, floor supervisors, monitors) are continually moving through these areas. Picking tables constitute the third ranked problem; they generate high noise levels and are served by a picker who must work directly over the table.

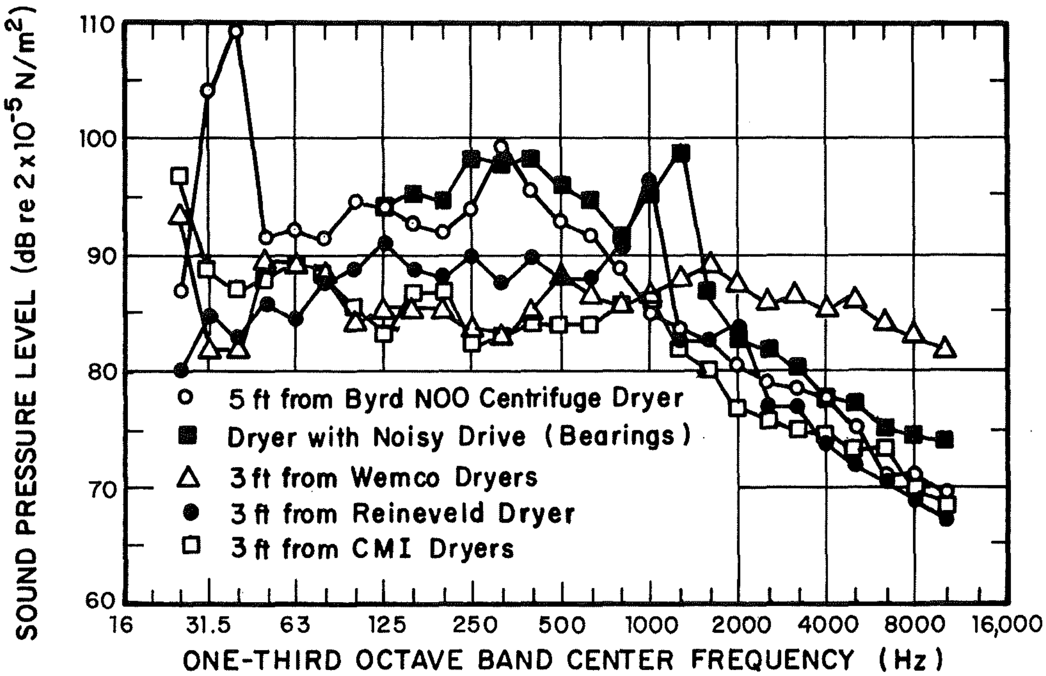

FIG. 17. NOISE OF SEVERAL DRYER INSTALLATIONS

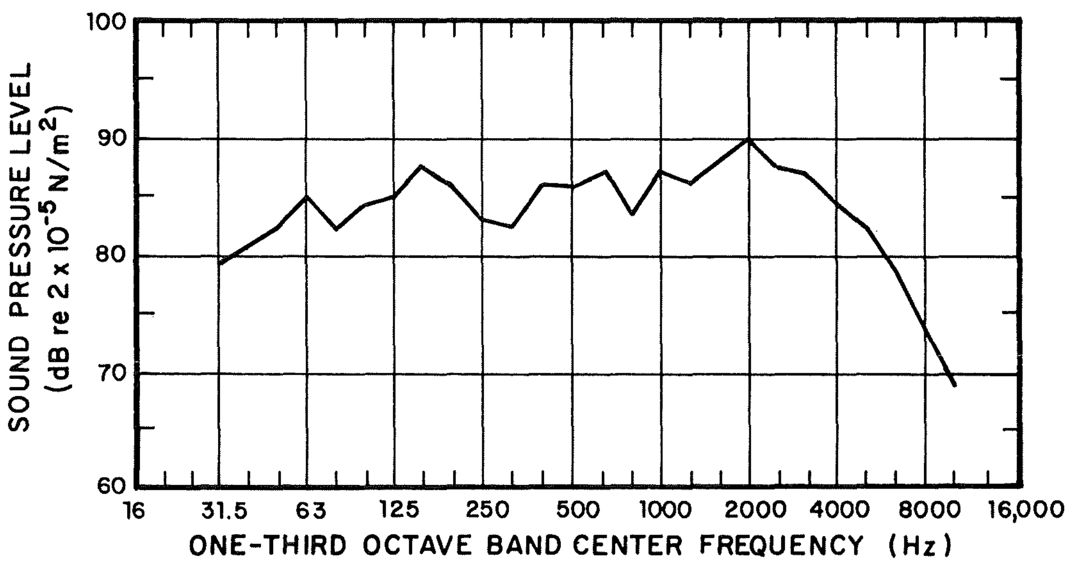

FIG. 18. NOISE AT 10 FT FROM SQUEALING FLIGHTED CONVEYOR

The fourth ranked group of Table VII consists of those machine and equipment items which make a significant contribution to the general plant noise. The items shown in the fifth group are those that make secondary contributions to overall plant noise. These sources are typically either separated from the main work spaces or have source levels below 90 dB(A). The last group is made up of items that do not constitute a problem if 90 dB(A) is the specified plant noise criterion. Note that all items except those in the last group must be quieted or removed if it is desired to provide a plant noise environment that is below 90 dB(A) everywhere.

TABLE VII. RANK-ORDERING OF EQUIPMENT IN TERMS OF NOISE

Rank	Equipment	Typical Sound Level at Worker Position (dBA)	Typical Worker Proximity
1	Car Shakeout	110-120	2 workers, full time
2	Screens	95-105	Predominant in-plant noise source; many workers, often near full time
3	Picking Tables	90-95	1 worker, full time
4	Blowers, Dryers, Air Pumps, Fans, Crushers, Air Valves, Feeders, Flighted Conveyors, Chutes	90-105	Maintenance and Operational Support Workers
5	Motors, Gear Drives, Liquid Pumps, Hoppers	85-95	Maintenance and Operational Support Workers
6	Belted Conveyors, Deister Tables, Flotation Cells, Water Falls, Rotary Pumps, Heavy Media Vessels, Cyclones	75-85	Maintenance and Operational Support Workers

VI. CONTROL OF PLANT NOISE INTRUSION INTO NEARBY COMMUNITIES

Reduction of Emitted Noise

As in most noise problems, the generally most effective means for control consist of reducing the noise at its source. The coal preparation plant noise that reaches nearby communities typically is due primarily to only a few items of machinery or equipment that are (a) much noisier than others, (b) located outside the plant buildings or near openings (doors or windows) in such buildings, and/or (c) located near the observation position. In most practical situations, one can pick out the offending item simply by listening to the noise and by knowing the operating cycles and closer-in noise characteristics of the likely problem items.

Once the prime contributors to the observed noise have been identified, one may quiet them by the various applicable techniques that have been described in the previous section.

For items located inside plant buildings near openings, significant noise reduction can often be obtained by closing these openings. Where total closure is not feasible - perhaps because of ventilation or continuous accessibility requirements - one may alternatively provide these openings with mufflers or barriers. Mufflers would in essence appear like tunnels or ducts extending from doors or windows, with acoustical lining on their insides. These tunnels and ducts should be curved or bent to eliminate all "line-of-sight" communication between the inside of the building and the outside, and they should be several times as long as their greatest cross-sectional dimension.

Barriers consist in essence of walls or panels placed outside of doors and windows, again so as to eliminate the possibility of line-of-sight contact between the inside and the outside. These barriers should not be flat and parallel to the building wall; they work better if they are curved or accordion-pleated. They do need to be covered with acoustically absorptive material on the side nearest the noise source, and they generally need to be considerably larger than the openings they protect.

Building walls that are of relatively light-weight sheet metal and/or plastic present little obstruction to noise. Since most of the noise goes through the walls, closing off of openings in such walls has no appreciable effect on the noise reaching nearby communities. In such cases, one needs to consider quieting of all of the noisy equipment in the plant and/or improving the plant walls - perhaps by adding secondary, preferably heavy, walls outside the ones that are already there.

Where possible community reaction to noise is a problem, one obviously should not reduce the in-plant noise produced by valves, and by air intakes and exhausts by ducting these to the exterior of the plant. If such ducting already exists and if the noise emanating from it may bother the community, mufflers should be added at the ends of these ducts.

Obstruction of Noise Propagation

Walls or earth berms constitute useful means for protecting communities from plant noise provided, however, these are close enough to the noise source and large enough so that the shortest sound path around these barriers is longer by a considerable percentage than the most direct sound path in absence of the barrier. Thus, impractically large barriers are required to have a significant effect on communities located at considerable distances from the plant.

Weather - notably wind and temperature gradients, as well as humidity - also affect the long-range propagation of sound. Some combinations of conditions enhance this propagation, others impede it. At any rate, one may always expect occasions where sound refracted by the atmosphere greatly reduces the effectiveness of a given barrier installation.

Contrary to much folklore, vegetation has relatively little effect on long-distance sound propagation. After all, only a small fraction of the sound energy arriving at a given location comes to it directly along the ground.

Distance is the only parameter on which one can count for the reduction of noise, with each doubling of the distance between a (concentrated) source and an observer resulting in a 6 dB reduction in noise. Although one can hardly expect to move existing plants and communities further apart, the distance parameter should be kept in mind in the siting of new plants or supporting equipment.

VII. ILLUSTRATIONS OF NOISE CONTROL PROGRAMS

In order to provide an overview of the noise control methods that may be used in a systematic noise control program, this section describes the approaches that should apply to three fictitious, yet typical, preparation plants of different sizes and ages.

General Approach

Any program logically should begin with a survey of the plant, to determine the noise levels in its various areas. For those areas in which excessive noise levels are found, the major noise source or sources must be identified and their contributions must be determined. In some areas, the major noise sources are obvious (e.g., in car shakeout areas); in others, the contributions of individual noise sources are difficult to separate. In the latter case, one may need to operate the various machines separately or to apply advanced acoustical techniques to evaluate the noise contributions made by the various sources.

As part of the noise survey, the reverberant quality of the noise plant spaces should be evaluated, in order to determine how much noise reduction can be achieved by use of acoustically absorptive materials. Where such materials are judged likely to be beneficial, their use should be considered in conjunction with source quieting. The cost-effectiveness of various mixes of source silencing and absorptive treatments should be evaluated.

Knowing the contribution made by each major noise source, one can determine the degree of noise control required for each. Since the noisiest source controls the noise level, one must begin with the noisiest source, then proceed with the next noisiest, and so on. From the information presented in Section V, one may select suitable cost-effective noise control treatments for each source. Where means for sufficient quieting of the sources are not available or prohibitively costly, rotation of personnel assignments (and carefully enforced administrative controls) and use of ear-protective devices should be implemented.

The following paragraphs present some illustrative "case studies" of aspects of noise control programs for some plants that are representative of those on which field studies have been performed.

Large Modern Plant

A typical large modern plant uses a heavy media separation process. The major processing equipment found in such a plant that processes about 1500 tons of raw coal per hour, is listed in Table VIII (together with the noise contributions made by each unit). All of this equipment is housed in a large girder-type building with cement floors and with walls of metal or flint rock siding for the walls. The various floors are not continuous, but have large openings, e.g., for chutes and conveyors.

The noise levels in this plant were found to be 90 to 95 dB(A) or greater. Reverberation measurements in the plant indicated that the average sound absorption coefficient of the large open plant spaces was of the order of 0.5; this rather high value implies that sound reflection plays no important role and that sound absorbing walls or ceilings would not reduce the in-plant noise levels appreciably.

Since the noise survey indicated general in-plant noise levels greater than 90 dB(A), assignment rotation for in-plant workers cannot reduce their exposure to acceptable levels, unless some source quieting is accomplished.

TABLE VIII. EQUIPMENT IN A LARGE MODERN PLANT

Equipment	Number of Units	Typical Noise Level dB(A)
Heavy Media Cyclones	18	80
Crushers	3	100
Rotary Breaker	1	100
Scalping Screens (Shaker Drive)	2	100
Clean Coal Screens (Shaker Drive)	25	95
Refuse Screens (Shaker Drive)	1	100
Centrifugal Dryers	10	95
Disk Filters	8	85
Vacuum Pumps	8	95
Rootes Blowers	4	95
Car Shakeout	1	115
Conveyors (belt)	10	80
Conveyor Drives	10	95
Chutes	36	90
Fans	2	95
Vibrating Feeders	4	90
Tappers or Air Blasts	10	100
Flotation Cells	8	75
Pumps	6	85

In order to determine the noise source contributions, the different machines were operated separately as far as possible. For most of the major equipment items, this could be done only when the plant was empty of coal, during the down shift. Measured data for empty machines were then adjusted for "full" operation. (For example, for screens, 5 dB(A) were added to the "empty" data for operation with clean bituminous coal, and 8 dB(A) were added for operation with refuse.) Blowers and pumps were run with everything else shut down; centrifugal dryers were operated alone and empty, and so on. As raw coal was fed into the plant, the change in the character and level of the noise was observed in order to pinpoint coal and refuse handling noise. The results of this measurement and estimation process are indicated in Table VIII.

The sources are rank-ordered in terms of their relative noise contribution as indicated in Table IX. If the end objective is to reduce the general in-plant noise level to 90 dB(A), all sources greater than 85 dB(A) must be treated. Table IX lists the machines or elements to be treated and the noise control treatments needed to reduce each level to 90 dB(A) or less. The order of listing in the table reflects roughly the relative importances of treating the sources, in terms of their noise levels and the number of people in their vicinity.

TABLE IX. EQUIPMENT NOISE CONTROL FOR A LARGE MODERN PLANT

Initial Noise Level dB(A)	Equipment	Noise Control Method
115	Car Shakeout	Replace with car dump
		Enclose operator and helper
100	Screens	Rubber decking and hold downs
90	Chutes	Ledges at impact point
		Dampening of sheet metal
		Opening air blasts
95	Centrifugal Dryers	Close fitting covers
95	Vacuum Pumps	Mufflers
		Lag receiver tanks
100	Crushers	Close fitting covers
95	Conveyor Drives	Enclosures
95	Blowers	Mufflers
		Covers
90	Vibrating Feeders	Partial enclosures
95	Fans	Mufflers
100	Tappers	Enclosures

Small Older Plant

Small plants typically were built for a specific mine, with no "foreign" raw coal shipped to the plant. The equipment found at these plants varies with the type of coal produced and the size of the plant. For the present example, the plant is assumed to process somewhat less than 300 tons of raw coal per hour, with primary separation accomplished by use of air tables. The processing equipment found in this typical plant is listed in Table X.

TABLE X. EQUIPMENT IN A SMALL OLDER PLANT

Equipment	Number of Units	Typical Noise Level dB(A)
Mine Car Dump	1	85
Air Tables	3	90
Crushers	1	100
Scalping Screens (Reciprocating)	1	98
Picking Table	1	98
Clean Coal Screens (Reciprocating)	5	95
Refuse Screens (Reciprocating)	1	100
Chance Cones	2	94
Conveyors (Drag or Flighted)	3	90
Conveyor Drives	3	95
Chutes	9	90

The construction and physical layout of equipment in this plant is less dense, since the plant has been modified to accommodate changes in the composition of the raw coal or shifts in market demand. The plant consists of the original separation plant, fitted with additions. The total length of conveyors per ton of coal is greater in this plant than in new plants, because of the fragmentation of material flow into the plant additions. The older portions of the plant are block or brick construction, with girder and slab type construction used in the newer sections.

TABLE XI. EQUIPMENT NOISE CONTROL FOR A SMALL OLDER PLANT

Initial Noise Level dB(A)	Equipment	Noise Control Method
100	Screens	Rubber decking and hold downs
98	Picking Table	Reduce shaking action, control free full of coal and refuse
94	Chance Cones	Enclose external surface to reduce noise radiation
100	Crushers	Enclose surface
90	Chutes	Ledges at impact point or dampening of sheet metal
95	Conveyor Drives	Enclosures
90	Conveyor (flighted)	Dampen sheet metal
90	Air Tables	Acoustic cover on sheet metal

The noise levels measured were in the 85 to 95 dB(A) range. Because of the greater physical separation between machines, the noisiest processes or machines could readily be identified. The results of source measurements are shown in Table XI. Reverberation measurements indicated that the acoustic absorption is large and that acoustical absorptive materials would be of little use. Noise control must center on reduction at the source or blocking the direct noise radiation.

In order to provide general in-plant noise levels that are less than 90 dB(A), the equipment listed in TAble XI must be quieted. This table also shows the noise control methods to be used to achieve the required amount of noise reduction. The order of the items in the table corresponds to their estimated relative importance, in terms of both noise level and worker exposure.

Medium-Sized Plant

This example pertains to a plant that uses baum jigs for the primary separation process, with deister tables to separate the fine coal from the refuse, with a capacity of about 700 tons per hour. The processing equipment typical of such a medium-sized plant is listed in Table XII.

Evaluation of the noise sources was accomplished by some selective operation of individual machines; determining the relative contribution of the various sources was facilitated by the fact that the sample plant had newer separation processes added onto the primary process, with consequent spatial separation of the machines.

TABLE XII. EQUIPMENT IN A MEDIUM-SIZED PLANT

Equipment	Number of Units	Typical Noise Level dB(A)
Baum Jigs	1 Type J	100
	1 Type M	95
Rotary Dump	1	85
Scalping Screens (Reciprocating)	1	98
Picking Table (Reciprocating)	1	98
Crushers	2	100
Refuse Screens (Shaker Drive)	2	100
Clean Coal Screens (Shaker Drive)	8	95
Centrifugal Dryers	6	95
Disk Filters	2	85
Vacuum Pumps	2	95
Rootes Blowers	2	95
Conveyors (Flighted)	3	90
Conveyors (Belt)	3	80
Conveyor Drive	6	95
Chutes	21	90
Diester Tables	12	85
Vibrating Feeder	1	90
Fans	1	95

The general in-plant noise level was found to be between 90 and 95 dB(A). Control of the various noise sources to provide general in-plant noise levels below 90 dB(A) would require treatment of the noise sources listed as listed in Table XIII. The order of the listing again reflects the relative importance of silencing, taking both noise level and worker exposure into account.

TABLE XIII. EQUIPMENT NOISE CONTROL IN A MEDIUM SIZED PLANT

Initial Noise Level dB(A)	Equipment	Noise Control Method
100-95	Screens	Rubber decking and hold downs. Enclose shaking mechanism.
100-95	Jigs	Mufflers or duct air discharge from valves. Damp and cover sheet metal.
98	Picking Table	Reduce shaking action, control free fall of coal and refuse.
95	Vacuum Pumps	Mufflers Lag receiver tanks.
100	Crushers	Close-fitting covers.
95	Centrifugal Dryers	Close-fitting covers.
95	Blowers	Mufflers Enclosures
90	Chutes	Ledges at impact point. Dampening of sheet metal.
95	Conveyor Drive	Enclosures
90	Conveyors (Flighted)	Dampen sheet metal.
95	Fans	Mufflers
90	Vibrating Feeder	Partial Enclosure

VIII. CONCLUDING REMARKS

Noise Control for Existing Plants

Quieting of existing coal preparation plants to meet the provisions of the Federal Coal Mine Health and Safety Act of 1969 is not beyond the present state of knowledge; this quieting generally requires only the application of well-known techniques. Although most of the required noise control technology also is available, some has not been adapted to coal cleaning plant requirements or tested in relation to these requirements; the implementation of some noise control treatments may also be prohibitively costly.

It is likely that for many coal cleaning plants the most cost-effective solution to the problem of compliance with the above-mentioned Act will consist of a mix of machinery noise control treatments, administrative controls (i.e., worker exposure limitation), worker enclosures, and ear-protective devices. The make-up of this optimum mix will vary from plant to plant, depending on the equipment, the acoustical properties of the building, current work schedules and practices, worker and union attitudes, and on current safety education and administrative procedures.

Because of the significant potential costs associated with the quieting of the large machinery found in coal preparation plants, noise control programs merit careful planning. This planning ideally should be based on a thorough evaluation of the noise levels in the various noisy areas and of the worker exposure durations in these areas, on a delineation of the noise contributions made by the various items of equipment, and on cost studies of alternative mixes of machinery, administrative, and worker-related noise control approaches. The design of machinery noise control treatments should be based on a full understanding of the particular machine generating and radiating noise - otherwise one is faced with a cut and try approach that usually is both costly and ineffective.

Noise Considerations in New Plant Design

It is likely that new plants can be made relatively quiet at no appreciable additional cost, if the plant designer keeps the noise limitation requirement in mind during the design process. It usually costs little to select the quieter of two alternative pieces of equipment - e.g., screws, conveyors, vibratory feeders. In addition, the designer may develop a plant lay-out where many items of noisy equipment, such as pumps and blowers, are placed in the same acoustically treated room - thus keeping their noise out of the plant. It may also be feasible to replace several smaller items by fewer larger-capacity ones, thus resulting in less total noise, or at least concentrating the noise in one location, where it may be contained by a simple enclosure. Similarly, it may be cost-effective to collect several similar intakes and exhausts (of fans, blowers, vacuum pumps, valves) into a single manifold, and to muffle only the single exit of that manifold.

Recommended Investigations

The study that led to this report has revealed the potential utility of several further studies and demonstration programs. These are described below.

Chute Quieting

Dams that retain some of the flowing material in chutes can be used only where sufficient incline is available; otherwise the flow becomes obstructed. The various concrete liners that have been tried in chutes with some success primarily to increase their wear-life, also should reduce chute noise, but this effect has not been studied. The use of rubber or plastic liners in chutes has also been considered, and some applicable commercial products are available, but their wear properties are improved. Application of structural damping materials to the outsides of chutes is expected to reduce their noise; although several such materials are commercially available at reasonable cost, their compatibility with cleaning plant requirements remains to be determined.

An investigation of liners and damping treatments may be expected to yield cost-effective practical means for the control of chute noise. Such an investigation must be concerned not only with noise reduction, but also with the wear, survivability and repairability of such liners and treatments.

Quiet Screen Development

Screens are among the noisiest and most ubiquitous items of cleaning plant equipment. It is not known whether impacts of coal on coal or coal on steel are the predominant noise sources, and the radiation of noise generated by the driving mechanisms is not fully understood. Potential noise control measures include covering the decks and/or side-plates with an elastomeric material, replacing the steel decks with plastic ones, providing vibration isolation between the decks and side-plates and damping the side-plates - but the utility of these measures appears to have been investigated insufficiently or not at all.

A program aimed at development of a quiet screen is recommended. Such a program should be based on a careful study of the noise sources, vibration propagation paths, and radiation paths and locations. It should investigate the aforementioned potential noise control measures, not only from the noise reduction standpoint, but also in terms of wear, effects on screen operation, and cost.

Other Investigations

Several other efforts appear likely to be useful, although perhaps not quite as directly as those discussed above. These include:

- Review of noise control measures employed in European coal cleaning plants, where stringent noise codes have been in force for many years, and in industries that use equipment similar to that in coal cleaning plants
- Demonstration of noise control retrofit of an existing coal cleaning plant
- The design of a quiet new coal cleaning plant, and development of a design guideline manual
- Design and demonstration of acoustical ducts and mufflers for blowers, air compressors, and valves.

APPENDIX A

COOPERATING ORGANIZATIONS

Allis Chalmers

Barnes & Tucker

Bethlehem Steel Corporation

Gandy Coal Company

Heyl & Patterson, Inc.

Huber Colliery Blue Coal Company

Jeffrey Manufacturing Company

Jones & Laughlin Steel Corporation

McNally Pittsburg Manufacturing Corporation

Pittsburgh Consolidation Coal Company

Roberts & Schaefer Company

Theodore Barry and Associates

APPENDIX B

AVERAGE ACOUSTICAL ABSORPTION COEFFICIENTS MEASURED IN COAL PREPARATION PLANTS

Octave Band Center Frequency (Hz)	Absorption Coefficient in	
	Large Rooms	Small Rooms
63	0.3	0.15
125	0.3	.15
250	0.4	.15
500	0.4	.11
1000	0.5	.12
2000	0.5	.15
4000	0.5	.17
8000	0.8	.15

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Coal Cleaning Plant Noise and its Control (Original title: Noise Control in Surface Mining Facilities)			5. Report Date May 1974
			6. Performing Organization Code
7. Author(s) Ma1974 E. E. Ungar, G. E. Fax, W. N. Patterson, H. L. Fox			8. Performing Organization Rept. No.
9. Performing Organization Name and Address Bolt, Beranek and Newman, Inc. 50 Moulton Street Cambridge, MA 02138			10. Project/Task/Work Unit No.
			11. Contract/Grant No. H0133037
12. Sponsoring Agency Name and Address Bureau of Mines 4800 Forbes Avenue Pittsburgh, Pa. 15213			13. Type of Report & Period Covered Final 6/26/73 to 6/5/74
			14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstracts

Criteria applicable to noise in coal cleaning plants are presented, and the generally applicable noise control principles and approaches are discussed. The operating characteristics and equipment of coal cleaning plants are described. Considerations entering in the selection and design of noise control means are delineated, and specific means for equipment noise reduction are described.

The limited utility of acoustically absorptive materials in plant spaces is indicated, administrative means for reducing worker noise exposure are pointed out, and ear-protective devices are described briefly. The reduction of plant noise reaching nearby communities is discussed. Programs leading to quieter machines and coal cleaning plants are suggested.

17. Key Words and Document Analysis. 17a. Descriptors

Noise
Noise Abatement

17b. Identifiers/Open-Ended Terms

Coal Cleaning Plants

17c. COSATI Field/Group

18. Distribution Statement	19. Security Class (This Report)	21. No. of Pages
Release Unlimited	UNCLASSIFIED	
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35(10-70) US COMM-DC 40329-P71