

**PERSONAL PROTECTIVE DEVICES***Harry F. Schulte***GENERAL PHILOSOPHY**

It is one of the fundamentals of industrial hygiene that personal protective devices are "last resort" types of controls, to be used only where engineering controls cannot be used or made adequate. It should be noted that this fundamental is stated unequivocally in the standards adopted under the Occupational Safety and Health Act.<sup>1</sup> There are many jobs in industry which are short-term or which must be conducted where exhaust ventilation or other control measures cannot be employed on short notice. Protective devices are also extremely important as a second line of defense against inadvertent or unexpected conditions. Thus, when a man dons a respirator or a face shield before opening a container of toxic material he does not expect to need this equipment, but he is prepared and protected if the toxic material escapes its confinement.

Personal protective devices appear to be very simple to provide and use in contrast to such equipment as exhaust ventilation or sound absorbing barriers. It is the purpose of this chapter to show that this is not necessarily true, and to provide the reader with essential information on the selection and correct manner of use of personal protective devices. In making a selection of equipment to be used the employer is advised to consider the wishes of the workers who must use the equipment, since worker acceptance is the key factor in a successful protective equipment program. For this reason the comfort factor should be given considerable weight at the expense of costs but not of protection. Full discussion of the use of the devices with the employees, training in their use and instructions for care and maintenance are very important. For example, handing a man a respirator and telling him to use it is not only an ineffective technique, but it can be very dangerous.

**PROTECTION AGAINST INHALATION HAZARDS****Where Used**

There will always be a temptation to resort to respirators as a cheap substitute for a ventilation system. If this is done it is clear that management has not carefully considered the alternatives since reliance on, and effective use of, respirators is definitely not cheap. A careful study may be required to determine that no other effective control measures can be used. Respirators are designed to protect only against certain specific types of substances and in certain concentration ranges, depending on the type of equipment used. Many other factors should be considered carefully in

making the decision that other engineering controls are not practical. Nevertheless, there are many places where respirators can and should be used with full knowledge of their limitations and requirements.

**Approval Systems and Schedules**

The U. S. Bureau of Mines gave its first approvals of oxygen breathing apparatus in 1918 and gradually extended this activity to include all types of respirators. Each approved respirator and each approved filter, canister or cartridge bears an approval stamp or mark. Approvals are issued according to a series of "schedules" which describe the tests to be performed on each type of respirator and the standards it must meet to receive approval. Lists of approved devices are issued periodically by the Bureau and supplements are added to include newly approved devices. The last complete list of approved devices was issued by the Bureau of Mines as Information Circular No. 8436 and included devices approved up to December 31, 1968.<sup>2</sup> Supplements were issued in January 1970 and February 1971.

The approval schedules themselves are subject to occasional reviews and new schedules are developed to meet the needs for protection against new hazards or to reflect the development of new kinds of devices. Where respirators are used regularly, these schedules should be consulted since they set forth the precise information to be obtained in the test procedures as well as the limitations of the tests. Prior to 1971 the U. S. Department of Agriculture performed tests and issued approvals on respirators to be used in working with pesticides. This function has now been taken over by the Bureau of Mines. With the passage of the Occupational Safety and Health Act and the subsequent formation of the National Institute for Occupational Safety and Health (NIOSH), the approval system has been in the process of change. In 1972 NIOSH took over the approval function from the Bureau of Mines for aboveground uses. Considerable research is now underway to expand the scope of the approval tests and to develop more satisfactory procedures to meet the changing and expanding needs.

**Particle-Removing Air Purifying Respirators**

*Applications and functions.* These devices are designed to protect the wearer against inhalation of material dispersed in air as distinct particles — as a dust or fume in the case of solid particles or as a mist or fog in the case of liquid droplets. They consist, principally, of a facepiece with some type mechanical filter. The material to be protected

against may be a nuisance dust such as sawdust, a pneumoconiosis-producing dust such as silica or coal dust, a toxic dust like lead oxide, a metal fume like cadmium, a highly toxic dust like beryllium oxide or a radioactive dust such as plutonium. These examples range in their degree of protection required from relatively minor to extremely high. Respirators to meet this range of requirements differ chiefly, *but not solely*, in the efficiencies of their filters.

**Limitations.** The user of any air purifying respirator must be certain that the atmosphere contains adequate oxygen and that the only harmful materials present are those which can be removed by the respirator to be worn. There are many ways in which air can leak around the filter, seriously reducing the protective capability of the respirator. Failure of the filter to seat properly in its holder, leaking valves and imperfect sealing of the respirator to the wearer's face are all significant. Some of these factors can be controlled by proper design but all require good and frequent inspection and maintenance.

**Facepieces.** There are two basic types of facepieces used on air purifying respirators — half masks and full face masks. The half masks do not cover the eyes and hence offer no eye protection nor do they interfere as much with vision as do the full face masks. The half mask must contact a rather complex facial surface and the possibility of leaking is greater than in the case of the full face mask. Obviously, faces vary considerably in their dimensions from one individual to another and since a given respirator is usually made in only one size, a successful fit for the respirator cannot be made on all persons. Recently some manufacturers have begun making some respirators in several sizes. Where this choice is not available, it is essential that the employer stock several different models of respirators, usually from several different manufacturers. A fitting program, to be discussed later, is required to provide adequately fitted respirators.

A serious problem with full face respirators is obtaining an adequate seal for the worker who must use corrective glasses. Where the temples of conventional eyeglasses emerge from the facepiece, there is a serious place of leakage. Some masks provide methods of mounting a special set of corrective lenses inside the respirator facepiece. Half masks are usually held on the face by means of a single set or a double set of elastic bands. The double sets of straps are practically a necessity in assuring a reasonable face fit and each set should fasten to separate suspension points on the respirator. Full face masks, being much heavier, are supported by a head harness which should have at least five adjustable straps.

Most respirator facepieces contain valves to direct the flow of air from outside, through the filter, into the nose and then back outside. Valveless respirators are being used, but are not approved for use with hazardous materials. The most important valve is the exhalation valve which opens during expiration allowing expired air to pass directly outside the mask. It closes during

inhalation and must close positively and quickly to prevent toxic material being drawn into the facepiece.

The inhalation valve is located close to the point where the filter attaches to the facepiece. It opens during inhalation to allow air to be drawn in through the filter and closes during exhalation to prevent the passage of moisture-laden expired air through the filter. Some approved respirators do not have inhalation valves. Obviously, all valves should offer minimal resistance to air flow, but low resistance is particularly important in the exhalation valve. Resistance to exhalation is much less tolerable than is resistance to inhalation.

**Filters.** Filtration by fibrous filters is the method universally used in respirators for removing particles from the air. The filter material may be a loosely or tightly packed mass of fibers of cotton, wool, synthetic fibers, glass or mineral fibers, or it may be a paper made of these materials. The filter efficiency is influenced by the particle size, shape and density of the aerosol and by a number of other factors determined by the filter and the respirator.

The diameter of the fibers used in the filter is important since higher collection efficiencies are obtained with finer fibers. The tightness with which the fibers are compressed is another factor leading to higher efficiency. As a filter is used in a dusty atmosphere its efficiency usually increases with time since the layer of collected dust becomes an additional filter. It should be noted that all of these factors leading to increased filter efficiency also lead to increased resistance to breathing. This limits the extent to which these factors can be used to obtain higher particle removal efficiency. The only way to compensate for high filter resistance is by providing large filter surface areas. Thus, many filters are folded in various ingenious ways to achieve large surface areas in small spaces. Filters may be incased in "cans" or holders to protect the folded filter.

There are approval schedules for respirators for protection against (1) pneumoconiosis-producing and nuisance dusts, (2) toxic dusts (not significantly more toxic than lead), (3) metal fumes (not significantly more toxic than lead), (4) chromic acid mist, (5) dusts significantly more toxic than lead and (6) various combinations of these. A summary of some of the requirements for approval are given in Table 1 taken from the AIHA-ACGIH Respirator Manual.<sup>3</sup>

**Special Purpose Respirators.** Because of recognition of the necessity of maintenance and regular servicing and cleaning of respirators, there has been increased interest in the possibility of single-use respirators. These could be discarded when breathing resistance became excessive or the respirator became dirty or damaged. Some simple respirators of this type have been used in the past — a surgeon's mask is an example — but they have never been approved because of their low efficiencies and lack of exhalation valves. Recently several manufacturers have begun making single-use masks, and one has been approved under a new

TABLE 36-1  
U.S. BUREAU OF MINES APPROVAL SCHEDULES AND TESTS  
TEST CONDITIONS AND PERFORMANCE REQUIREMENTS  
FOR DISPERSOID RESPIRATORS

Dispersoids Covered by Respirator for Protection against	Test Dispersoid	Concentration of Dispersoid, mg/m <sup>3</sup>	Duration of test, hr	Maximum Allowable Leakage, mg	Maximum Final Resistance to Air Flow, mm of H <sub>2</sub> O
Pneumoconiosis-producing and nuisance dusts	Silica dust; geometric mean not more than 0.6 μ; σ <sub>g</sub> = 1.9	50 ± 10	1.5	3.0	50
Toxic dusts (not significantly more toxic than lead)	Litharge, ~75%; free metallic lead, ~25%; geometric mean not more than 0.6 μ; σ <sub>g</sub> = 1.9	15 ± 5	1.5	0.43 (Pb)	50
Metal fumes (not significantly more toxic than lead)	Freshly generated lead fume	15 ± 5	5.2	1.50 (Pb)	50
Chromic acid mist	Electrolytically generated chromic acid mist	15 ± 5	5.2	1.0	50
Pneumoconiosis-producing and nuisance mists	Mist formed by atomizing a silica dust-water suspension	10 ± 5	5.2	5.0	50
Various combinations of above types of dispersoids	Respirator must meet requirements for each type.*				

\*For example, the protection against dusts not significantly more toxic than lead, the respirator must meet the requirements for the first two items in this table, that is, for pneumoconiosis-producing and nuisance dusts and for toxic dusts not significantly more toxic than lead.

From RESPIRATORY PROTECTIVE DEVICES MANUAL published by American Industrial Hygiene Association and American Conference of Governmental Industrial Hygienists, 1966.

Bureau of Mines approval schedule recently adopted for such masks. Replacement (and disposal) costs must be balanced against cleaning and maintenance costs.

Nuisance dust masks, including some not carrying Bureau of Mines approvals, may still have some use in industry. These may be useful in woodworking shops, on workers operating machines on dusty roads and farms, and for workers sensitive to pollens in certain seasons. Their costs are likely to be lower than those for approved masks and the reasons for their lack of approval should be given careful consideration. Thus a mask may fail to meet approval standards because of high breathing resistance, and this is likely to make it unacceptable for long wearing by workers. On the other hand, a mask may be a simple device for which no approval schedule exists, and it may be adequate, highly acceptable and useful to the librarian required to clean dust from stacks of books. Such masks must be kept strictly separate from masks used for genuine protection against hazardous materials.

A new type of respirator which is being employed where high efficiency must be combined

with low breathing resistance is the powered filter respirator. In this device a battery-powered pump forces air through the filter, and by way of a hose, into the facepiece. The rechargeable battery, pump and filter are carried in a compact unit worn on the belt or other harness. For heavy work requiring large air volumes and low resistance to breathing in atmospheres containing highly toxic materials, this powered filter device is proving both useful and popular. Workmen cleaning coke ovens and uranium miners are among those who are using this respirator.

#### Gas and Vapor-Removing Air Purifying Respirators

*Applications.* These respirators are designed to protect the wearer against the inhalation of materials in the air that are present in the form of gases or vapors. Respirators for protection against such materials are equipped with a container or canister filled with a sorbent which absorbs, adsorbs or reacts with the hazardous gas in the atmosphere. Some sorbents are highly specific for a particular compound and so the respirator containing only this sorbent gives no protection against any other material. Other sorbents take

out whole classes of compounds such as acid gases or organic vapors.

**Limitations.** Like the particulate removing respirator, the gas removing device is useless unless adequate oxygen is present. Unless the device is specifically equipped with a filter in addition to the sorbent, it will not offer adequate protection against any hazardous particulate substances. Leakage around canisters can also occur as around filters but this is less likely. Leakage around the facepiece is also possible but, since these respirators usually offer less resistance to breathing than filter types do, there is a slightly smaller chance of this type of leakage. Once a sorbent canister is opened and used, the sorbent may absorb moisture or other deleterious materials from the air and deteriorate even without further usage.

For respirators designed for use under highly dangerous conditions some canisters are equipped with devices which change color when sorbent depletion approaches. For respirators designed for use under less hazardous conditions the odor of the gas penetrating the canister is the only warning. For these reasons simple gas removing respirators are most frequently designed for a single usage in dealing with a specific situation.

**Facepieces.** Essentially the same information relating to facepieces on particulate removing respirators applies also to gas and vapor removing respirators. Because many gases and vapors are also irritating or damaging to the eyes, full face respirators are much more frequently required than half masks. Half mask respirators usually carry relatively small sorbent canisters which can be used only for short periods in relatively low concentrations of gas. Even with the full facepiece and its head harness, the sorbent canister for heavy duty usage may be too heavy to be supported on the facepiece. It may be worn on a chest harness or strapped to the belt. The canister is then connected by a hose to the facepiece.

**Sorbents.** As previously noted, some sorbents may be used only in dealing with specific chemical compounds or with classes of compounds. Thus manufacturers have specific sorbents for ammonia or chlorine. Many canisters contain combinations of materials to assure absorption of a specific compound. It is important to note whether protection against the substance required is claimed on the canister of the device to be used. Obviously, it is not always possible to include the complete list of all such compounds on each canister, and the canister may effectively remove some materials not listed. A list of sorbents for a large number of materials is given in the Respirator Manual.<sup>4</sup> The Bureau of Mines makes approval tests on only a limited number of common industrial toxic chemicals.

Since there is usually little warning of impending canister failure, the instructions of the manufacturer must be carefully followed regarding the length of time the device can be worn and the circumstances of its use. The effectiveness of a canister depends on the presence of a reactive chemical and canisters usually deteriorate with time. Here again, the manufacturer's instructions re-

garding shelf life should be followed and outdated canisters should be discarded.

**Types.** Gas masks are full facepiece units with large canisters. The names of the substances against which the mask gives protection are written on the canister and, in addition, the canisters are given specific colors for identification purposes.<sup>6</sup>

Chemical cartridge respirators are half mask respirators with small cartridges and are used for protection against the inhalation of atmospheres that are not immediately dangerous to life. Those used for protection against organic vapors are limited to use in concentrations not exceeding 0.1% by volume of such vapors; they are not satisfactory for all organic compounds. Mouthpiece respirators are small, compact devices for self-rescue in short term emergency situations (Figure 36-1). Instead of a facepiece this device fits in the mouth with a clip to put on the nose to force breathing through the mouth and the respirator.

Various combinations of filter and vapor removing respirators are available. A widely used device of this type is the universal gas mask which contains a filter plus sorbents for organic vapors, acid gases, ammonia and for the oxidation of carbon monoxide. This mask is used where the nature of the contaminants cannot be completely identified or where it is known that the atmosphere



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Figure 36-1. Mouthpiece Respirator — Self Rescue Device.

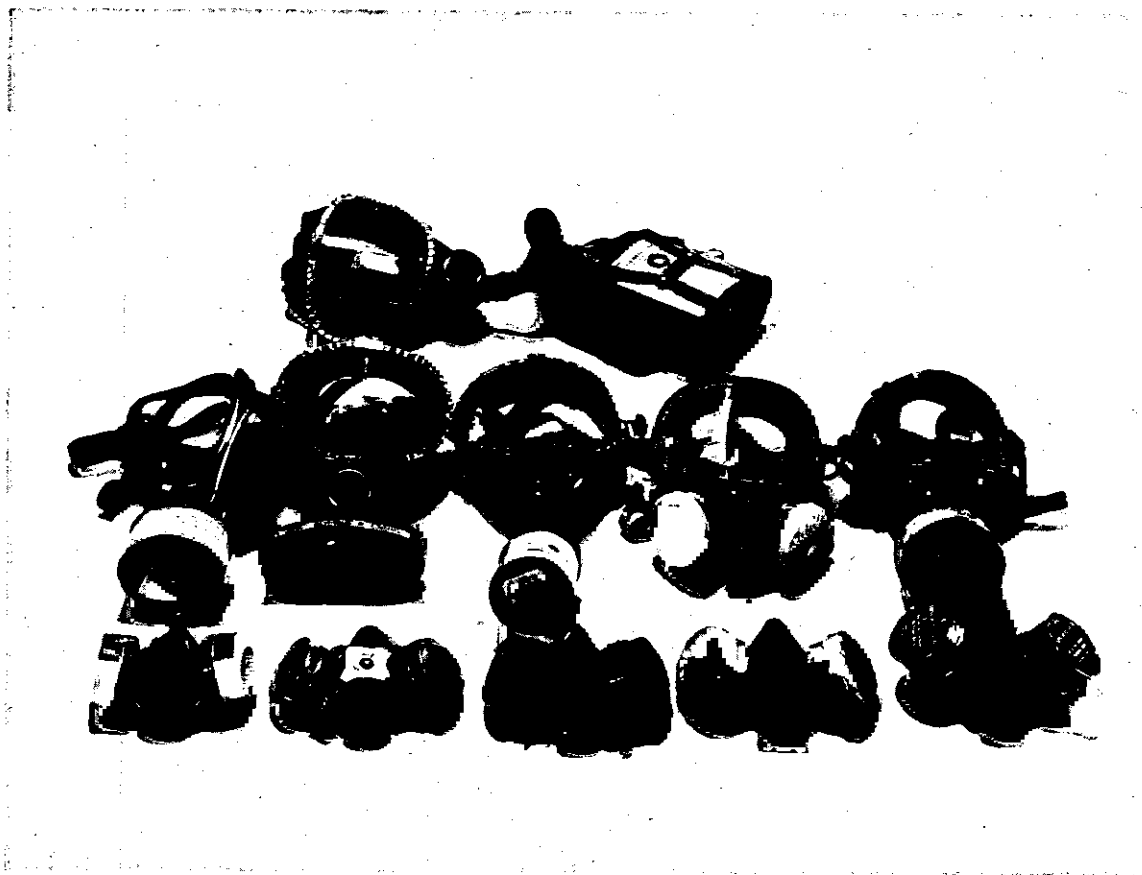
contains several of the above materials. It is the best respirator for protection against oxides of nitrogen in moderate concentrations. It must be remembered that it offers no protection when there is little or no oxygen present. Some manufacturers use the same basic facepiece for a variety of applications and various filters and canisters can be used on the same unit. Figure 36-2 illustrates air purifying respirators.

#### **Atmosphere Supplying Respirators**

*Applications.* When a lack of oxygen is known, or suspected or when a very high degree of protection is required the only suitable device is the atmosphere supplying respirator. This consists of a source of air or oxygen which is fed through a hose to a mask or a helmet. Intermediate mixing and regulating equipment may be required. Supplied air devices offer essentially no resistance to breathing, and the atmosphere supplied may be cool and more acceptable than that from other types of respirators.

*Facepieces.* A variety of facepieces are used with atmosphere supplying respirators. Half masks and full face masks are similar to those previously described although the valves are somewhat different. In addition to these, helmets may be used which cover the entire head and a cover may extend down to the waist as in the abrasive blasting hood. Another type of facepiece is the air supplied face shield. In this, the air is supplied by a hose to a perforated or slotted tube at the top of the face shield and the jets of air are directed downward past the eyes, nose and mouth. It is difficult to adjust this device to avoid entraining contaminated air and blowing it into the breathing zone. There are other combinations of atmosphere supplying equipment with hoods, blouses and complete clothing

*Hose types.* There are several varieties of the hose types including the hose mask with blower, hose mask without blower and the air-line respirator. The hose mask with blower can be used in any



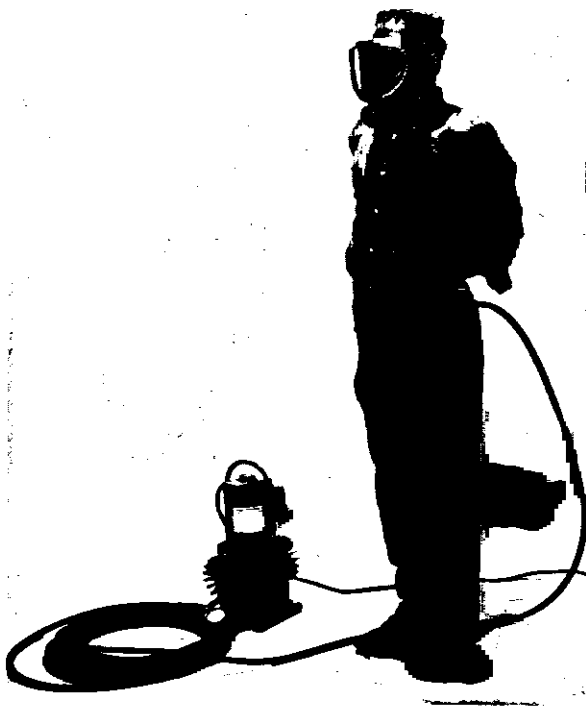
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**Figure 36-2. Air Purifying Respirators.**  
Front Row — Half Masks  
Second Row — Full Face Masks  
Rear — Universal Gas Mask.

atmosphere provided that enough respirable air is supplied to the wearer by means of the blower. The blower must be hand operated and the blower operator serves as an observer capable of rescuing the wearer in case of accident. The hose mask without blower is used under conditions not immediately dangerous to life and from which the wearer can escape without the aid of the respirator.

The air-line respirator (see Figure 36-3) consists of a source of compressed air to which the facepiece is connected by means of a small diameter hose. In the line is a pressure reduction valve and some type of flow regulating device. This equipment is used for protection in atmospheres that are not immediately dangerous to life or health or from which the wearer can escape without the aid of the respirator.

There are two basic types or modes of operation of air-line respirators — continuous flow and demand. In the first, the air is fed to the facepiece continuously and a positive pressure is maintained inside the mask at all times and any leakage will be outward. Considerably more air is used than is consumed in breathing. In the demand type a valve which regulates the flow of air opens only when a slight negative pressure is produced inside the mask as a result of inhalation. Thus, only air used in breathing is drawn from the source. Since a negative pressure is produced inside the face-



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Figure 36-3. Airline Respirator.

piece it must fit tightly to the face or contaminated air will be drawn in. Usually the demand type has a by-pass valve so the wearer can switch to continuous flow if he desires. A newer variation is the pressure-demand type of flow regulation. In this, a small positive pressure is always maintained in the facepiece even on inhalation. The demand valve opens to supply air when the positive pressure decreases to a certain level as a result of inhalation. Thus leakage is always outward if a poor fit of facepiece to face is obtained. *Self-contained breathing apparatus.* In this apparatus the wearer carries his own supply of air or oxygen and so he is able to move about without attaching hoses which limit his travel distance and maneuverability. Since the wearer is limited to the supply of air which he can carry, several methods are used to conserve this supply. Demand and pressure-demand valves may be used in the same manner as in the air-line respirator. A bypass for continuous flow is also provided, but can be used only for very short periods or the supply will be quickly exhausted. Either air or oxygen may be used in this type of apparatus.

Another type of device uses recirculation to conserve the oxygen supply. In this unit the exhaled air is not expelled but passes through an absorber which removes carbon dioxide and then enters a breathing bag. Here it mixes with fresh oxygen from the gas cylinder and then passes back to the facepiece for rebreathing. Oxygen only enters the breathing bag when the pressure in the bag drops below a fixed value. Since the oxygen content of exhaled air is still about two-thirds of that of inhaled air, it is only necessary to make up this difference from the tank and thus the recirculating type can be used for much longer periods for the same quantity of oxygen carried. Both demand and recirculating equipment are marked for use only for a specified period of time ranging from thirty minutes to three hours.

A third type of self-contained breathing apparatus uses a chemical source of oxygen which is liberated when carbon dioxide and moisture are absorbed from the exhaled air. A breathing bag is provided to mix the incoming oxygen with the purified exhaled air. This apparatus can be used for thirty minutes only and includes a timer to warn of the approaching limit (see Figure 36-4) Once the canister is opened it cannot be resealed for further use even if it has been used for only a few minutes. Like all chemical cartridges it has a limited shelf life even if unopened. *Combination types.* One variety of air-line respirator utilizes a small cylinder of compressed air worn on the user as an emergency device. If anything happens to the regular air supply the wearer simply disconnects his air line, automatically switching to the small cylinder supply and unhurriedly leaves the hazardous area. In place of a compressed gas supply, a filter or a sorbent canister may also be used for emergency conditions. Even with these devices air-line respirators are not approved for use in atmospheres immediately dangerous to life.

*Sources of air or oxygen.* The hose mask simply



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Figure 36-4. Self-Contained Breathing Apparatus.

uses air drawn from a source outside the contaminated atmosphere. The air-line respirator may use a compressed gas cylinder of air or oxygen or a compressor which picks up outside air. If the compressor is driven by a gasoline or diesel engine extreme care must be taken to see that the engine exhausts away from the pump intake and no exhaust gases enter the breathing air system. Water-lubricated compressors, or those not requiring internal lubrication, are the best sources of compressed air for these devices since heating may cause breakdown of lubricating oil forming carbon monoxide. Oil-lubricated compressors, if used, should be equipped with thermal overload switches to turn them off if overheating occurs. In any case, the compressor should be followed by a trap and filter to remove dirt, oil and water from the air line. If a regular building supply is to be used for an air-line respirator the system must be checked repeatedly to be certain that it does not contain even small concentrations of carbon monoxide.<sup>6</sup>

A new alternative source of oxygen for the self-contained breathing apparatus is liquid air or liquid oxygen. Several devices using this oxygen source have been approved by the Bureau of Mines. Air from this source is cooler and may have a "fresher" odor than compressed air.

**Maintenance.** All types of respirators require

maintenance and cleaning. The highly complex atmosphere supplying devices must be inspected for signs of wear and deterioration and to make certain that all of the parts are functioning properly. Other types of respirators are simpler but still require regular inspection. Rubber parts deteriorate with time and exposure to ozone and other gases. Hence, hoses, facepieces and valves must be inspected regularly and parts or whole respirators replaced when necessary. All respirators should be brought in for cleaning occasionally and emergency devices cleaned after every use when cylinders of gas or canisters are replaced. Emergency devices and self-contained breathing apparatus should be inspected monthly since they are usually to be used under very hazardous conditions.

When respirators are used routinely they should be brought in regularly to be dismantled, washed and dried, inspected and parts replaced as necessary, new filters or canisters put in and the whole reassembled and stored in a clean place.

### Special Topics

**Worker Acceptance Factors.** Good equipment is ineffective if the equipment is not accepted and used by the workers. Hence, factors leading to such acceptance must be carefully considered by management. All respirators are uncomfortable and irksome to wear but consideration of the comfort factor in respirator selection can do much to gain worker acceptance in using respirators when they are needed. Low breathing resistance is important, and while the Bureau of Mines specifies maximum values of permissible resistance, there are still differences among approved respirators. If face fit can be obtained only by very tight strap tension, the respirator cannot be worn long and its use will be avoided. A particularly important point is management's interest in the program. If every effort is made to provide conditions where respirators are not necessary then they will be better accepted when they are necessary. Regular cleaning and maintenance is evidence of management's interest. An educational program in respirator use is essential.

**Training.** Respirators are complex devices and cannot simply be handed to the worker with the assumption that they will be used properly. When the worker is told to use a respirator he should see the various devices available to him and have their method of operation explained including all essential parts. He should then try on the device and test the fit of the facepiece. This may be done by covering the exhalation valve, if possible, and then exhaling sharply or by closing the intake ports and inhaling. Most manufacturers include instructions for leak testing with the respirators and these directions should be followed. The worker should be taught to inspect the respirator before each use. The subject of training is discussed at considerable length in the Respirator Manual<sup>7</sup> and is an extremely important topic. Where considerable numbers of respirators are worn, it is advisable to designate a specific individual to be responsible for fitting and training.

**Heat problems.** All respiratory equipment is very

uncomfortable and fatiguing to use under hot conditions. Supplied air equipment such as air-line respirators may be most satisfactory under such conditions and complete supplied air suits may be necessary. A small compact vortex cooler is available which can be worn on the belt or harness to supply cool air.

**Communications.** Some voice communication is possible while wearing a respirator but sounds are muffled and attempts to talk loudly may loosen the face fit. With most full face masks it is possible to replace the exhalation valve with a combination valve and speaking diaphragm which permits much better voice transmission. When good communication over considerable distance is necessary, it is possible to equip the full facepiece with a battery operated microphone transmitter which transmits to an outside speaker or to receivers or earphones worn by others.

**Codes and sources of information.** As noted, the Bureau of Mines issues approvals for all types of respiratory protective devices and the approval schedules which can be obtained from the Bureau contain full information on how the respirators are tested and the standards they must meet. The Bureau has also issued a list of dust respirators approved for use in coal mines.<sup>8</sup> The American National Standards Institute has issued its American National Standard Z88.2-1969 entitled *Practices for Respiratory Protection* which contains much useful information.<sup>9</sup> The most complete publication in this field is the *Respiratory Protective Devices Manual* published by the American Industrial Hygiene Association and the American Conference of Governmental Industrial Hygienists. The National Safety Council has recently published a series of articles on respiratory protection in *National Safety News*.<sup>10</sup>

#### **A Respirator Program for Industry**

The important elements of the successful plant respirator program have been discussed in previous sections of this chapter. Here they will be summarized to provide a means for checking to be certain that all factors are covered in a particular situation.

**Determination of need.** This will require knowledge of the hazards anticipated in carrying out a particular job. An estimate will be required of the possible concentrations of toxic material that could be produced; whether existing engineering controls, such as ventilation, can adequately meet the needs; the anticipated duration of the required protection and any limitations imposed by the job. The latter includes the intensity of the physical activity required and whether or not the worker must be able to move about without encumbering hoses. Obviously, the determination of the need for respiratory protection is a technical decision and can best be made by an industrial hygienist.

**Selection of equipment.** Much of the same information required in establishing the need for respiratory protection is required here also. In addition, one must have a knowledge of the types of devices available for the particular circumstances encountered. Since it is impossible to expect each plant to have on hand every type of device manufactured, equipment kept on hand must be pur-

chased in advance on a basis of surveys and studies of anticipated needs. Here, there is a requirement for close cooperation between the person in charge of the respirator program and the plant's purchasing and stores department. Preliminary education of appropriate persons in this department may be necessary since their tendency will be to stock items on a basis of price without regard to important distinctions between different pieces of equipment.

**Training.** This is very important and requires continuous study and updating of knowledge by the person giving the training. The latter should be the person responsible for selection of respirators to be carried in stores, or at least he should be in very close touch with this aspect, since his direct contact with workers using protective devices makes him aware of their needs.

**Supervision and enforcement.** The support and encouragement of supervisors, such as foremen, are essential to the program. The foremen, particularly, should be asked to participate in fitting and training even though they may have little occasion to use respiratory protective devices. This provides an opportunity to demonstrate the importance of the activity and gains their support for the program. Without this support many workers will not use the equipment correctly nor care for it adequately.

**Inspection.** Industrial hygienists and safety engineers in the plant must include regular inspection of the condition of respirators as one of their routine duties. It is particularly important that emergency devices such as those mounted on walls or in cabinets be checked regularly. The most important inspections, particularly of smaller devices, are those given by the worker himself. His training must include information on the importance of this and how to do it adequately.

**Maintenance.** In most plants there should be a central cleaning station where respirators are brought in regularly for cleaning and replacement of worn or damaged parts. In very small plants this may be done by the worker himself with the aid of the safety engineer, industrial hygienist or plant nurse.

**Storage.** New respirators should be stored in their original container in a clean, cool dry place before being issued. Cleaned respirators if not immediately reissued should be placed in a dust-tight container, such as a plastic bag. The worker also should be instructed to store his respirator properly after it is issued to him. A respirator crammed into a tool kit can be permanently distorted in shape so that it cannot fit. Dust accumulated on the interior of the mask is readily breathed in and wearing such a mask may be a cause of more exposure than failing to wear it.

**Management interest.** Top management should give some evidence of support of the program. This may be done, in part, through the plant paper or magazine or through shop bulletins or other means of indicating interest or concern. It is the responsibility of the person in charge of the program to keep management informed about the program if he is to obtain their interest and support.



## PROTECTION AGAINST NOISE

The previous section of this chapter has dealt at considerable length with the subject of respiratory protection. Much of this is also applicable to devices used to protect against noise and other hazards. With hearing protective devices, both ear plugs and ear muffs, there is a need for experimentation in trying different types of devices to meet specific needs. Since the noise hazard is not as acute as the respiratory hazard more experimentation is justified. Both plugs and muffs attempt to prevent the penetration of sound through the outer ear to the inner ear; however, some sound also reaches the inner ear by conduction through bone and tissue. Thus, any protective device is limited in the degree of protection which can be achieved. In sound fields in excess of 120 decibels no protective device will give adequate protection for continuous exposure.

When ear protectors are first used by a worker, he experiences a sensation that his own voice is very loud since outside noises are reduced. As a result, he tends to speak softer making it more difficult to communicate with others especially if they are wearing protectors also. Noises signaling dangers around the worker may be muffled and their warnings not heeded.

### Ear Plugs or Insert Devices

Ear plugs are small conical or cylindrical devices made to fit into and seal the ear canal against the entrance of sound. The more closely the plug approximates the shape of the ear canal the more positively it will seal. Plugs are usually made of a soft pliable material like soft rubber or plastic so they can be inserted into the ear canal with positive force without being uncomfortable. Many models have soft flanges which can seal the canal even if contact with the body of the device is incomplete. Attempts have been made to improve the usefulness and acceptability of ear plugs by introducing models with "valves" or perforations which were to allow passage of sound of certain frequencies or to block loud but not soft sounds. None of these has been successful and the plain plug remains the best. Since fitting to the ear canal is important some manufacturers make plugs for individual ears by making casts or impressions of the ears and then moulding and curing a plastic material in the shape of the impression. While such devices would appear to have a great advantage in effectiveness and comfort, this is not always the case.

Malleable wax material is available which can be moulded into the ear and discarded after use. Wadded cotton has often been used, but actually is comparatively ineffective. Cotton impregnated with wax or vaseline is much more effective. A very fine glass wool material has been introduced in recent years, often called Swedish Wool after its country of origin. This material can be rolled into plugs and gives almost as good protection, if properly used, as a good commercial plug. Dispensers for this material can be installed and the material is more acceptable to many workers than regular ear plugs.

The degree of sound attenuation provided by

ear plugs varies in different frequency bands or octaves. For good, well-fitted plugs this varies from 25 decibels in the low frequency or low pitched sounds to 40 decibels at frequencies over 1000 Hertz. Fitting of the plugs is very important in achieving good results. Most plugs come in several sizes and the correct size must be chosen to fit the individual's ear canal. Frequently different sizes are needed for the two ears. Fitting by the Medical Department is a good way of achieving this part of the program's purpose. The physician can examine the ear canal carefully for size and at the same time detect any ear infections or canal irregularities which may rule out the use of ear plugs. Some persons simply cannot wear ear plugs.

### Ear Muffs

Ear muffs are much like communications type earphones in appearance although the ear cup is usually deeper. They are equipped with a headband which may go over the head or around the back of the neck. The latter type permits the wearing of a hat but usually offers slightly less hearing protection. They may also be mounted on a helmet or hard hat. The degree of attenuation obtained varies with the sound frequency and may range from 20 decibels at low frequency to 45 decibels at high frequency. There is a standard method of measuring attenuation by muffs, but it is complex and requires special equipment. Most users will have to rely on the attenuation data supplied by the manufacturer.

To attain good protection the muff should seal over the ear and the seal may be made of foam rubber or liquid-filled or grease-filled cushions. The latter two are somewhat more effective and comfortable. Large cup volumes and small cup openings lead to greater attenuation.

Proper fitting is important with muffs, but is not quite so individual a matter as with plugs. The worker should be offered a choice of several models to achieve the best fit and to gain his acceptance of the device. Where communication is necessary in a high noise level environment, ear muffs can be equipped with earphones and battery operated radios. The microphone can be muffled and mounted directly in front of the mouth.

### Plugs or Muffs?

Good ear plugs may give slightly higher attenuation in the very low frequency range while muffs give better attenuation in the middle ranges. Above 1000 Hertz there is little from which to choose on a basis of the degree of protection afforded. Plugs are more acceptable to some workers while muffs are preferred by others. Where exposure to noise is intermittent, muffs are somewhat more easily removed and replaced when needed. Plugs are easier to carry than muffs, but for the same reason are more easily lost. They are also less expensive. Muffs are more comfortable for use in cold weather. Both plugs and muffs deteriorate with time and should be inspected frequently.

### Evaluation

If ear protection is required, there should also be a medical program which includes audiometric

testing of exposed workers. Results of such testing will determine whether continued exposure is advisable even if protective devices are used. Obviously, every attempt should be made to control the noise by engineering methods and eliminate the need for personal protective devices. One author puts the case as follows — “When the only possible control method is ear protection, it is important — rather it is essential — that the ear protection program be continually monitored by knowledgeable and enthusiastic people who are dedicated to the task of protecting the hearing of noise-exposed employees.”<sup>11</sup>

#### PROTECTION OF SKIN AND BODY

This section deals with the subject of what is usually called protective clothing and includes protection of the various parts of the whole body either completely or partially as may be required. The term, protective clothing, is a correct one although much protective clothing offers no more direct bodily shielding than would be offered by ordinary street dress. Since street clothing might be ruined or rendered unsuitable for street use if worn in the shop, the shop clothing provided is “protective” of one’s ordinary clothing. Chemicals, dirt, heat and cold are the chief hazards against which protective clothing are used. Certain rather specialized occupations require unusual types of protection including firemen, aircraft crews, missile fuel handlers, astronauts and divers. In general, this section is not directed to these specialized vocations but much of what we have learned about protective clothing comes from experience in providing protection for workers in such unusual environments.

There is a wide variety of materials available today to meet the requirements of many types of conditions. Fabrics such as cotton, glass fibers, Orlon, Nylon, Dynel and even Teflon are available for jackets and coveralls. These can be made impervious by coating with various plastics, rubber or Neoprene. Plastics are also available in sheet form and can be made into clothing with glued or heat-sealed seams. Respiratory protective devices often are worn with protective clothing and, in many cases, become an integral part of such clothing (see Figure 36-5).

While some protective clothing is supplied and cleaned by the worker it is more commonly done by the employer, especially if the wearing of such clothing is a requirement of the job. In many cases, work clothing cannot and should not be taken home since such clothing could become a hazard to persons handling it there. This is particularly true of workers handling radioactive materials, pesticides, beryllium and other highly toxic materials. If the employer is responsible for cleaning the clothing he, too, must decide whether to send it to a commercial laundry or to set up his own cleaning facility. For clothing contaminated with ordinary dirt, soil, grease and perspiration, a commercial laundry may be an acceptable method of handling the problem. In many cases, one or more plant laundries will have to be provided depending on the variety of exposures encountered.



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Figure 36-5. An Air Ventilated Blouse with Integral Respirator.

There is also the problem of maintenance and of replacement. Garments must be inspected before or after cleaning and worn garments discarded. Those not meeting standards of cleanliness required may have to be recycled. For radioactive materials, this may mean monitoring of each garment with a special instrument. Where the exposure is to certain chemicals, it may mean periodic tests on occasional selected garments after cleaning.

Training in the use of protective clothing is important, especially with complex gear. Even with simple laboratory coats and coveralls, workers should be given some instructions in how to care for such garments and how and when to turn them in for cleaning and replacement. For complex garments, especially those including respiratory protective equipment, regular training and refresher courses should be given. Here again, some *one* person should be in charge of selection, storage, maintenance and training in the use of such equipment. An important element in this

training is that dealing with the methods of putting on and taking off this clothing. Special standardized techniques may be necessary where clothing has or could have become heavily contaminated. If care is not exercised, contaminating materials can be brought into contact with the worker's skin or transferred to his street clothing. Separate lockers for work clothing and street clothing are necessary when hazardous materials are handled. These lockers may be on opposite sides of the shower room.

### **Protection Against Contamination**

Situations included in this category are those where there is no immediate danger to the skin from contact with the contaminating material, but where it is undesirable to have the worker expose himself in his street clothing. This includes the mechanic or machinist exposed to dirt and grease, the operator handling toxic dusts, the laboratory employee handling various chemicals that could damage his clothing and the person working with radioactive materials or bacteriological agents. The emphasis in all of these cases is on limiting the spread of the contamination. When the worker leaves his job, he should not transfer the hazardous or undesirable material to clean parts of the plant or to places outside the plant. Clothing for these applications is often called anti-contamination or anti-C clothing. It should be noted that also within this category of jobs are those where extreme cleanliness is required for the protection of the product being made. In that case, the aim is to prevent the spread of contamination from street clothing or the worker to the product. The same requirements and procedures also prevail here.

Garments worn in these situations are principally of cotton or synthetic fibers and usually are not impervious to liquids or dusts. The mechanic and the chemical plant operator usually wear coveralls. If the material is difficult to remove he may also wear gloves and some type of cap. Footwear may consist of a pair of shoes which are left in the plant. In working with more dangerous material like toxic dusts or radioactive materials more strict regulations are necessary. Here a complete change of clothing including socks and underwear is needed and showering is essential. For heavily contaminated work special attention must be given to sealing all openings in the clothing. For dirty jobs which are not done routinely, openings may be sealed with masking tape and two suits of coveralls may be worn. If possible, the clothing should be designed to minimize the number of openings, decorative buttons and folds as these items collect contamination and make it difficult to remove.

Many workers wear full coverage clothing all day in doing their routine jobs. They may also wear surgeon's gloves or similar types to give the required sensitivity in handling objects, but these are not satisfactory if the work subjects the gloves to abrasion. Head covering in this case is usually a simple cloth cap although a hard hat may also be required on certain jobs. In addition to shoes worn only in the plant, special shoe covers may

also be required. These may be of heavy cloth, plastic coated cloth, plastic or rubber. These are particularly important to the worker who must move from one department or operation to another. By changing shoe covers he prevents the spread of the particular type of hazardous material in one department to another where a different material may be handled.

Rooms where workers remove heavily contaminated clothing must be well ventilated since removing contaminated clothing can cause suspension of the contaminant in the air where it becomes hazardous to everyone in the room. For the same reason, chutes and bins where contaminated clothing is deposited should have exhaust ventilation. For limiting contamination, consideration should be given to the possibility of using disposable clothing made of paper or plastic, particularly on very dirty jobs. Cleaning costs should be balanced against the costs of replacement and disposal. In making this evaluation careful consideration should be given to the disposal cost as this is often neglected.

### **Protection Against Corrosive Chemicals**

Included in this category are situations where the contaminant can have an immediately damaging effect on the skin. These include exposures to strong acids and acid gases, alkalis, some organic chemicals and strong oxidizing agents. Also included are those requiring protection against very heavy contamination where ordinary anti-C clothing would permit skin contamination to levels where complete removal would be difficult. Clothing in this category is usually impervious to liquids, gases and vapors and may be made of fabrics impregnated with rubber or plastic. Rubber "frog suits" have been used for work in heavy concentrations of dangerous radioactive materials. The worker may be required to shower with the suit on and then shower to clean himself after carefully removing the suit using standardized procedures. Respiratory protective equipment is almost always required in conjunction with this clothing. It may be worn under the clothing or it may be an integral part of the clothing. An air line may be attached directly to the clothing for ventilation or it may go directly to a respirator. The head cover is usually part of the clothing in the form of a hood. Gloves must be impervious and may also be an integral part of the clothing.

Wearing impervious clothing imposes serious limitations on the amount of time the worker can wear the clothing and the strenuousness of his activity. Unless the clothing is ventilated with an air line, perspiration will rapidly accumulate inside the clothing and the body temperature may increase except in cold environments. These conditions impose a serious stress on the worker. Air-ventilated clothing is much more comfortable and permits wearing the clothing a longer period of time although it may limit the movements of the worker. Air-ventilated clothing must be studied and evaluated carefully because improper design can result in only parts of the clothing being ventilated. The air line must discharge through several openings to supply the various parts of

the suit. Where workers must work in impervious clothing for long periods close medical surveillance is required.

#### **Protection Against Skin Penetration**

Certain materials will pass through the intact skin and produce systemic toxic effects without necessarily doing any damage to the skin or causing pain. Situations involving these materials include exposure to hydrogen cyanide, missile or rocket propellant and the radioactive form of hydrogen known as tritium, either in elemental form or as water vapor. The clothing requirements for these exposures are practically the same as those discussed in the previous category. They are grouped separately because the effects produced can be very serious and there is little or no warning of failure of the protection. Thus, there is more need for frequent inspection and testing of the clothing worn in this type of exposure situation. Respiratory protection is always required.

#### **Protection Against Heat and Cold**

For mild exposure to heat the clothing should be light and well ventilated. At higher temperatures most clothing restricts the body's ability to remove body heat by evaporation of perspiration and forced ventilation of the clothing is necessary for prolonged work at elevated temperatures. Obviously, the design of clothing for protection against heat and cold emphasizes thermal insulation and the principles on which such design is based are well known. If there is a great deal of radiant heat, as around a furnace or flames, aluminized plastic, cloth or asbestos may be used to provide a reflective surface.

Air supplied clothing is particularly useful since the supplied air may be heated or cooled to maintain thermal equilibrium. Air for breathing may also be heated or cooled and very cold air may be tempered if taken in through a hose wrapped around the worker's body under the insulating clothing. For work at very low temperatures, particular attention must be paid to protection of the fingers, toes, ears and nose since they are the parts most difficult to keep at an adequate temperature and frostbite may result from exposure. Thick gloves which are necessary greatly limit manual dexterity and electrically heated gloves may be required under some conditions.

There are special pieces of protective gear used to protect parts of the body against heat, flame and sparks. The welder's leather apron and his face mask are examples. Foundry workers wear leather leggings to protect their legs against spilled molten metal. They also wear special foundrymen's shoes called Congress shoes which can be pulled off quickly if hot metal is spilled into the shoes.

There are many other devices used for the protection of the individual worker against falls, falling objects, flying particles, burns and injuries, such as safety hats, shoes, gloves, goggles, etc. They are not covered in this chapter since they are considered to be strictly "safety" items. See Chapter 47 for a general discussion of these items.

## **EMERGENCIES**

By its very nature, personal protective equipment is important in dealing with emergencies. Mine explosions and cave-ins, industrial fires, natural disasters and gas leaks all present occasions when men must receive protection against severe and unusual conditions while saving life and property. Engineering controls such as ventilation are completely inadequate and usually inapplicable in such situations; therefore complete reliance must be placed on protective clothing and respiratory protective devices. Some of the same devices used in the daily plant activities may be applicable but in most cases it will be necessary to use more specialized devices such as self-contained breathing apparatus or fire-resistant clothing.

Equipment for dealing with emergency situations must be stored where it is readily available and yet not be placed where it can be damaged by the accident causing the emergency. This requires careful analysis to anticipate the possible emergencies and accidents which can arise. An important characteristic of emergency protective devices is that they are *stored* which means that they are actually used very rarely. Since much equipment suffers deterioration even during storage, it is necessary to set a regular schedule of inspection and testing of each device.

Most such devices are fairly complex and require trained persons for their use. An untrained person attempting to rescue an injured man in a building filled with toxic vapors is very likely to become a casualty himself. Men must be trained in how to function in an emergency and in the use of all emergency equipment. Retraining exercises must be given at regular intervals since instructions are easily forgotten, equipment is changed, and personnel may be transferred. The essential beginning of any emergency planning is a thorough analysis of the possibilities of accidents. This analysis, in itself, may lead to the correction of unsafe conditions.

## **STANDARDS AND INFORMATION**

The approval schedules of the Bureau of Mines for respiratory protective equipment are standards in a sense as has already been noted. The American National Standards Institute has prepared consensus standards on many items of protective equipment and these are listed in the bibliography of the chapter. There are needs for additional standards for some equipment and for the revision and updating of many existing standards. The process of producing standards is a lengthy one, and changes and improvements in the various devices are being introduced continuously. There must be a willingness to experiment and test new and nonstandard devices under non-hazardous conditions in order to secure improvements in protection and acceptability.

In addition to the written standards there are various guidebooks to the selection, use and maintenance of personal protective devices prepared by organizations concerned with health and safety. These are listed at the end of the chapter and the appropriate guide should be consulted by anyone

responsible for supervising the use of these devices. Such guides have been prepared by the National Safety Council, the American Conference of Governmental Industrial Hygienists, the American Industrial Hygiene Association, the International Atomic Energy Agency and others. Most manufacturers of protective equipment furnish information on the degree of protection which can be achieved by their devices and on their proper use, care and maintenance.

#### References

1. *Occupational Safety and Health Administration Standards, Personal Protective Equipment*, Federal Register, 36:10590 (No. 106, May 29, 1971).
2. SCHUTZ, R. H. and E. J. KLOOS. *Respiratory Protective Devices Approved by the Bureau of Mines as of Dec. 31, 1968*, Information Circular #8436, Bureau of Mines, Pittsburgh, Pa.
3. *Respiratory Protective Devices Manual*, AIHA-ACGIH, p. 91, 1963.
4. *Ibid.*, pp. 56-58.
5. *American Standard Safety Code for Identification of Gas Mask Canisters*, K13.1-1961, American National Standards Institute, 1430 Broadway, New York, 10018.
6. VENABLE, F. S. and E. D. POLICK. "Your Compressed Air: Fit to Breathe?," National Safety News, 89:28-32, 1964.
7. *Respiratory Protective Devices Manual*, AIHA-ACGIH, Chapter 13.
8. SCHUTZ, R. H. *Approved Dust Respirators for Coal Mines*, Information Circular #8509, Bureau of Mines, Pittsburgh, Pa.
9. *American National Standard Practices for Respiratory Protection*, Z88.2-1968, American National Standards Institute, 1430 Broadway, New York, 10018.
10. "Series on Respiratory Protection," National Safety News, April-December 1971.
11. BONNEY, T. B. *Industrial Hygiene Highlights*, p.

208, Industrial Hygiene Foundation, Pittsburgh, Pa., 1968.

#### Preferred Reading

American Industrial Hygiene Association Journal  
Health Physics  
National Safety News  
Industrial Hygiene Highlights  
Annals of Occupational Hygiene (British)  
Staub (German)

#### Additional Reading

Additional Standards from the American National Standards Institute:

American National Standard for Occupational and Educational Eye and Face Protection, Z87.1-1968.

American National Standard Safety Requirement for Industrial Head Protection, Z89.1-1969.

American National Standard for Men's Safety-Toe Footwear, Z41.1-1967.

*Respirators and Protective Clothing*, International Atomic Energy Agency, Safety Series #22, Vienna, 1967.

HYATT, E. C. "Current Problems and New Developments in Respiratory Protection," *Am. Ind. Hyg. Assoc. J.* 24:295-304, 1963.

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*Industrial Noise Manual*, American Industrial Hygiene Association, Chapter 10, 1966.

PLUMB, E. E., E. L. MENDENHALL and M. C. ROBBINS. "Evaluation of Protective Clothing and Equipment for Operations in Oxygen-Rich or Deficient Atmospheres Approaching -100°F," *Am. Ind. Hyg. Assoc. J.* 27:29, 1966.

CROLEY, J. J. "Protective Clothing — Responsibilities of the Industrial Hygienist," *Am. Ind. Hyg. Assoc. J.* 27:140, 1966.



**CONTROL OF NOISE EXPOSURE***Vaughn H. Hill***DEFINITION OF PROBLEM****Measure Noise Level**

From an engineering control standpoint, the first step in a hearing conservation program is to measure the noise levels in all working areas. Areas in which the noise level does not exceed 90 dBA\* need not be considered further since noise reduction is not required.

**Determine Exposure Time**

In areas where the noise level does exceed 90 dBA, a study should be made to determine the actual worker exposure time. Then using this exposure time and the measured noise level, one can determine whether or not the government standards are exceeded. Details regarding the use of government criteria are given in Chapter 25. It may be desirable to use a dosimeter to determine the actual daily noise exposure for comparison with government criteria. Dosimeters are discussed in Chapter 25.

**Evaluate Extent of Hazard**

If the combination of noise level and exposure time indicate that government criteria are exceeded, an evaluation should be made to determine the most economical solution to the problem. Considerations for making such an evaluation are: (1) reduction of noise level, (2) reduction of exposure time, (3) segregation of worker from noise, (4) substitution of more quiet machine or process or (5) provision of worker with personal protection such as ear muffs or plugs. Under the Occupational Safety and Health Act this latter option is available only if others fail. Usually all of the following will be involved in making the best evaluation: (1) management, (2) medical, (3) personnel, (4) manufacturing, (5) engineering and (6) maintenance. This chapter will be limited to the problem of reducing noise in working environments.

**CONSIDERATION OF ALL POSSIBLE MEANS OF NOISE CONTROL**

In a subject as broad as industrial noise control, it is impractical to discuss all possible solutions to all problems. Therefore, typical problems of the type occurring most commonly in industry will be discussed with the hope that the reader will acquire an understanding of the principles of noise control that will guide him in solving a much wider variety of problems.

The mode of attacking a noise problem is somewhat analogous to that of controlling any

environmental hazard. Appropriate control measures include such things as change in plant layout and design, substitution of less hazardous method, reduction of the hazard at its source, and reduction of the hazard after it has left its point of origin.

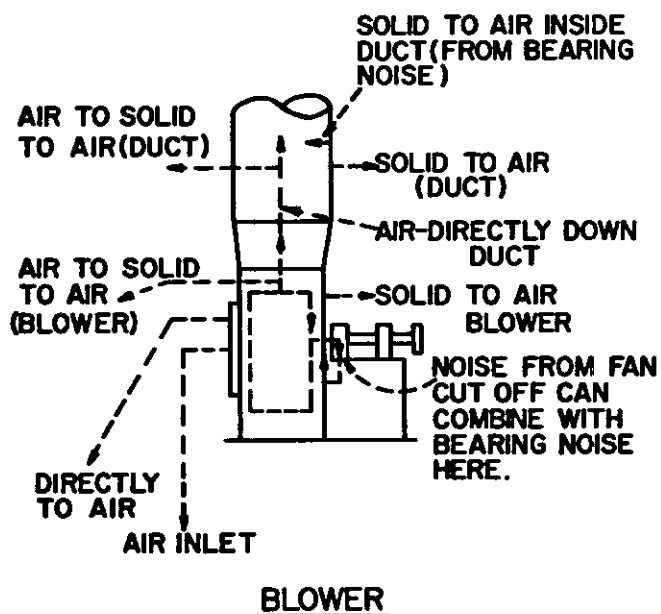
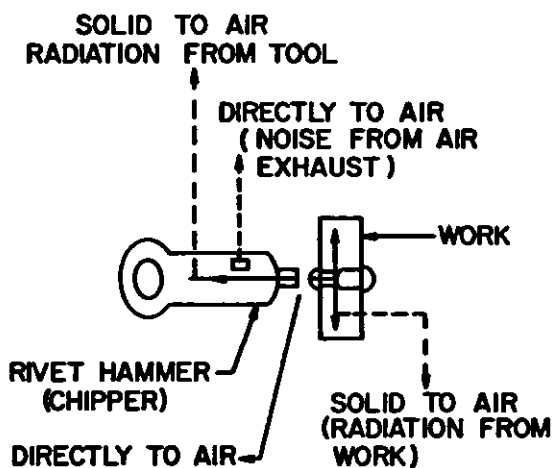
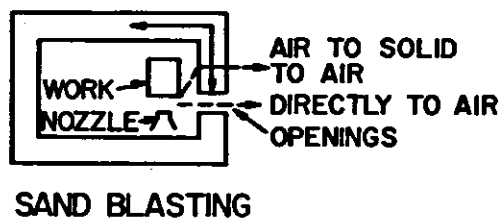
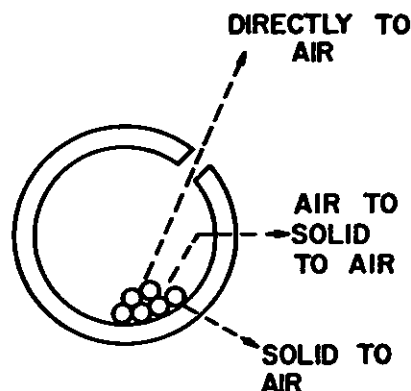
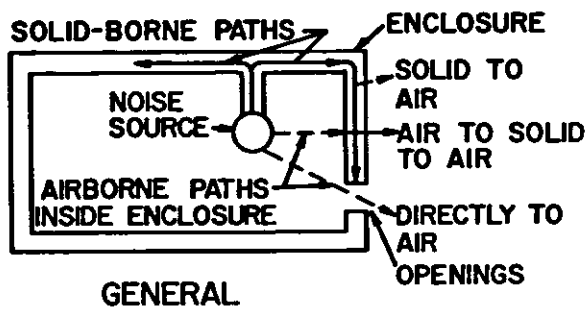
In analyzing a noise problem one must consider that sound from a source can travel by more than one path to the point at which it becomes objectionable. Therefore, noise flow diagrams such as shown by Figure 37-1 are a definite aid to accurate analysis of a given problem. For instance, this shows that sound sources inside enclosures can have (a) direct radiation of sound through openings in the enclosure, (b) sound radiation from the enclosure due to solid borne vibration from the source and (c) indirect radiation from the enclosure, that is, airborne from the source to the inside of the enclosure and subsequent reradiation from the outside of the enclosure. The problem is to determine which paths carry the most sound energy and then select appropriate methods of obtaining the desired reductions along those paths.

It has proved helpful to follow a planned method of analysis so that no possible control measure is overlooked. The following outline can be used in making such an analysis:

**Noise Control Analysis Outline**

- I. Plant Planning
- II. Substitution
  - A. Use quieter equipment
  - B. Use quieter process
  - C. Use quieter material
- III. Modification of the Noise Source
  - A. Reduce driving force on vibrating surface
    1. Maintain dynamic balance
    2. Minimize rotational speed
    3. Increase duration of work cycle
    4. Decouple the driving force
  - B. Reduce response of vibrating surface
    1. Add damping
    2. Improve bracing
    3. Increase stiffness
    4. Increase mass
    5. Shift resonant frequencies
  - C. Reduce area of vibrating surface
    1. Reduce overall dimensions
    2. Perforate surface
  - D. Use directionality of source
  - E. Reduce velocity of fluid flow
  - F. Reduce turbulence

\*Note: This figure may be changed by regulation or law. Check for the current standard requirement.



Tyzzar, F. G.: Reducing industrial noise. Amer. Ind. Hyg. Assoc. J. 14:264-95, 1953.

Figure 37-1. Noise Flow Diagrams.



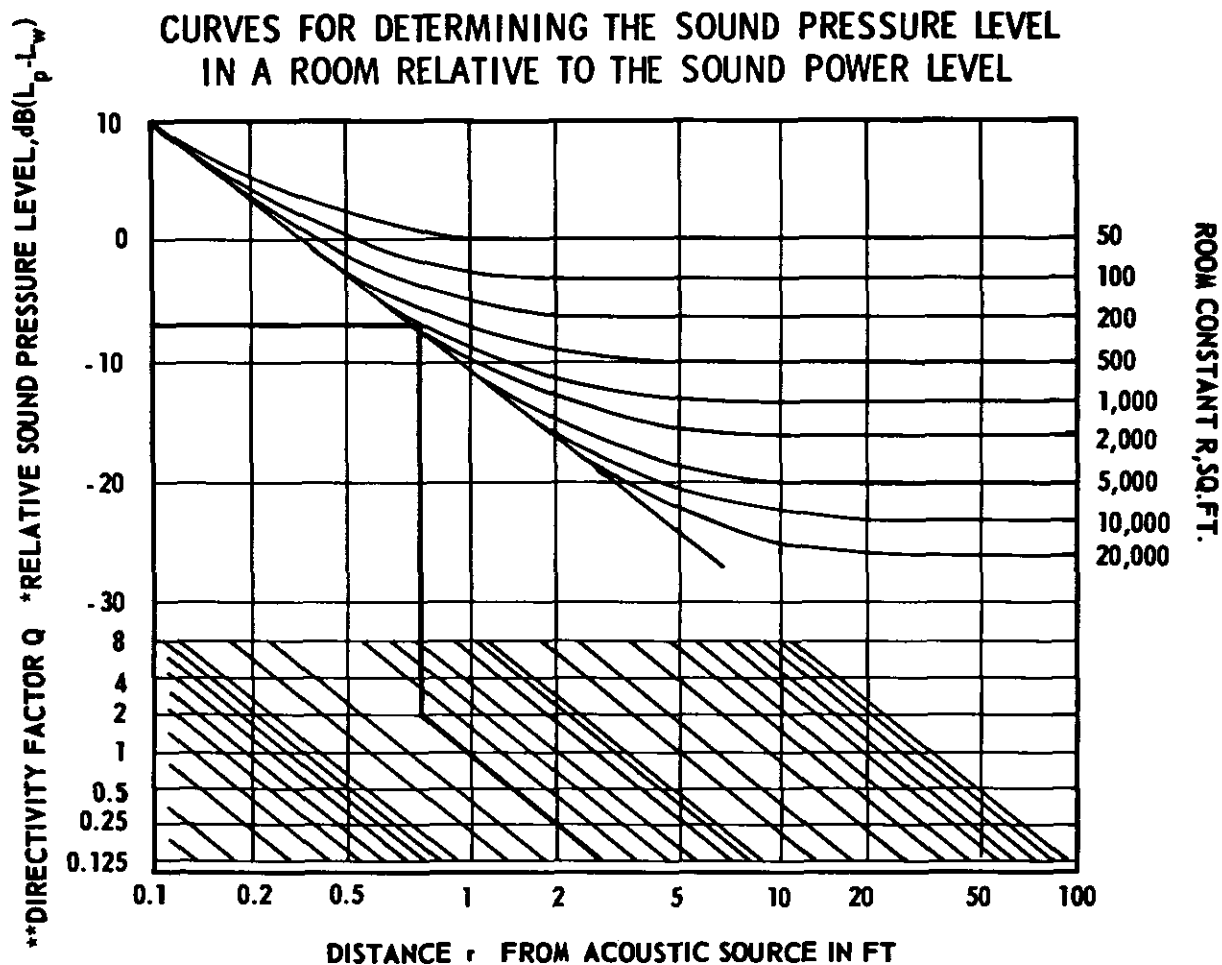


Figure 37-2. Curves for Determining the Sound Pressure Level in a Room Relative to the Sound Power Level.

#### IV. Modification of the Sound Wave

- A. Confine the sound wave
- B. Absorb the sound wave
  1. Absorb sound within the room
  2. Absorb sound along its transmission path.

Examples of many of these possible control measures will be illustrated in this chapter.

#### Plant Planning

**Noise specifications.** An immediate step essential to those concerned with noise control is to stop buying new noise problems. Minimum essential designs for processes and equipment must involve light, high speed machines, high pressures, high flow velocities, light building structures and minimum floor space. All of these can lead to noise problems if limits are not specified. Noise specifications are a *must* for new equipment. To properly use noise specifications one must understand Figure 37-2. This graph shows the relationship between sound power level ( $L_w$ ) and sound pressure level ( $L_p$ ) and their relationship to distance

from the source ( $r$ ), directivity factor ( $Q$ ) and room constant ( $R$ ).

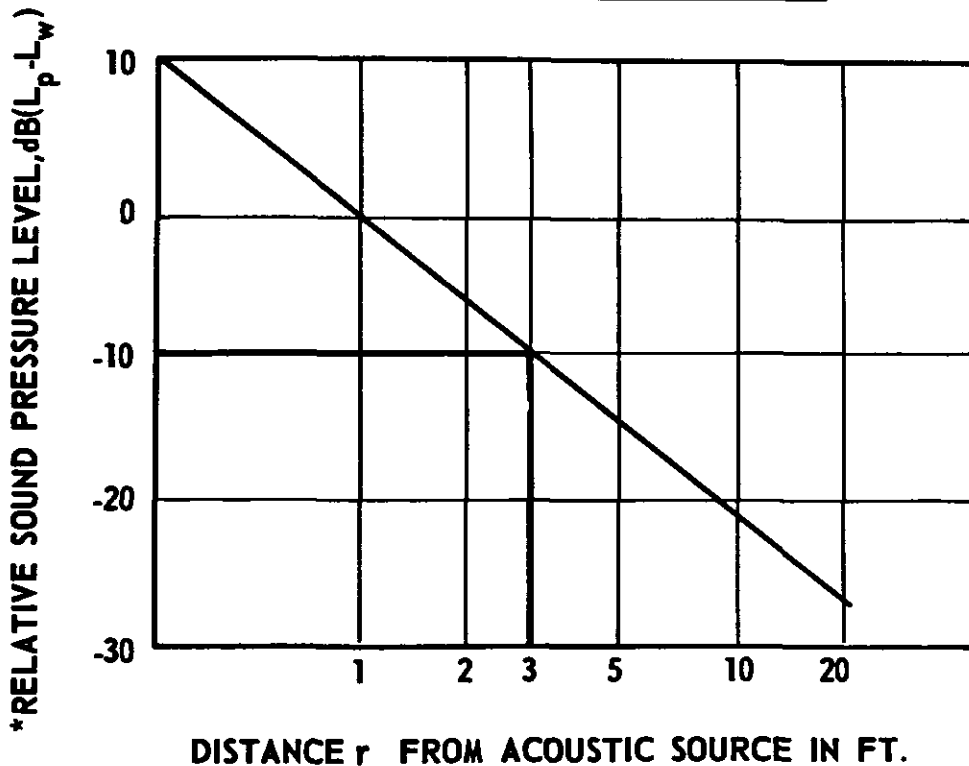
$L_w$  is total energy of the sound source and is independent of the distance or environment. It is calculated, not measured. See Chapter 23 ("Physics of Sound") for further discussion.

$L_p$  is sound energy flow per unit area at some distance ( $r$ ) from the source. It varies with distance from the source, directivity and room constant. Therefore, these environmental conditions must be specified when expressing noise in terms of sound pressure level.

**Free field radiation.** When a sound source is in a free field (where there are no reflections) it will diminish with the square of the distance from the source. The relation between  $L_w$  and  $L_p$  in this case is shown by Figure 37-3.  $L_p$  can be measured with a sound level meter or analyzer.

**Room constant ( $R$ ).**  $R$  is a measure of the ability of a room to absorb sound. It can be calculated as follows:

# FREE FIELD NOISE RADIATION POINT SOURCE - NONDIRECTIONAL



$$L_w = L_p + 20 \text{ Log}_{10} r + 0.5 - T$$

Figure 37-3. Free Field Noise Radiation Point Source — Nondirectional.

$$R = \frac{\bar{\alpha} S_t}{1 - \bar{\alpha}} \text{ sq. ft.}$$

where  $S_t$  = total area of room bounding surfaces in sq. ft.

$\bar{\alpha}$  = average sound absorption coefficient of room bounding surfaces

$$= \frac{S_1 \alpha_1 + S_2 \alpha_2 + \dots + S_n \alpha_n}{S_1 + S_2 + \dots + S_n}$$

where  $S_1, S_2, \dots$  = area of each absorbing surface in sq. ft.

$\alpha_1, \alpha_2, \dots$  = corresponding coefficients of absorption

R can be estimated from Figure 37-4 as an alternative to the calculation.

**Directivity factor (Q).** Q is a measure of the degree to which sound is concentrated in a certain direction rather than radiated evenly in a full spherical pattern. Directivity factors for typical radiation patterns are shown in Figure 37-5. They are actually portions of spherical radiation patterns as related to the surface area of a sphere which is  $4\pi r^2$ .

For spherical free field radiation, that is, where there are no reflections, the radiation pattern is illustrated at the upper left of Figure 37-5 and  $Q=1$ .

For hemispherical radiation, such as shown at the upper right, or in areas where the sound source is near the center of the floor in a large room the same sound source would produce twice the concentration of sound energy at a point on the surface of the hemisphere as it would on the surface of a sphere of the same radius. The surface area of the hemisphere is  $4\pi r^2/2$  and  $Q=2$ .

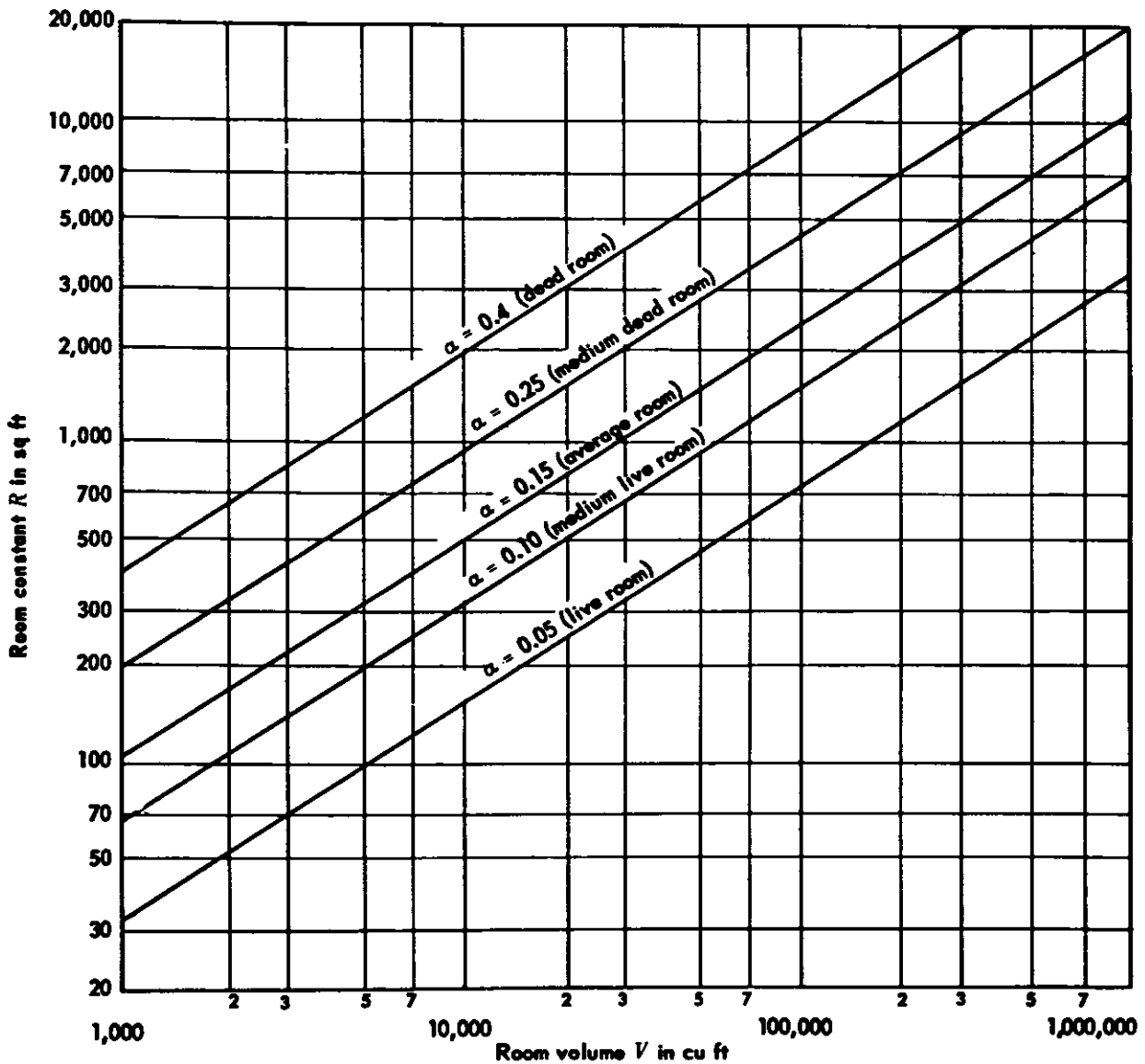
Similarly, if the sound source is near the intersection of the floor and a wall of a room such that 1/4 spherical radiation exists as shown at the lower left, the radiating area can be expressed by  $4\pi r^2/4$  and  $Q=4$ .

Similarly, if the sound source is near the intersection of the floor and two walls of a room such that 1/8 spherical radiation exists as shown at the lower right, the radiating area can be expressed by  $4\pi r^2/8$  and  $Q=8$ .

The source might also have a directional noise radiation pattern indicated by the vendor. If so, this would have to be taken into account in addition to the environmental radiation pattern discussed above.

This is a simplified presentation of directivity, but should be sufficient for most industrial situations.

Noise measurements made in the vendor's test laboratory can be modified to estimate the



**ROOM CONSTANT FOR TYPICAL ROOMS**

Beranek, L. L. (ed): Noise and Vibration Control. New York, McGraw-Hill, p. 277.

**Figure 37-4. Room Constant for Typical Rooms.**

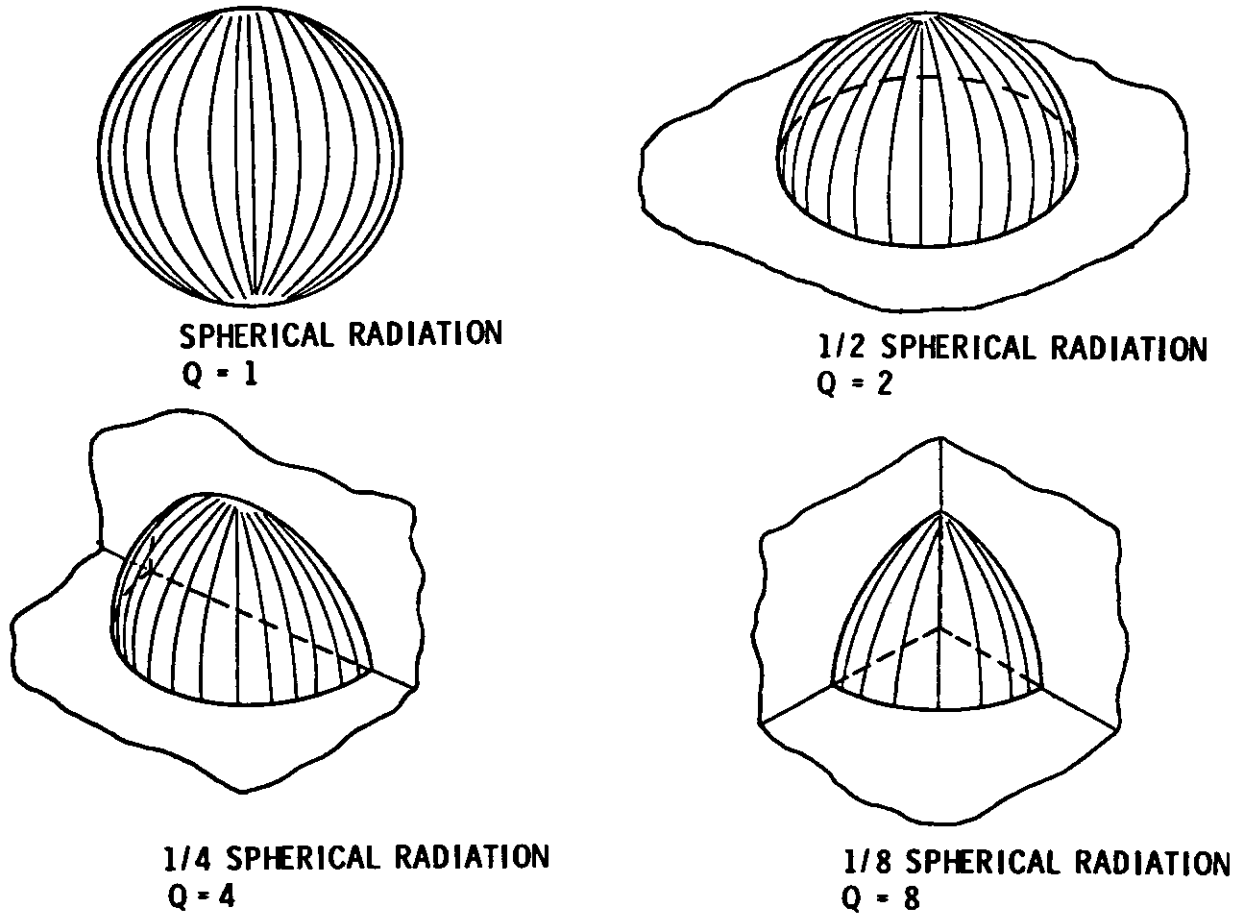
levels in the purchaser's intended environment by the use of Figure 37-2. The power level of the noise source will be the same in both locations. The sound pressure level in the purchaser's environment will be the difference between  $L_p - L_w$  in the vendor's shop as compared to  $L_p - L_w$  in the purchaser's environment.  $L_w$  is determined from previous calculations by working through Figure 37-2 and the measured  $L_p$ . Then  $L_p$  for the purchaser's environment can be determined by working through Figure 37-2 for the new conditions.

**Substitution.** Sometimes it is possible to substitute a quieter machine, process or material. It is very

likely that noise was not considered at the design stage of existing projects (plants). For new projects it will probably be less expensive to buy quiet equipment than noisy equipment that will require noise reduction treatment. Figures 37-6 through 10 illustrate some substitute possibilities.

**Quieter materials.** The materials used in the construction of buildings, machines, pipes, chutes and containers have a vital relation to noise control. Some materials and structures have high internal damping; others have little and ring when struck. These latter are the potential trouble makers and should be avoided where the possibility of vibrational excitation is involved. Ringing can be re-

## DIRECTIVITY FACTOR (Q), SIMPLIFIED RELATIONSHIPS



duPont de Nemours & Co., Wilmington, Delaware.

Figure 37-5. Directivity Factor (Q), Simplified Relationships.

duced by damping the material or reducing the exciting impact by means of resilient bumpers. Figures 37-11 and 12 illustrate the use of quieter materials. Damping will be discussed later in this chapter.

### Modification of the Noise Source

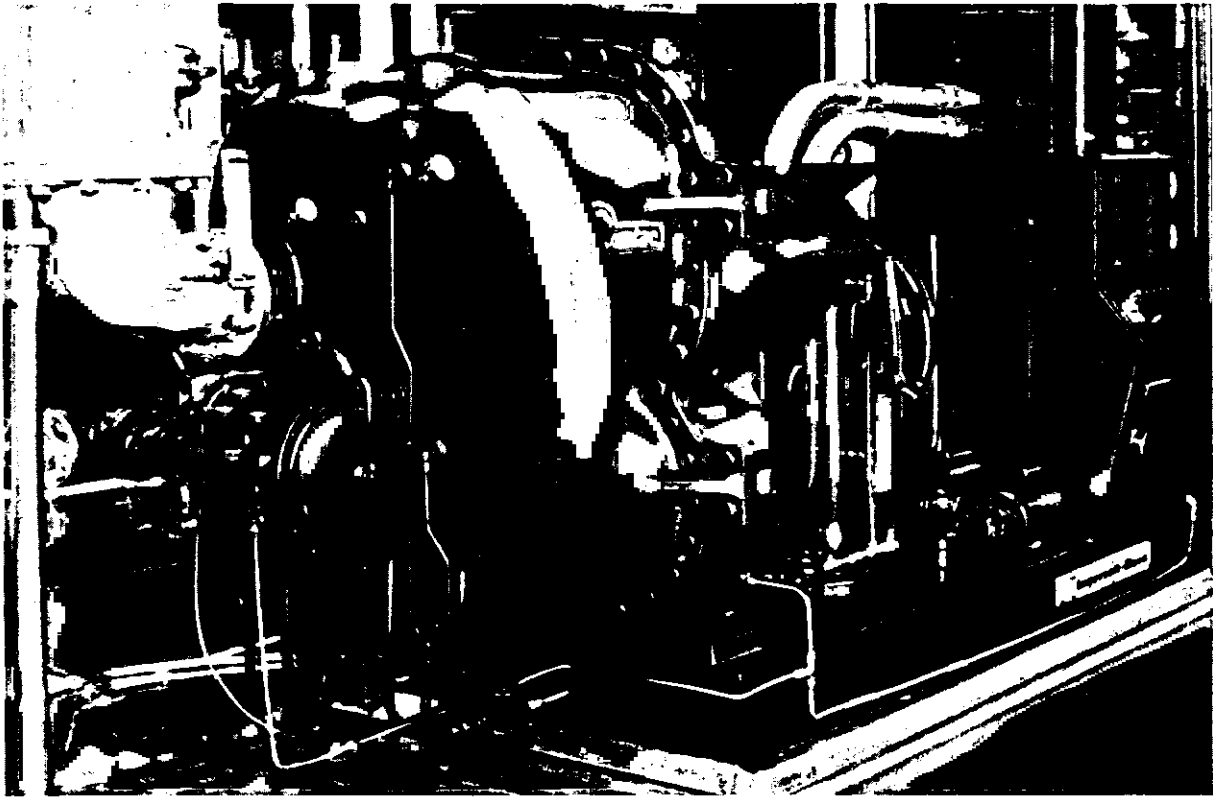
There are two basic noise sources: (1) vibrating surfaces and (2) fluid flow. In either case, usually, the nearer the source one can affect treatment, the less expensive will be that treatment because it will be minimum in size.

*Direct sound away from area of interest.* Many industrial sound sources are directional, that is, they radiate more sound in one direction than in others. Common examples of directional sources are intake and exhaust (vent) openings, partially enclosed sources, and large sheet metal surfaces. It is sometimes possible to utilize directionality of the source to provide noise control in a particular region of the sound field. This type of control is achieved by directing the source so that a minimum in the sound field occurs at the point or area of interest. A typical example is a vertical vent stack that directs the sound above the populated

area, or a vent stack cut off at an angle to direct the sound to one side. When the sound source is in a room it is not possible to achieve worthwhile noise reduction by source direction when the point of interest lies in the reverberant portion of the sound field. For enclosed areas containing little sound absorption the reverberant field may extend to within a few feet of the source, and direction of the source will have little effect on the sound levels throughout most of the area. Under these conditions there will be some advantage in directing the source to an area of highly absorbent material, for this effectively reduces the source strength as far as the remainder of the room is concerned. Figure 37-13 is an example where sound has been directed away from the point of interest.

*Reduce vibrating surface.* This type of noise source will consist of a driving force, coupled to a sound radiating surface. Control at the source may then consist of reduction of the driving force, reduction of the radiating surface response to the driving force or reduction of the radiating efficiency of the vibrating surface.

*Reduce driving force.* The driving (vibration ex-



Ingersoll Rand, Allentown, Pennsylvania.

**Figure 37-6. QUIETER EQUIPMENT — CENTRIFUGAL COMPRESSOR:** This high speed centrifugal multi stage compressor has a heavy cast case which encloses the impellers and interstage cooling system. It also encloses the noise so that operating areas around the compressor do not exceed 90 dBA provided motor and external piping noise is controlled. This compressor is a good example of a machine well designed for noise control.

citing) force is often the result of unbalance or eccentricity in a rotating piece of equipment. Such forces increase with increase in rotational speed, therefore the speed should be kept to a minimum. Figure 37-14 is an example of the effect of speed reduction. A large machine running at slower speed might be a better selection as far as noise is concerned. Certainly eccentricity and balance

should be checked to be sure they are within normal tolerance. Good alignment, lubrication, and bearing maintenance are also important in minimizing noise. Figure 37-15 shows the noise reduction achieved by improving maintenance on a blower system. Driving forces can also be caused by reciprocating members such as pistons or rams.

Impact type driving forces are produced in

**Figure 37-7. QUIETER EQUIPMENT — V-BELT DRIVE.**

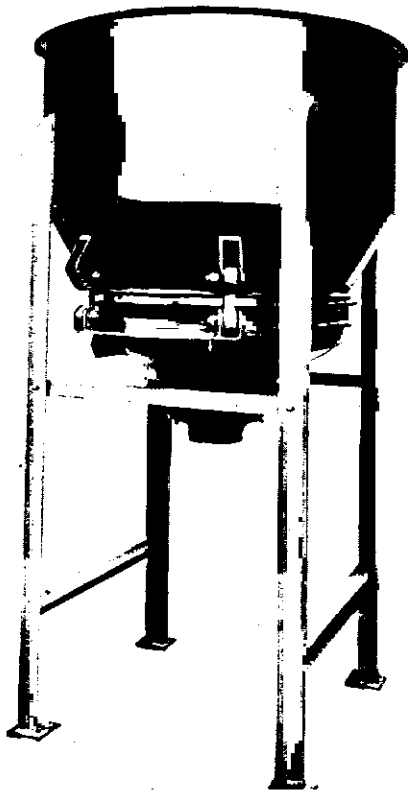
A rubber toothed type belt with flanged grooved pulleys was used to drive a pump. Noise levels were too high in the octave bands above 2400 Hz. The grooved pulleys and toothed belt were replaced with a V-belt drive. Reductions of more than 15 dB were obtained in the octave bands above 2400 Hz as shown below.

The frequency distribution of noise created by

a toothed belt drive is dependent on the tooth passage rate — the higher the speed, the higher the frequency.

If a toothed type belt must be used, the noise could have been reduced by enclosing the belt and pulleys. The enclosure should be lined with sound absorbing materials which is effective for the frequency range of interest.

Frequency — Hz — octave band	20- 75	75- 150	150- 300	300- 600	600- 1200	1200- 2400	2400- 4800	4800- 9600	9600- 19,200
Noise Reduction in dB	5	4	4	2	0	6	17	18	25



Vibra Screw Incorporated, Totowa, New Jersey.

**Figure 37-8. QUIETER EQUIPMENT — VIBRATION ISOLATED HOPPER.** An 8 ft. dia. hopper with electric solenoid type vibrator was creating excessive noise. A live bottom bin by Vibra Screw was installed as shown below and a noise reduction achieved as shown here. The noise reduction is due to the fact that the cone only is vibrated, there is much less vibratory power required and there is no metal to metal impacts.

Frequency—Hz—								
octave band—center								
frequency of band	63	125	250	500	1000	2000	4000	8000
Noise Reduction—dB	7	6	20	22	16	12	12	9

most metal or plastic fabricating operations such as punching, forging, riveting and shearing. Because of the short duration of most impact forces, considerable noise reduction can be achieved by modifying the system to provide a smaller force over a longer period of time. Figure 37-16 shows how this can be accomplished with a punch. Figure 37-17 illustrates this principle on a 48" shear. Here the cutting blades are segmented and skewed to give a shear type cut.

Impact type forces can also be reduced by providing resilient bumpers at the point of impact. Examples of this method include lining tumbling barrels, chutes, hoppers, stock guides, etc. Figures 37-11 and 12 illustrate this method of control.

It is a rare case where a machine causes

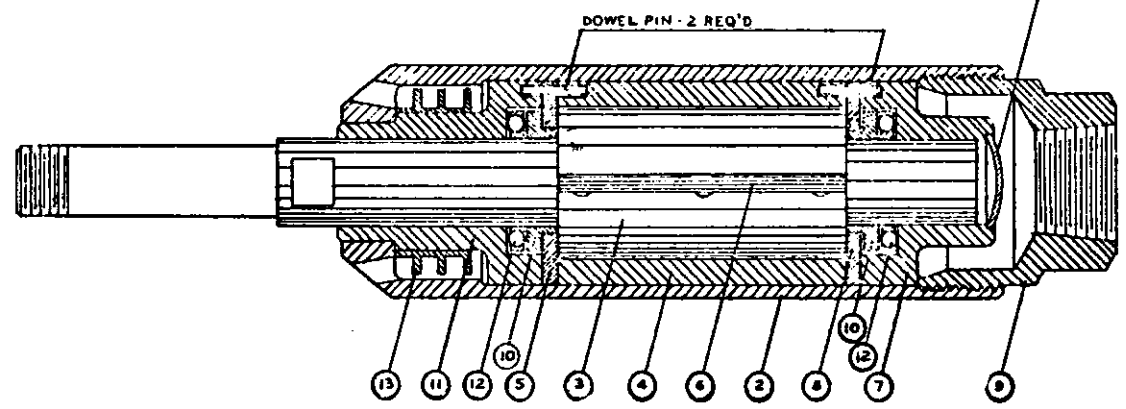
sufficient vibration of a building to cause the building to radiate noise in excess of 90 dBA. However, a common pitfall about equipment mounting should be pointed out here. It is becoming common practice to mount machines and their drives on a common base of steel weldments. This is fine for alignment and shipment, but for vibration producing machines such as cutters, pulverizers, grinders, blowers, compressors, the steel base can become a serious noise radiator. This problem can easily be overcome by constructing the steel base so that after installation it can be filled with nonshrinking concrete or sand. If it is desired to vibration-isolate the equipment, the isolators should be between the concrete filled steel base and the building floor. The heavy base is also desirable in this case so that center of gravity of the equipment will be lower, that is, nearer the level of the vibration isolation mounts. For stability's sake the level of the isolators should be as close as practical to the vertical center of gravity of the vibrating machine. Since good vibration isolators are readily available and manufacturing instructions for selection and installation are adequate for most cases, further discussion will not be given here. Vibration isolation is usually not necessary except near offices or control rooms or where process equipment dictate the need. Vibration isolation of equipment can cause the more serious problem of pipe line failure at the flexible joints in the lines required by the increased vibration of the isolated equipment.

*Reduce response of vibrating surface.* The response of a vibrating member to a driving force can be reduced by damping the member, improving its support, increasing its stiffness or increasing its mass. When the frequency of the driving force is equal to the natural frequency of the member being vibrated, large surface displacements are usually developed. This condition is known as resonance. Most mechanical structures have a family or series of resonances which are rather widely spaced in the low frequency range but are more closely spaced at higher frequencies. Because of the large surface displacements developed at resonance, there is usually increased noise radiation. Resonant vibration may be limited effectively by damping, decoupling or detuning by shifting the natural frequency. Optimizing a damping treatment is usually a complicated procedure best left to the experts if the cost can be justified. For many industrial problems it is satisfactory to use a simple rule of thumb approach. For the rough treatment typical of industrial environments, constrained layer damping is usually preferred. This means covering the vibrating surface with a thin sheet of damping material plus an outer covering of sheet metal. The sandwich so formed is cemented (both surfaces) and bolted together on 6" to 8" centers. The rule of thumb is that for vibrating panels having a thickness of up to 16 gauge, use an outer steel plate (restraining plate) of the same gauge as the vibrating plate. For vibrating plates of 16 gauge to 1/8" thick, use a restraining plate of 16 gauge steel. For vibrating plates of 1/8" to 1/4" thick, use a 1/8" thick re-

115000-B-2 7/16

FIGURE 37-9

An Elliott No. 1380 tube cleaner (2-7/8" dia.) created excessive noise. A new design, Elliott No. 115,000 was substituted. The new design had a built in muffler for the air discharge of the turbine drive as shown by the drawing. Noise reduction DISC PLUG-1 REQ'D achieved is shown in the table.



14	CA PLUG	P-8161K	1																			
13	MUFFLER UNIT	115088	1																			
12	THRUST BEARING	112054	2																			
11	FRONT BEARING ASSEM	112050	1																			
10	THRUST WASHER	112037	2																			
9	MACHINE COUPLING	112031	1																			
8	REAR PLATE	112027	1																			
7	REAR BEARING ASSEM.	112009	1																			
6	PADDLE	112008	5						TC-													
5	FRONT PLATE	112007	1						TC-													
4	SHELL	112006	1						TC													
3	ROTOR	115005 A	1						TC-													
2	BODY	115002-2 7/16	1						TC													
1	ASSEMBLY	115000-B-2 7/16							TC-													
	PART # 4E	PART No	REQ	CHG	OUT	L	M		ENGR	CHANGE												
											BODY DIAM 2 7/16		SHAFT THRD 3/4"		HOSE CONN 3/4" NPT.							
															TYPE "DBT" - MUFFLED							
															AIR DRIVEN MOTOR							
															(EXTRA LONG ROTOR)							
															FOR							
															BY H CR JD		DATE 6-13-66					
															ELLIOTT COMPANY		SE-					
															SPRINGFIELD OHIO		115000-B-2 7/16					
															NEWARK N J							

Elliott Company, Springfield, Ohio.

Figure 37-9. An Elliott No. 1380 tube cleaner (2-7/8" dia.) created excessive noise. A new design, Elliott No. 115,000 was substituted. The new design had a built-in muffler for the air discharge of the turbine drive as shown by the drawing. Noise reduction achieved is shown in the table.

straining plate. For vibrating plates of 1/4" thick or heavier, use a 1/4" thick restraining plate. The common damping materials are damping felt, elastomeric damping sheeting and sheet lead. All material selected should be compatible with the temperature and environmental conditions involved such as exposure to chemicals and oils. It is to be noted that the flat unsupported surfaces are the ones radiating the most noise. Corners of box-like structures, reinforcing bosses, etc., are so rigid they probably do not require damping. This simplifies the damping treatment because it eliminates many double curved surfaces which would be difficult to laminate. Manufacturers of damping materials can advise regarding the most effective use of their materials. Do not hesitate to use the heavy restraining plates suggested above. They make the panel significantly stiffer and reduce not only resonance but the driven response as well. The extra weight and stiffness might be the most important factor in reducing the noise. Figure 37-18 illustrates constrained layer damping and

damping by means of filling structure with sand. Figure 37-19 illustrates noise control by increased mass and stiffness. Reduce efficiency of noise radiating surface. The sound energy generated by vibrating surfaces depends not only upon the velocity of surface motion but also upon the area of the radiating surface. Because the displacement of most surfaces is limited by the constrained edges, the surface velocity will decrease with frequency, and the area must increase if constant sound output is to be maintained. Therefore, the effective radiation of low frequency sound is usually limited to large surfaces. Conversely, any surface of more than several square inches can effectively radiate sound at frequencies above 1000 Hz. In general, any regularly shaped area with one dimension greater than one-fourth wavelength can effectively radiate sound at the frequency corresponding to that wavelength in air. Surfaces radiating low frequency sounds can sometimes be made less efficient radiators by di-



Ingersoll Rand, Allentown, Pennsylvania.

**Figure 37-10. QUIETER EQUIPMENT — PORTABLE AIR COMPRESSOR:** The Ingersoll Rand portable air compressor shown above was designed with noise control as a specification. All functional components of this diesel — engine powered machine including engine, compressor, mufflers, fuel tanks, receiver separator tank and frame are completely enclosed in an aluminum, glass fiber, sheet steel sandwich-panel material. Improved cooling by increased air flow through mufflers was required for this enclosed machine. The noise reduction achieved by this design is shown below.

Frequency — Hz — octave band center frequency of band	63	125	250	500	1000	2000	4000	8000
Noise reduction in dB	8	13	24	17	10	10	10	14

viding them into smaller segments or otherwise reducing the total area. The use of perforated or expanded metal can often result in less efficient sound radiation from sheet metal guards and cover pieces.

*Turbulent fluid flow.* A very common industrial noise source is high velocity fluid flow. The strange thing about it is that usually the velocity required by the industrial process is not high enough to

create a serious noise problem. For example, where compressed air is used to clean or wipe a product, such as blowing water from a freshly extruded plastic, the noise source is the sonic velocity of the gas passing through the pressure reducing valve. The noise source is not the air velocity which wipes the water from the plastic. This problem (and many more similar ones) can be solved by placing a muffler just downstream from the

**Figure 37-11. QUIETER EQUIPMENT — RESILIENT LINING FOR TUMBLING BARREL.**

The tumbling of steel balls against the steel shell of a ball mill can produce excessive noise. By lining the steel with resilient material this noise

will be reduced by a considerable amount. One such mill lined with rubber produced the noise reduction shown below.

Frequency — Hz — octave band — center frequency of band	63	125	250	500	1000	2000	4000	8000
Noise reduction — in dB	3	4	6	7	11	12	15	19



## RESILIENT HAMMER HEAD

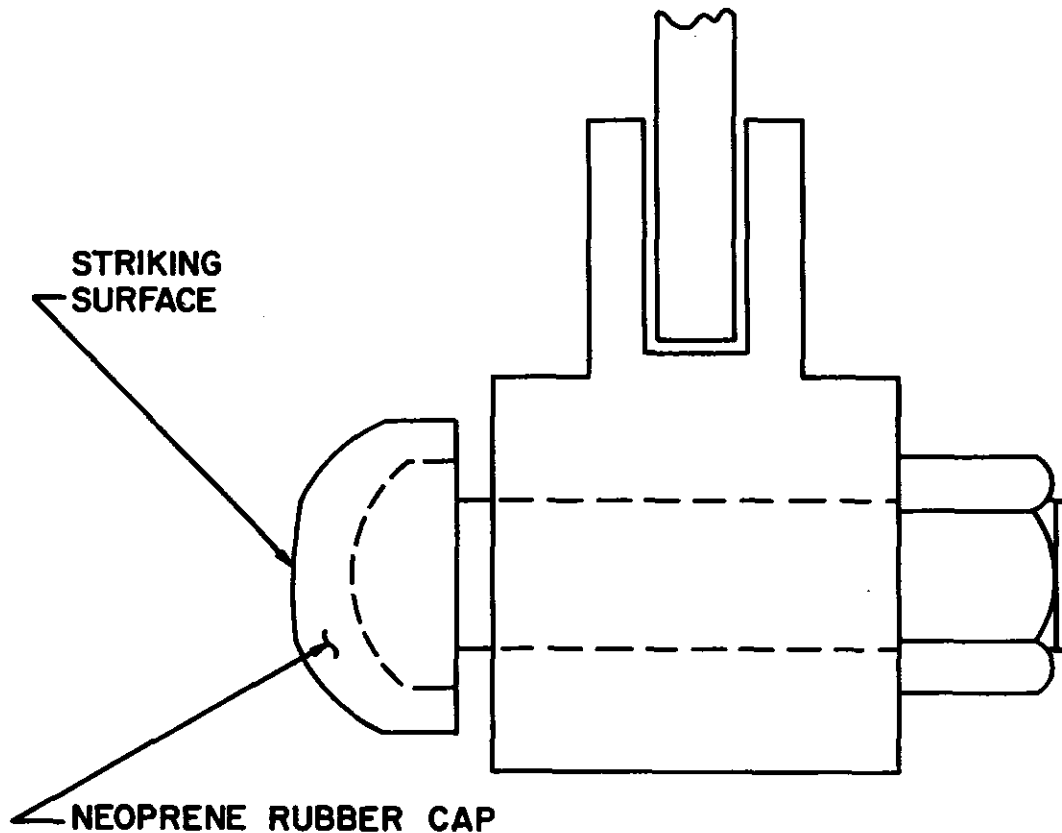


Figure 37-12. QUIETER MATERIAL — RESILIENT HAMMER HEADS: Rotary dryers commonly use hammers (Knockers) on the outside of the dryer shell to prevent product buildup on the inside. The metal to metal impact noise produced is usually objectionable. This noise can be reduced by providing resilient heads for the hammers. By providing sufficient striking area between hammer and shell, the resilient facing material can usually be made to transmit the desired vibration to the dryer shell without causing the objectionable metal to metal impact noise. In one case, the overall noise level was reduced 28 dB. Common materials used for the face of hammers are Adiprene®, neoprene, nylon, Fabreeca and rawhide.

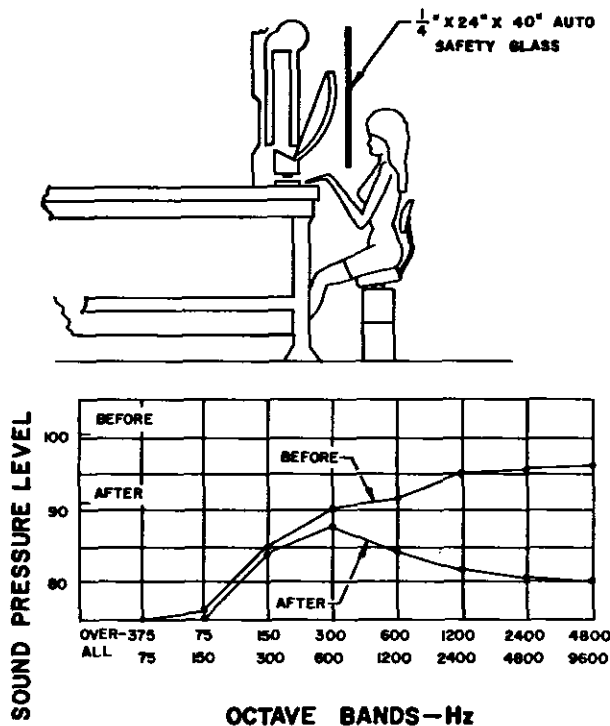
NOTE: Lempco Automotive, Inc., supply nylon hammer heads and Garland Mfg. Co. supply rawhide hammer heads.

valve as shown by Figure 37-20. The muffler is to remove noise from the sonic velocity in the valve. Then with the nozzle downstream from the muffler designed for minimum velocity to do the job, there should be no noise problem. Velocities as high as 10,000 ft. per minute can be used without excessive noise, and even this velocity may not be needed for many processes. The rule is, for low noise don't use velocities higher than necessary. In particular, don't use sonic velocities. Beware of gas pressure reducing valves.

Where the ratio of upstream to downstream absolute pressures is 1.9 or greater, sonic velocity and excessive noise is produced — unless the reduction is controlled through the use of a special valve which avoids sonic velocity. A valve which

accomplishes this achieves a gradual pressure drop and expanding volume such that sonic velocities are not reached. The valve consists of a stack of plates as shown by Figure 37-21 and each plate has small gas passages as shown by Figure 37-22. The high pressure gas enters from below as the stem rises. When the stem passes by the ID of a plate, the gas flows through the tortuous path to the plate O.D. where it is at the low pressure level. As the valve stem rises, more plates (and passages) are exposed and more volume of gas passes. This is called the "Drag Valve." It can be designed for any desired noise level and gas flow.

For existing pressure reducing valves or for applications where quiet valves cannot be used due to dirty gas or lack of economic justification,



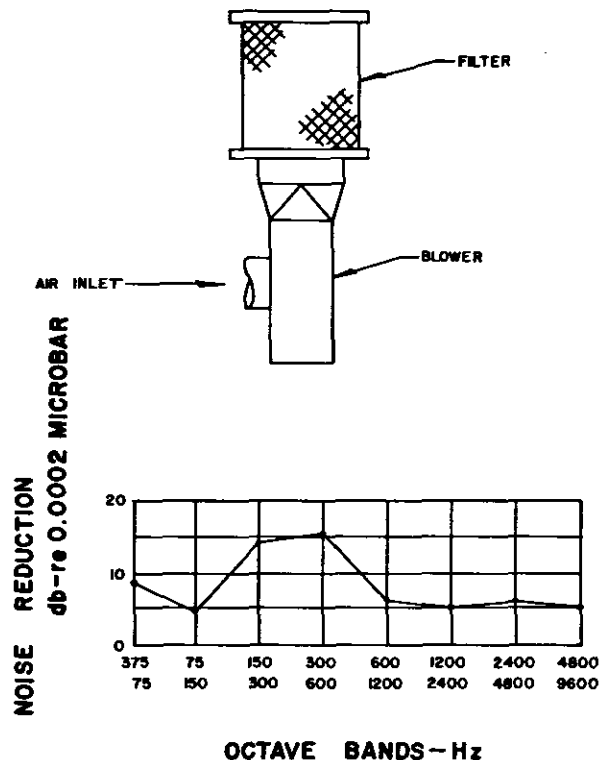
AIHA Noise Committee: Industrial Noise Manual, 2nd Edition. Detroit, American Industrial Hygiene Association, 1966.

**Figure 37-13. NOISE SHIELD — DIRECT SOUND AWAY FROM POINT OF INTEREST.** The use of shields between a noise source and an employee is usually quite effective when both the source and the employee are close to the shield and when the noise is predominantly high frequency. An example is shown on the punch press which uses compressed air jets to blow foreign particles from the die. The installation of 1/4" thick safety glass shield gave the reduction shown in the graph.

other means of noise control are available. If commercial mufflers can be used, the noise can be controlled as shown by Figure 37-23. If mufflers cannot be used, external pipe covering can be applied as shown by Figure 37-24. This last treatment is not as economical as it might appear since sound can travel long distances down pipes with little attenuation and the pipe covering might be quite expensive. In addition, the sound might produce excessive vibration in downstream equipment and cause failure of such things as heat exchangers and packed columns or cause excessive noise radiation from suction bottles, etc.

To select mufflers for the usual type pressure reducing valves one must estimate the noise level just downstream from the valve. Unpublished work by K. U. Ingard provides a convenient method for doing this.

Figure 37-25 shows that by relating the absolute pressure drop ratio and the gas flow in lbs.

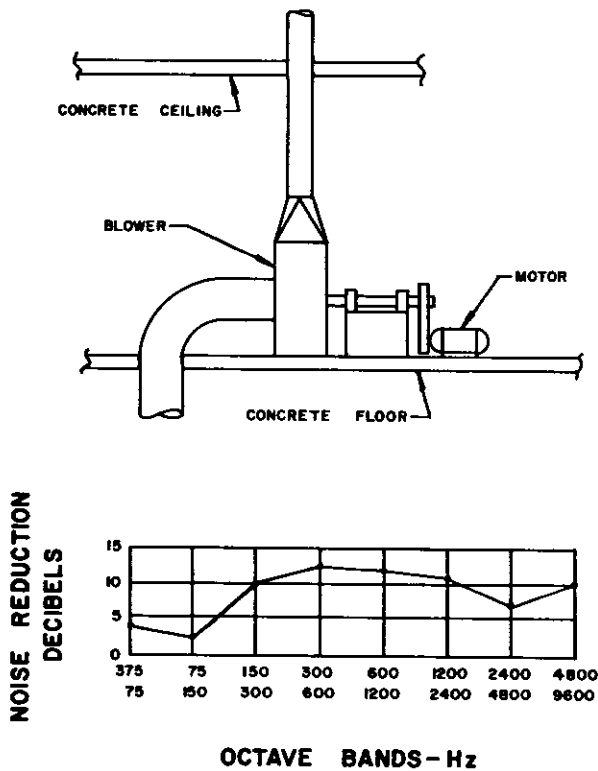


AIHA Noise Committee: Industrial Noise Manual, 2nd Edition. Detroit, American Industrial Hygiene Association, 1966.

**Figure 37-14. MINIMIZE ROTATIONAL SPEED.** The blower for a vapor collection system produced excessive noise while moving 3600 cfm at 2.8" static pressure. It ran at 3450 rpm and had a 12.5" diameter material wheel. It discharged into a cylindrical filter consisting of 1.5" thick glass fiber compressed to 0.75". A quieter fan was selected and the noise reduction achieved is shown on the graph. The new blower ran at 900 rpm and had a 32.265" diameter air wheel. A material wheel was not required since only air and oil vapor were being handled.

per minute, the overall sound power can be determined. Then by means of Figure 37-26 the octave band power levels can be determined. In Figure 37-26 the zero line corresponds to the overall power level as determined from Figure 37-25. The frequency scale used in Figure 37-26 is normalized to the frequency  $f_1 = 0.2 c/d$  where  $c$  is the speed of sound in the gas and  $d$  the equivalent valve diameter. The frequency  $f$  represents the center frequency of the corresponding octave band. To illustrate the use of Figure 37-25 and 26, consider the following example:

- Effective port area of valve = 1 sq. in.
- Mass flowrate = 50 lb. per minute
- Gas = air at 190°F
- Upstream pressure = 100 psig
- Downstream = 48 psig



AIHA Noise Committee: Industrial Noise Manual, 2nd Edition. Detroit, American Industrial Hygiene Association, 1966.

**Figure 37-15. REDUCE DRIVING FORCE — IMPROVED MAINTENANCE (BLOWER).** An exhauster running at 705 rpm, 6" static pressure, and 13,800 cfm was badly out of balance and the bearings needed replacing. As a result the blower produced excessive noise. After balancing and installing new bearings the noise was reduced as shown by the graph.

Determine the octave band power levels generated at the valve discharge and the octave band sound pressure levels in the 3" line just downstream from the valve.

From Figure 37-25 at 50 lb. per minute and a pressure ratio of 2.1 the overall power level ( $L_w$ ) would be 127 dB. The equivalent valve port diameter for an effective area of 1 sq. in. is —

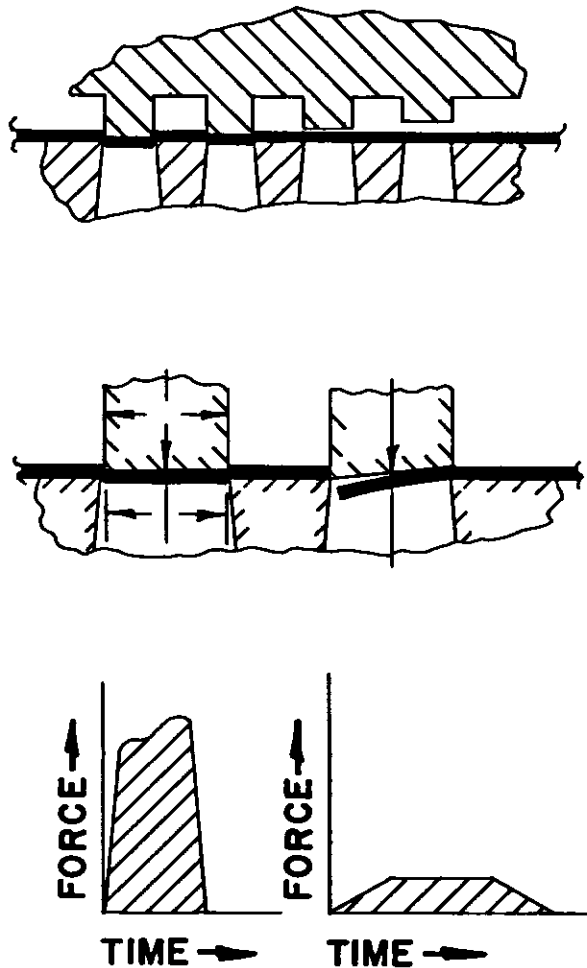
$$A = \pi \left[ \frac{d}{2} \right]^2$$

$$\text{when } A = 1 \quad d^2 = \frac{4}{\pi} \quad d = \sqrt{\frac{4}{\pi}} = 1.13''$$

From Keenan & Kaye Gas Tables,<sup>1</sup>  $C = 1248$  ft. per sec. for air at 190°F. Then:

$$f_1 = \frac{.2C}{d} = \frac{.2 \times 1248}{1.13} = \frac{.2 \times 1248 \times 12}{1.13} = 2650 \text{ Hz}$$

Checking the frequency ranges of the octave bands, we find that 2650 falls in the 6th octave band which has a frequency range of 1400 to 2800 Hz and a center frequency of 2000 Hz. Now referring to Figure 37-26 for  $f/f_1 = 1$



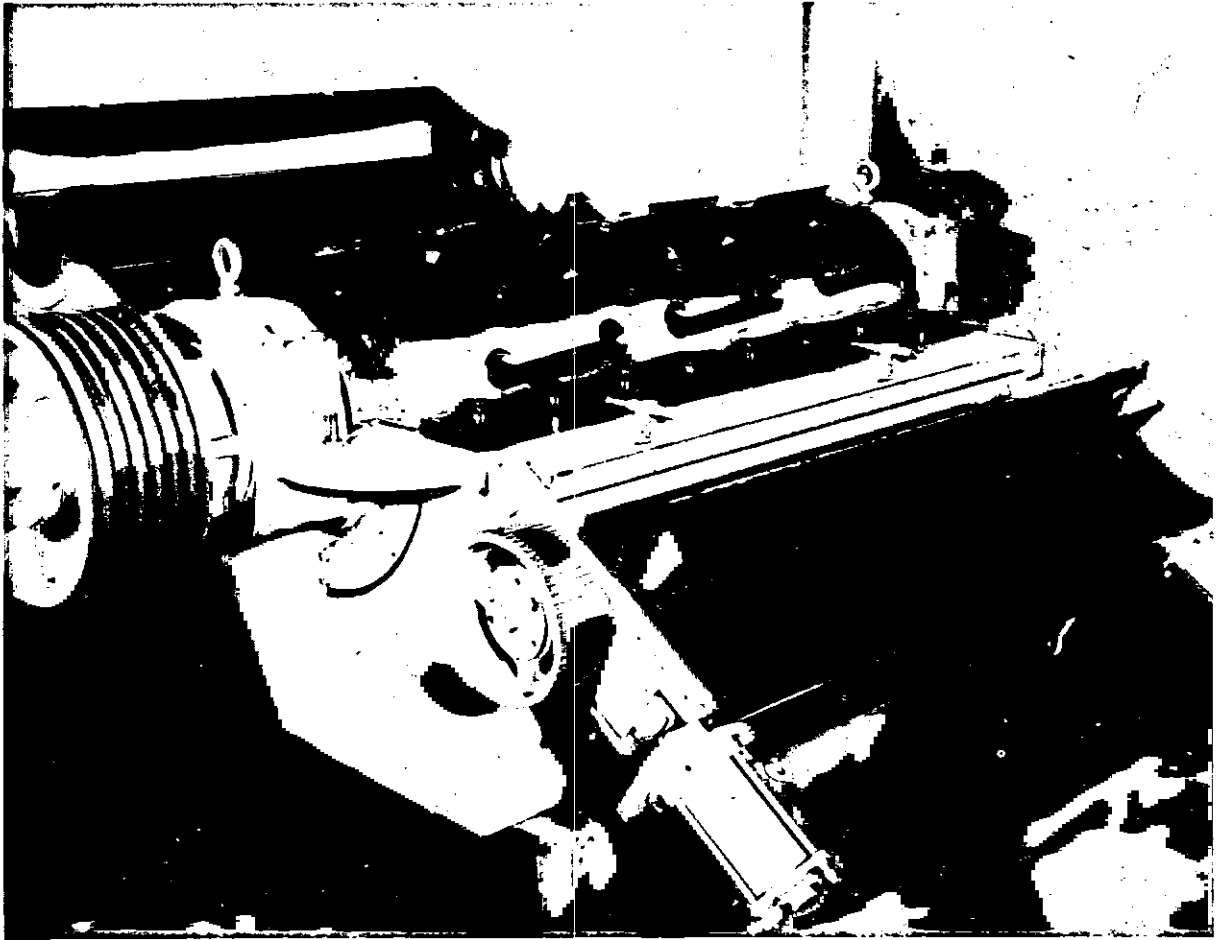
AIHA Noise Committee: Industrial Noise Manual, 2nd Edition. Detroit, American Industrial Hygiene Association, 1966.

**Figure 37-16. REDUCE DRIVING FORCE — SEGMENTED PUNCH AND SHEAR CUT.** Illustration of Stepped Punches for Punching Several Holes at One Stroke of the Press. Schematic illustration of blanking operation, showing the effect of shear angle on the punch. The force-time diagram for each condition is shown.

and a pressure ratio of 2.1, the octave band  $L_w$  for the 6th octave band would be 127-7 or 120 dB. To obtain  $L_w$  for the other octave bands, consider them relabeled as follows:

- For the 7th octave band  $f/f_1 = 2$
- For the 8th octave band  $f/f_1 = 4$
- For the 5th octave band  $f/f_1 = 1/2$
- For the 4th octave band  $f/f_1 = 1/4$  etc.

The next step is to determine from Figure 37-26 the number of dB to be subtracted from the overall  $L_w$  to obtain the octave band power levels. This would result in the values shown in column 5 of Table 37-1. Subtracting column 5 from column 4 gives the octave band power levels shown



duPont de Nemours & Co., Wilmington, Delaware.

Figure 37-17. Reduce Driving Force — 48" Film Cutter with Skewed, Segmented Blades.

Figure 37-18. REDUCE RESPONSE OF VIBRATING SURFACE BY DAMPING (EXTRUDER GEAR CASE).

duPont de Nemours & Co., Wilmington, Delaware.

The casing of a 2000 HP extruder gear was radiating excessive noise. The gear cover was  $\frac{3}{8}$ " steel. The base was 1" steel with 1" thick 9" deep ribs. Measurements with an accelerometer showed that the  $\frac{3}{8}$ " steel and the 1" steel were vibrating at approximately the same intensity. This indicated that all surfaces should be damped.

The  $\frac{3}{8}$ " steel was damped with  $\frac{1}{4}$ " damping felt No. 11 N (by Anchor Packing Co.) plus an outer covering of  $\frac{1}{4}$ " steel. The sandwich ( $\frac{3}{8}$ "

steel +  $\frac{1}{4}$ " felt +  $\frac{1}{4}$ " steel) was bolted together on 8" centers.

The irregularity of the 1" steel of the base made constrained layer damping (as used on the cover) impractical. Instead,  $\frac{1}{4}$ " steel plate was welded to the 9" deep ribs and the voids filled with sand. The photographs below show the gear before and after treatment. The table below shows the noise reduction achieved after treatment of only one of three units in the room.

Frequency — Hz — octave band — center frequency of band	63	125	250	500	1000	2000	4000	8000
Noise reduction — in dB	X	X	X	4	17	26	24	18

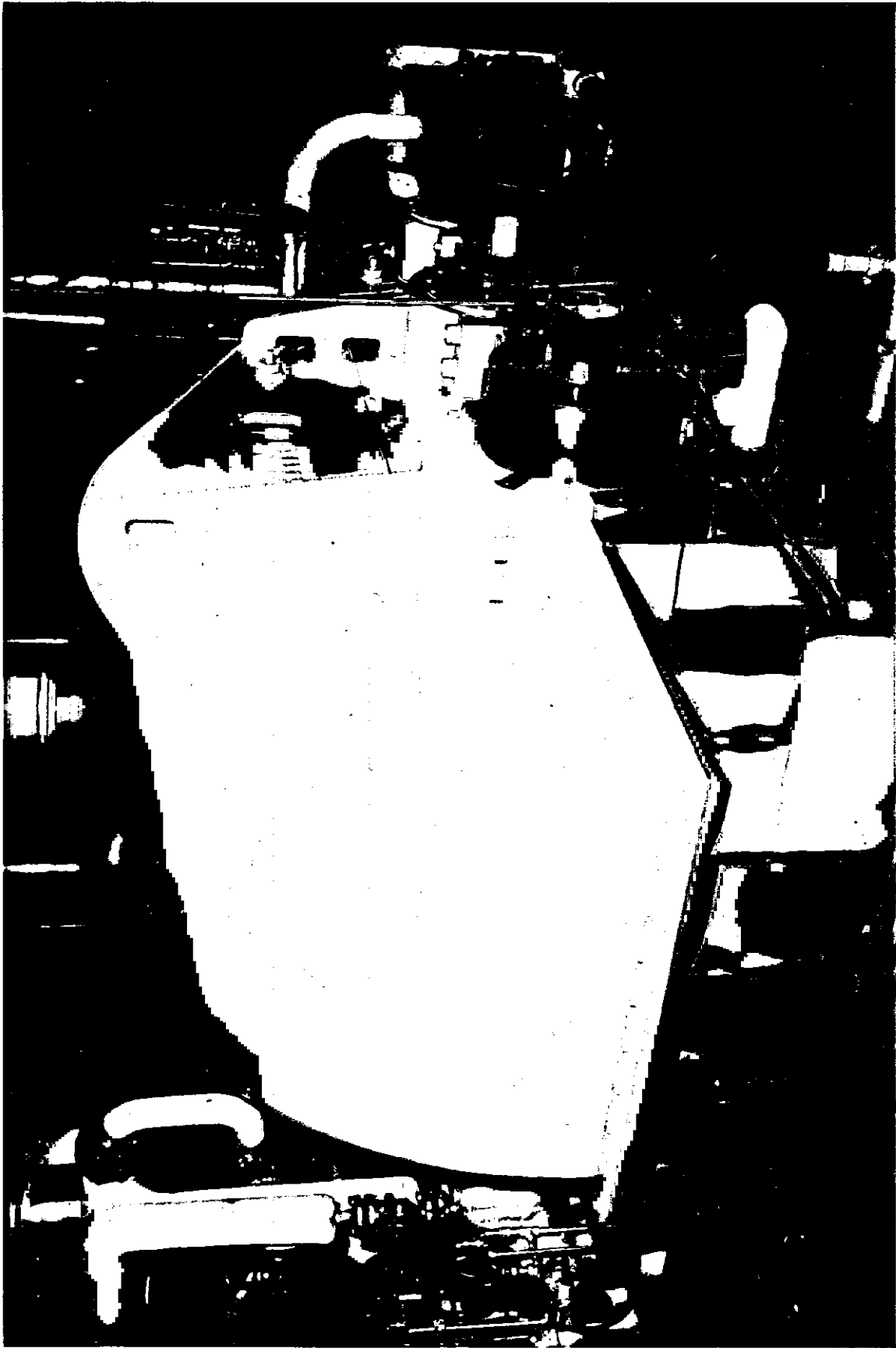


Figure 37-18. (BEFORE)

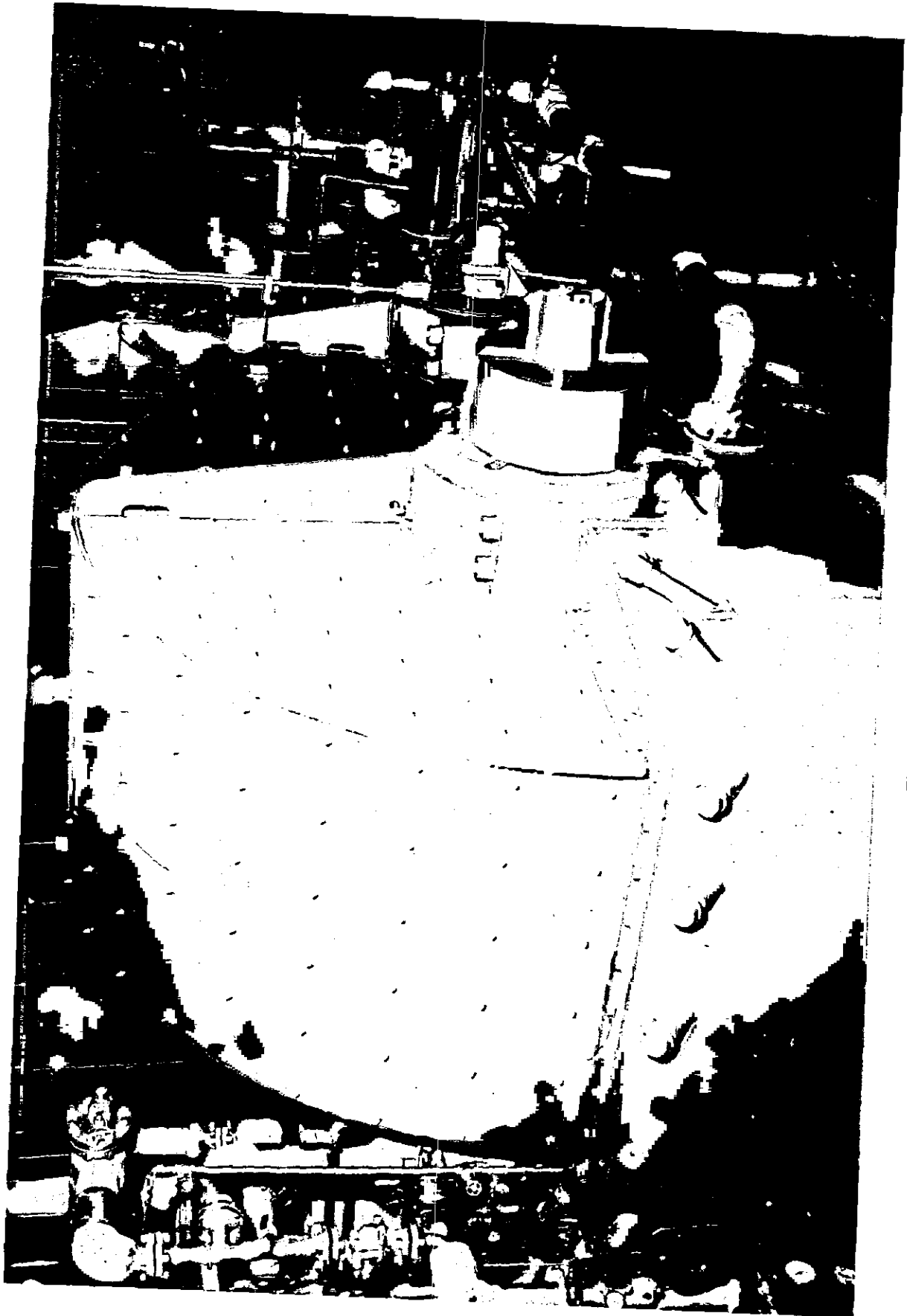
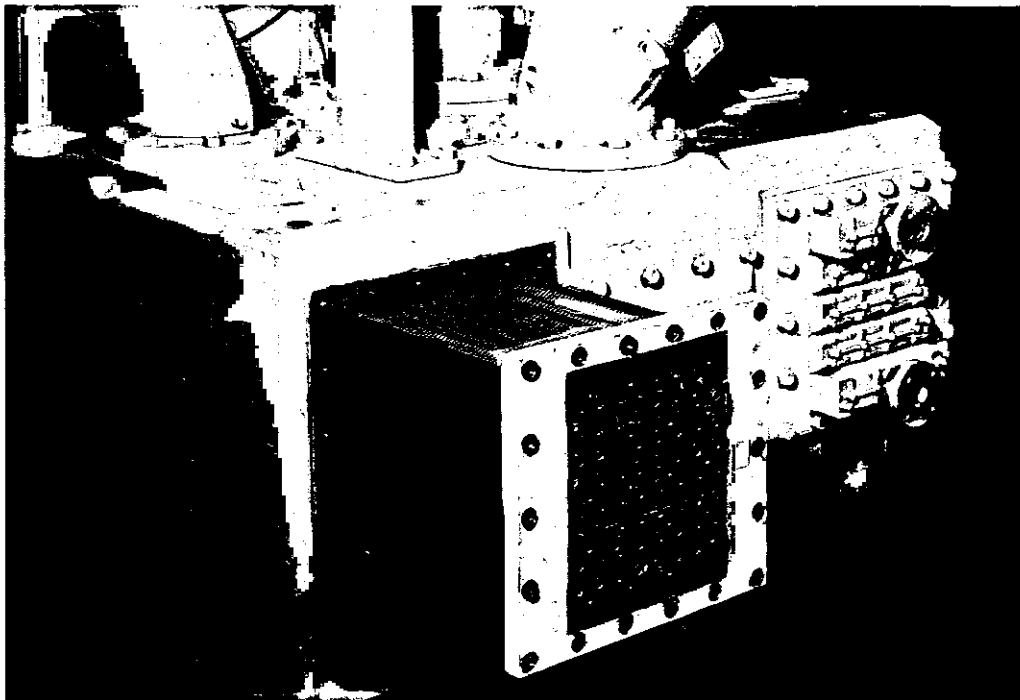
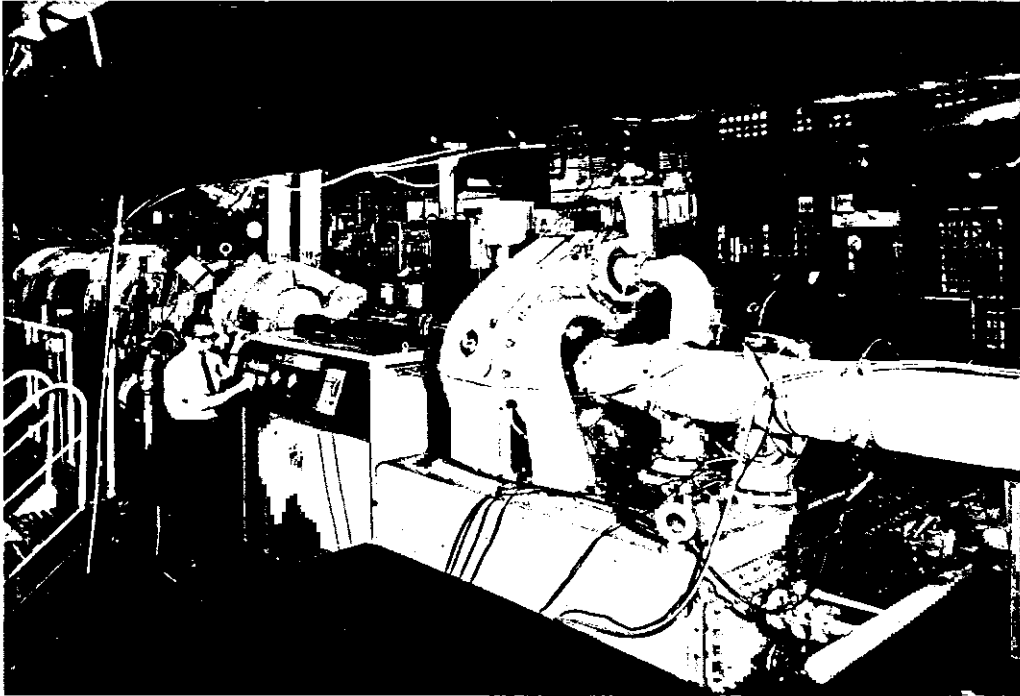
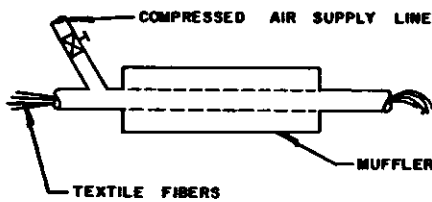


Figure 37-18. (AFTER)



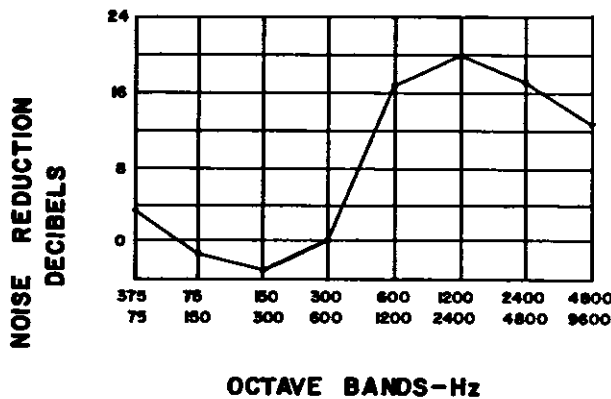
Studebaker — Worthington Inc., New York, New York.

**Figure 37-19. REDUCE RESPONSE OF VIBRATING SURFACE BY INCREASED STIFFNESS AND MASS (CENTRIFUGAL COMPRESSOR).** These two photographs show a Worthington multi stage high speed centrifugal compressor which had noise control in mind during the design stage. Note the heavy cast construction of this machine. To meet the environmental criteria of 90 dBA, the only parts that require acoustical covering are the gear case cover and the steel interstage piping couplings. Here is another case where extra weight in the machine indicates economical noise control without the inconvenience of enclosure.



AIHA Noise Committee: Industrial Noise Manual, 2nd Edition. Detroit, American Industrial Hygiene Association, 1966.

**Figure 37-20. ABSORB THE SOUND WAVE — ALONG ITS TRANSMISSION PATH.** An air ejector is used to strip waste textile fibers from perns. The curve shows the noise reduction achieved 3 feet from the ejector by means of the dissipative muffler. The air supply line is 1/2", the pressure 100 psi, and a 1" dissipative muffler was used. Notice that the noise levels in the 75 to 150 and 150 to 300 cps octave bands were increased slightly, which is characteristic of this type of muffler. The noise of this problem is due to the pressure reduction at the valve and not the velocity of air exhausting from the pipe. This is apparent since the pipe size is the same at the inlet and discharge of the muffler.



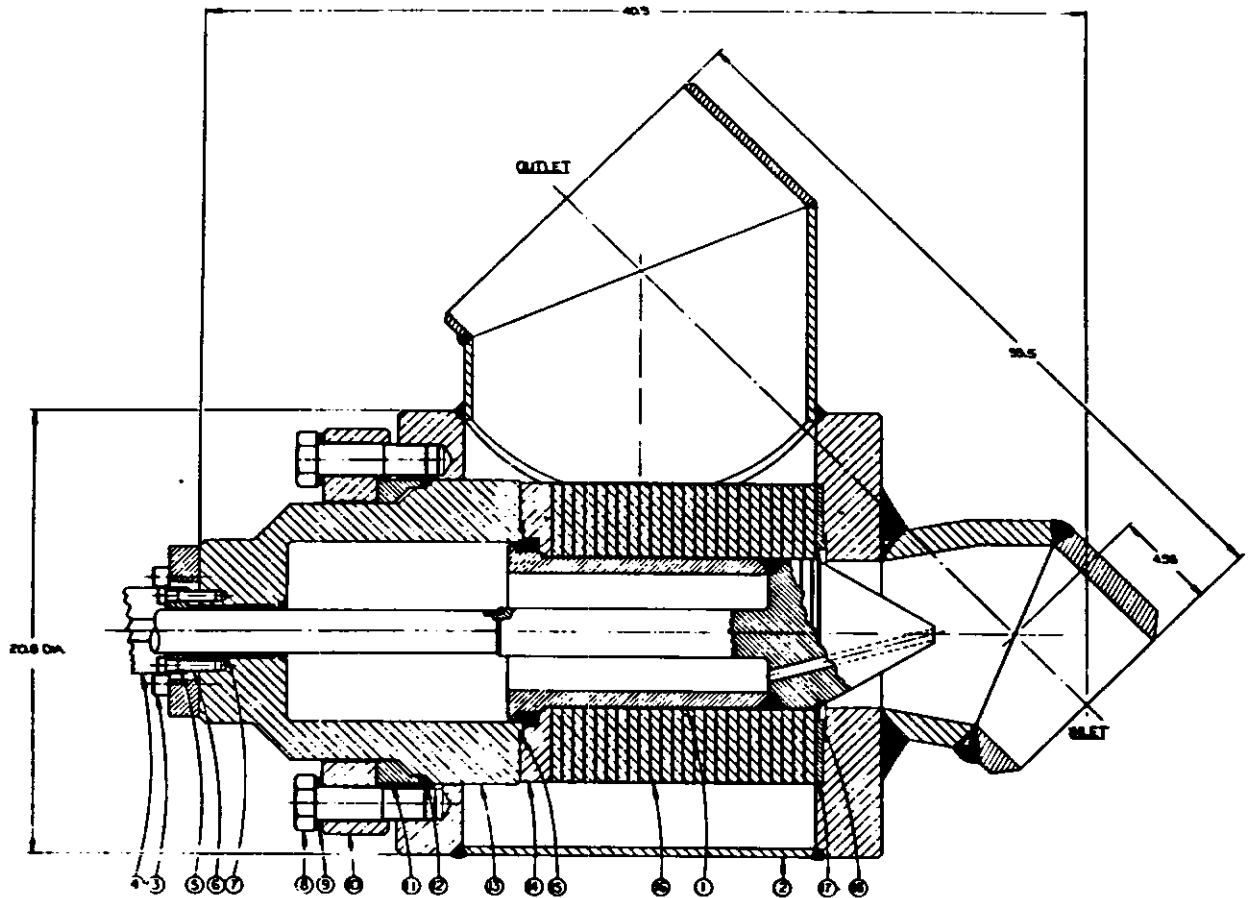
in column 6. The next step is to determine the sound pressure level ( $L_p$ ) in the 3" pipe just downstream from the valve. This can be determined by the following formula.

$$L_p = L_w - 10 \log_{10} D$$

where  $D$  = area of the pipe in sq. ft.

For a 3" pipe  $L_p = L_w - 10 \log 0.0491 = L_w + 13 \text{ dB}$

This means that the octave band levels of Column



Control Components, Los Alamitos, California.

**Figure 37-21. Reduce Velocity of Fluid Flow and Use Quieter Equipment — Quiet Pressure Reducing Valve.**



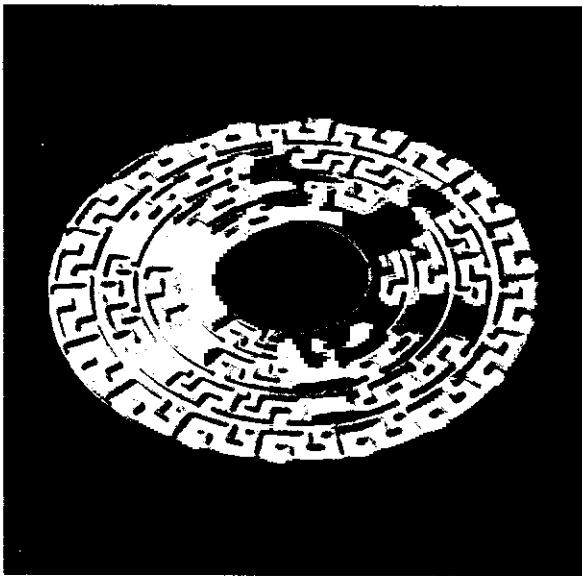


Figure 37-22. REDUCE VELOCITY OF FLUID FLOW AND USE QUIETER EQUIPMENT — QUIET PRESSURE REDUCING VALVE. The "Drag Valve" shown in the drawing at left and described on page 14 is a pressure reducing valve which can provide the desired pressure drop but at the same time limit the maximum velocity thru the valve to minimize the vibration and erosion and limit the noise reduction to most any desired level. The photograph at left shows a typical plate which illustrates the tortuous path the gas must take in passing from the inside (high pressure) to the outside (low pressure). For one design where 300 PSIG air was being vented to atmosphere, the noise reduction shown below was achieved as compared to venting through the more common orifice type valve.

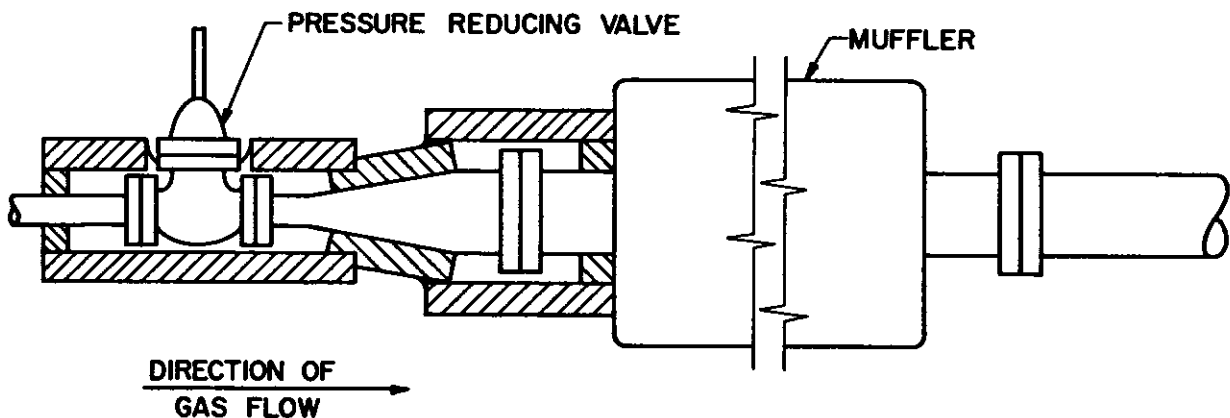
Frequency— Hz—octave band— center fre- quency of band	63	125	250	500	1000	2000	4000	8000	16000	31500
Noise reduc- tion—in dB	24	19	28	17	18	25	34	34	29	25

6 would have to be increased by 13 dB to obtain the octave band sound pressure levels that would have to be contained by the pipe walls or pipe walls plus covering, or would be the basis for selecting a muffler to reduce noise transmission down the pipe.

*Streamline the flow.* Once the velocity of a gas stream has been reduced to a minimum, additional reduction might be achieved by streamlining any obstructions in its path. The higher the velocity the more important it is to streamline the flow path.

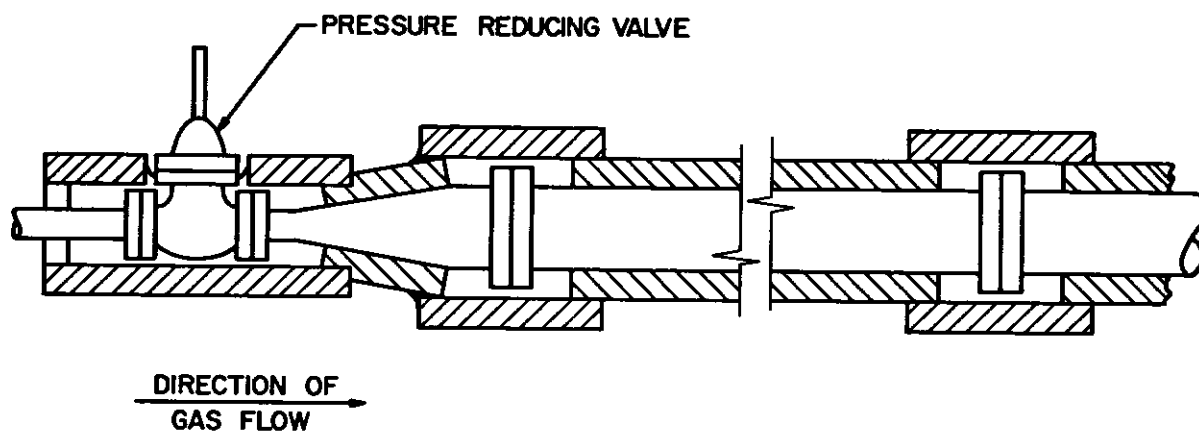
#### Modification of Sound Wave

*Enclosures or partial enclosures.* When enclosing a sound source with an unlined enclosure, the noise level inside the enclosure will build up to a considerably higher level than that measured without the enclosure. To avoid a lengthy calculation of this reverberant buildup, one can line the enclosure. If this is done so that the average sound absorption coefficient inside the enclosure is at least 0.70, the reverberant buildup will be insignificant. This allows one to select materials for the enclosure which have a transmission loss (TL) equal



duPont de Nemours & Co., Wilmington, Delaware.

Figure 37-23. CONFINE THE SOUND WAVE — MUFFLE AND ACCOUSTICAL LAGGING: Cover valve and piping between valve and muffler with 2" fiberglas (3 to 4 lb/cu ft plus an outer covering of Coustifab 488C). For unusually high pressure drops and flows, 16-gage steel weather covering might be required.



duPont de Nemours & Co., Wilmington, Delaware.

**Figure 37-24. CONFINE THE SOUND WAVE — ACOUSTICAL LAGGING ONLY:** Cover valve and downstream piping as described on Figure 23. This method might require the covering of a considerable amount of piping (100 ft or more). In this case, one must be careful not to excite equipment located downstream from the valve. Exceptions of such equipment would be thin-walled heat exchangers, separators, and spray towers.

to the difference between the noise level without the enclosure and the desired noise level with the enclosure. It is good practice to add 5 dB to this difference as a factor of safety. Table 37-2 lists the TL of the more common building materials. This method assumes that the enclosure of the noise source is complete and well sealed. If the enclosure is not complete and well sealed refer to Figure 37-27 for estimating the effect on TL of the leaks or openings. Figure 37-28 shows some common seals and fasteners used for acoustical enclosures. If openings are needed for ventilation or feeding materials into or out from the enclosure, mufflers should be installed at these openings to maintain the desired TL of the rest of the enclosure. If the desired TL is not very great, partial enclosures, that is, enclosures with fairly large openings might be sufficient. The effectiveness of a partial enclosure can be determined by calculating the percent open area as compared to a complete enclosure, and then referring to Figure 37-27.

**Absorb sound wave.** In general, sound absorbing materials are soft and porous. They are porous so that the sound wave can enter the material but the material must have a high enough flow resistance to reduce the amplitude of the sound wave. If the material is too dense (has too high a flow resistance) the sound will be reflected. If the material is not dense enough (flow resistance too low) the sound wave will pass through unchanged. Materials are rated in their ability to absorb sound by their sound absorption coefficient ( $\alpha$ ). This is the percent of incident sound which is absorbed in striking it. Table 37-3 lists the sound absorbing coefficients of various materials. The Acoustical Materials Association periodically publishes such data for materials manufactured by their members.

It is important to note that  $\alpha$  varies with frequency. Figure 37-29 illustrated this for 6 lb./ft.<sup>3</sup> Fiber glass. Notice that below 1000 Hz,  $\alpha$  drops off markedly for ½" thick material. At 1" thickness this drop in  $\alpha$  occurs below 500 Hz. For 3" material the drop in  $\alpha$  occurs when the frequency is less than 250 Hz. The point is, when using  $\alpha$  in a noise control problem it is important to use  $\alpha$  at the frequency of interest.

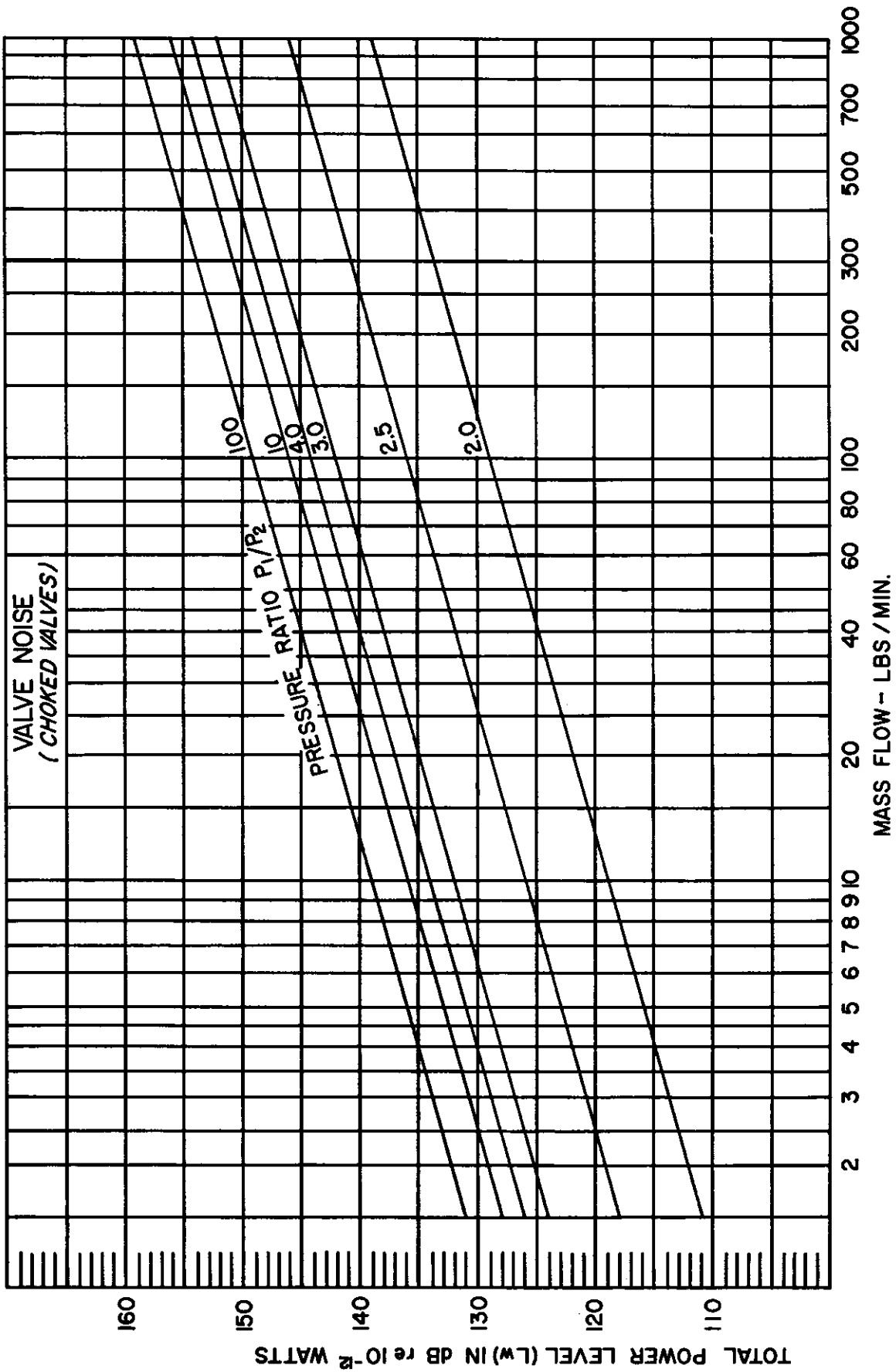
#### Room Absorption

Noise control by absorption in room bounding surfaces is very limited in effectiveness and relatively expensive due to the large surface areas which must be treated. Seven to 10 dB is probably the maximum reduction that can be expected, and in most cases 5 dB would be the best one could accomplish. Room absorption can only reduce the reverberant buildup in a room and therefore is not very effective for the worker if he must be close to the noise source. Room absorption is most effective where (a) the room has little or no sound absorbing material in it before treatment, (b) the room has multiple noise sources (4 or more), each producing about an equal amount of noise, and (c) the noise of any one machine alone does not exceed the criteria. If these conditions exist and room absorption appears to be the most attractive means of noise control, the reduction can be estimated as follows:

$$\text{Noise Reduction in dB} = 10 \log_{10} \frac{A_2}{A_1}$$

where  $A_1$  = total number of absorption units (sabins) in the room before treatment

$A_2$  = total number of absorption units (sabins) in the room after treatment.

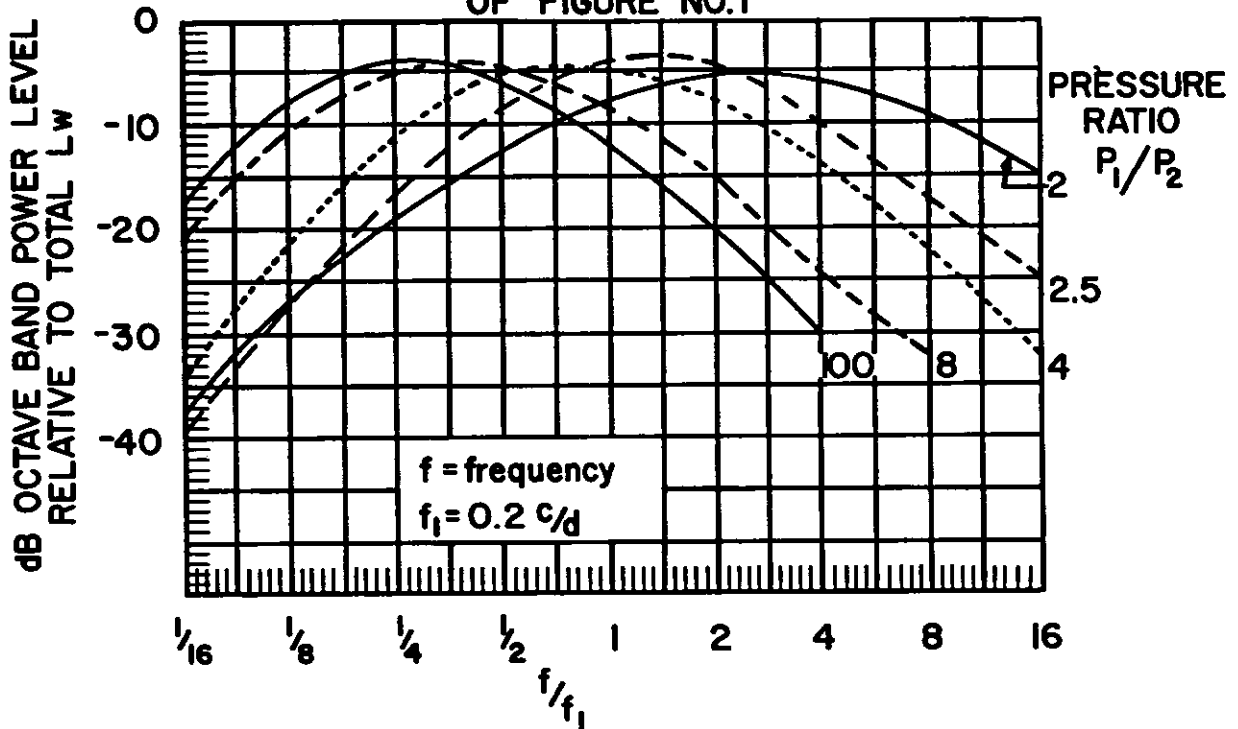


Ingersoll Rand, Allentown, Pennsylvania.

Figure 37-25. Valve Noise (Choked Values).

## VALVE NOISE OCTAVE BAND POWER LEVEL

ZERO dB CORRESPONDS TO THE TOTAL LW  
OF FIGURE NO.1



Ingersoll Rand, Allentown, Pennsylvania.

Figure 37-26. Valve Noise (Octave Band Power Level).

A sabin is a measure of the sound absorption of a surface and is the equivalent of one sq. ft. of a perfect absorptive surface.

This formula is presented in monograph form in Figure 37-30. The total number of absorption units mentioned above is the sum of all the room surface areas multiplied by their respective absorption coefficients. Absorption due to other materials and people should also be included in the calculation.

### Absorption along Transmission Path

The most common example of noise absorption along the transmission path is the commercial muffler. Figure 37-31 illustrates the three most common types. The most common one shown by the upper sketch is the straight through lined duct type. It is very effective provided the lining is effective for the frequency of the sound involved, the length is adequate and the ID does not exceed 6". The performance of such a muffler can be estimated as follows:

$$\text{Noise Reduction in dB per foot of length} = 12.6 \frac{P^{1.4}}{A}$$

where  $\alpha$  = absorption coefficient of the lining material at the frequency of interest  
 $P$  = perimeter of the duct in inches  
 $A$  = cross sectional area of the duct in sq. inches

To simplify the use of this formula, Table 37-4 shows the value of  $12.6\alpha^{1.4}$  for various absorption coefficients. If the ID must be greater than 6" or if the noise reduction required makes it necessary to use a longer muffler than desirable, then the configuration shown by the center sketch of Figure 37-31 can be used. Here the absorptive center portion makes it possible to have relatively narrow flow passages through the mufflers. This provides good performance even where muffler length must be minimized.

Where mufflers having absorption linings cannot be used, the combination resonant, reactive, and dispersive type mufflers shown by the bottom sketch of Figure 37-31 can sometimes be used. The performance of these mufflers is strongly dependent on gas flow through them, and prediction of performance in a given application is very difficult. It is recommended that this type mufflers be bought on a performance guarantee.

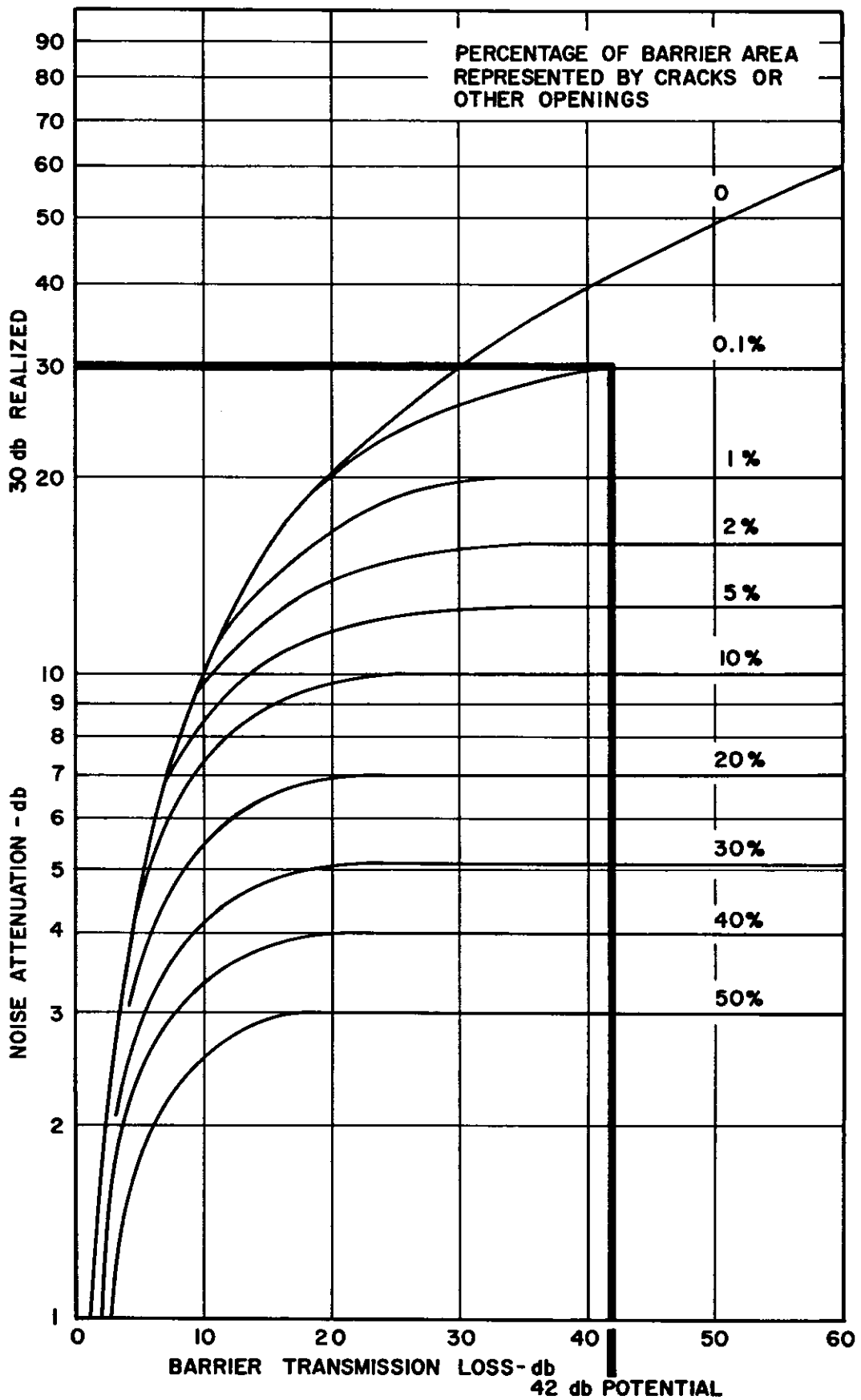
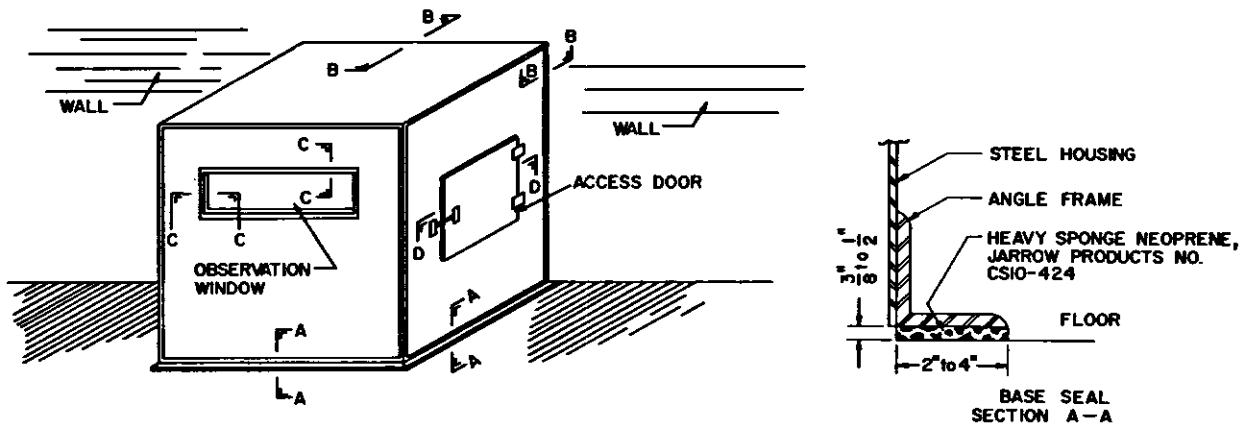
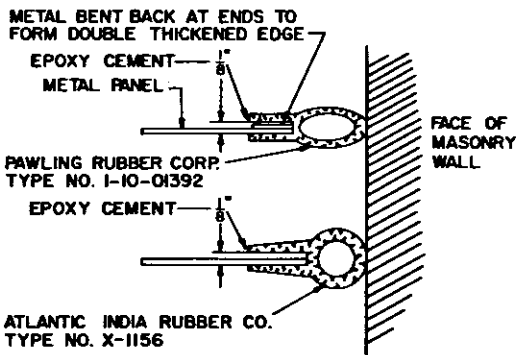


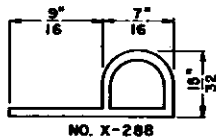
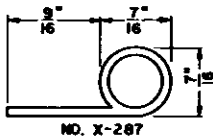
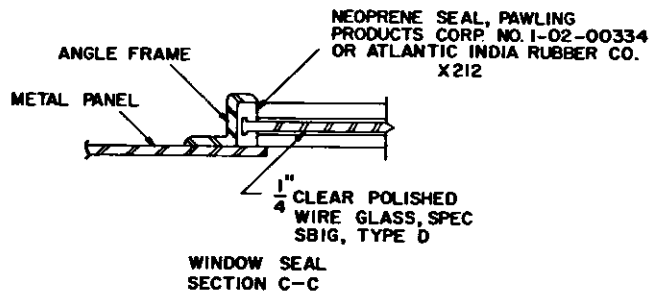
Figure 37-27. Effect of Leaks.



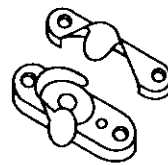
TYPICAL ENCLOSURE



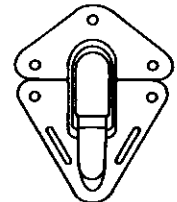
MOUNTING SEALS SECTION B-B



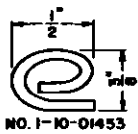
ATLANTIC INDIA RUBBER CO.



SASH LOCK TYPE NO. 1487 HAGER HINGE CO.



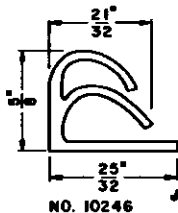
DRAW ACTION TYPE SESSIONS NO. 491110



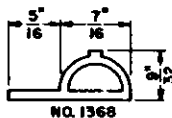
PAWLING RUBBER CORP.



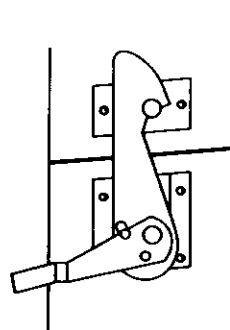
NO. I-10-02697



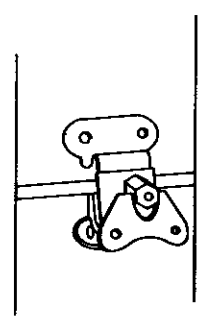
JARROW PRODUCTS, INC.



NO. 1368



HOOK LOCK TYPE

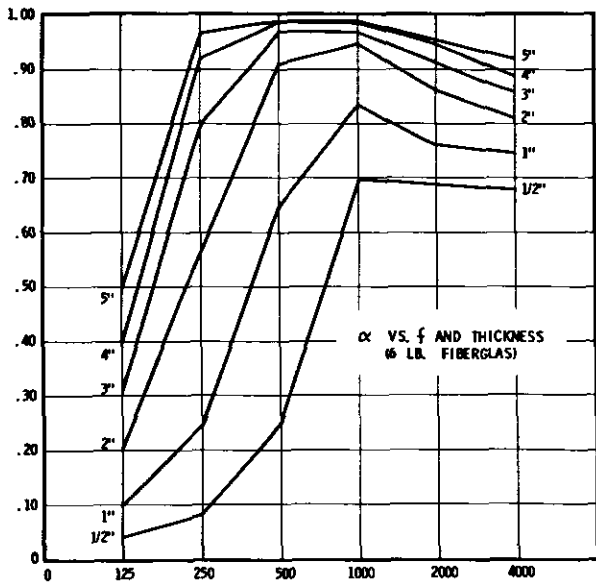


LINK LOCK TYPE

SIMMONS FASTENER CORP.

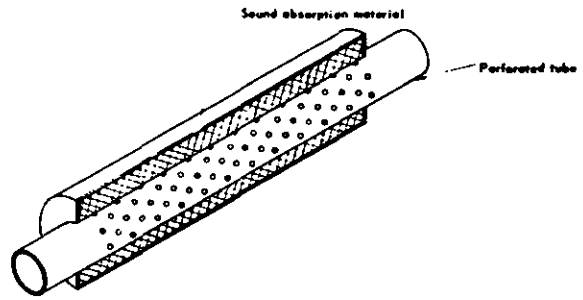
duPont de Nemours & Co., Wilmington, Delaware.

Figure 37-28. TYPICAL ACCESS DOOR SEALS AND FASTENERS. Note: An enclosure built to house a noise source must have all cracks and openings tightly sealed in order to reduce leakage of noise. The enclosure below illustrates applicable principles of sealing and fastening base, wall, door, and observation window. It should not be considered a complete enclosure design because of possible need for ventilation, accoustical lining, etc.

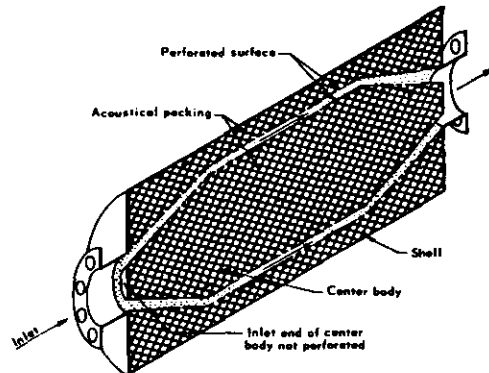


Owens-Corning Fiberglas, Toledo, Ohio.

Figure 37-29. Effect of Material Thickness and Frequency on Absorption.



DISSIPATIVE MUFFLER - STRAIGHT-THROUGH TYPE

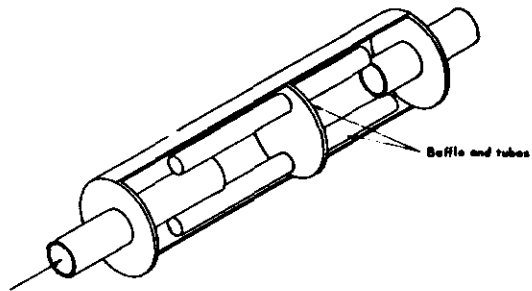


DISSIPATIVE MUFFLER - CENTERED-BODY TYPE



duPont de Nemours & Co., Wilmington, Delaware.

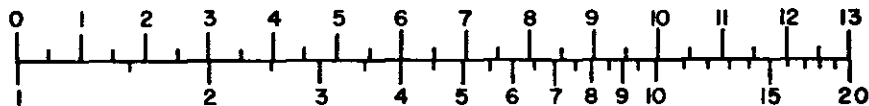
Figure 37-31. Mufflers.



NONDISSIPATIVE MUFFLER

## MONOGRAPH FOR DETERMINING EFFECT OF ROOM ABSORPTION

### DECIBEL REDUCTION



### ABSORPTION RATIO $a_2/a_1$

AIHA Noise Committee: Industrial Noise Manual, 2nd Edition. Detroit, American Industrial Hygiene Association, 1966.

Figure 37-30. Monograph for Determining Effect of Room Absorption.

**TABLE 37-1**  
**OCTAVE BAND SOUND PRESSURE LEVEL DETERMINATION**

Octave Band Number	$f/f_1$	$P_1/P_2$	Overall $L_w$	Relation of Overall to Octave Band $L_w$	Octave Band $L_w$	$L_p$ in 3" pipe
8	4	2.1	127 dB	-6	121	134
7	2	"	"	-5	122	135
6	1	"	"	-7	120	113
5	$\frac{1}{2}$	"	"	-11	116	129
4	$\frac{1}{4}$	"	"	-19	108	121
3	$\frac{1}{8}$	"	"	-27	100	113
2	$\frac{1}{16}$	"	"	-37	90	103

**TABLE 37-2**  
**Sound Transmission Loss of General Building Materials and Structures**

Item	Material or Structure	Thick- ness Inches	Wt. lb/ sq ft	Sound Transmission Loss (dB)										
				125	175	250	350	500	700	1000	2000	4000		
<b>A Doors</b>														
1	Heavy wooden door—special hardware—rubber gasket at top, sides and bottom	2½	12.5	30	30	30	29	24	25	26	37	36		
2	Steel clad door—well sealed at door casing and threshold			42	47	51	48	48	45	46	48	45		
3	Flush—hollow core—well sealed at door casing and threshold			14	21	27	24	25	25	26	29	31		
4	Solid oak—with cracks as ordinarily hung	1¾		12		15		20		22	16			
5	Wood door (30"×84") special soundproof constr.—well sealed at door casing and threshold.	3	7	31	27	32	30	33	31	29	37	41		
<b>B Glass</b>														
1		½	1½	27	29	30	31	33	34	34	34	42		
2		¼	3	27	29	31	32	33	34	34	34	42		
3		½	6	17	20	22	23	24	27	29	34	24		
4		1	12	27	31	32	33	35	36	32	37	44		
<b>C Walls—Homogeneous</b>														
1	Steel sheet—fluted—18 gage stiffened at edges by 2×4 wood strips—joints sealed		4.4	30	20	20	21	22	17	30	29	31		
2	Asbestos board—corrugated stiffened horizontally by 2×8 in. wood beam—joints sealed		7.0	33	29	31	34	33	33	33	42	39		
3	Sheet steel—30 ga	.012	½	3	6		11		16		21	26		
4	Sheet steel—16 ga	.0598	2½	13	18		23		28		33	38		



**TABLE 37-2 (Cont'd.)**  
**Sound Transmission Loss of General Building Materials and Structures**

Item	Material or Structure	Thick- ness Inches	Wt. lb/ sq ft	125	175	250	350	500	700	1000	2000	4000	
5	Sheet steel — 10 ga	.1345	5.625	18	23		28		33		38	43	
6	Sheet steel	¼	10	23	28	38	33	41	38	46	43	48	
7	Sheet steel	⅜	15	26	31	39	36	42	41	47	41	51	
8	Sheet steel	½	20	28	33		38		43		48	53	
9	Sheet Aluminum — 16 ga	.051	.734	5	8		13		18		23	28	
10	Sheet Aluminum — 10 ga	.102	1.47	8	14		19		24		29	34	
11	Plywood	¼	.73		20		19		24		27	22	
12	Plywood	½	1.5	8	14		19		24		29	34	
13	Plywood	¾	2.25	12	17		22		27		32	37	
14	Sheet Lead	⅛	3.9			32		33		32	32	32	
15	Sheet Lead	¼	8.2			31		27		37	44	33	
16	Glass fiber board — 6 lb/cu ft	1	½	5	5	5	5	5	4	4	4	3	
17	Laminated Glass Fiber (FRP)	¾				26		31		38	37	38	
D	Walls — Nonhomogeneous												
1	Gypsum wallboard—two ½" sheets cemented together — joints wood battened	1	4.5	24	25	29	32	31	33	32	30	34	
2	Gypsum wallboard—four ½" sheets cemented together — fastened together with sheet metal screws — dovetail-type joints paper taped	2	8.9	28	35	32	37	34	36	40	38	49	
3	¼" plywood glued to both sides of 1×3 studs 16 in. O.C.	3	2.5	16	16	18	20	26	27	28	37	33	
4	Same as 3 above but ½" gypsum wallboard nailed to each face	4	6.6	26	34	33	40	39	44	46	50	50	
5	¼" Dense fiberboard on both sides of 2×4 wood studs 16 in. O.C. — Fiberboard joints at studs	4½	3.8	16	19	22	32	28	33	38	50	52	
6	Soft type fiberboard (¾") on both sides of 2×4 wood studs 16 in. O.C. — Fiberboard joints at studs	5	4.3	21	18	21	27	31	32	38	49	53	
7	½" gypsum wallboard on both sides of 2×4 wood studs 16 in O.C.	4½	5.9	20	22	27	35	37	39	43	48	43	
8	Two ⅜" gypsum wallboard sheets glued together and applied to each side of 2×4 wood studs 16 in. O.C.	5	8.2	27	24	31	35	40	42	46	53	48	
9	2" glass fiber (3 lb/cu ft) + lead — vinyl composite (0.87 lb/sq ft)						4		4		13	26	31

**TABLE 37-2 (Cont'd.)**  
**Sound Transmission Loss of General Building Materials and Structures**

Item	Material or Structure	Thick- ness Inches	Wt. lb/ sq ft										
				125	175	250	350	500	700	1000	2000	4000	
10	3/8" steel + 2.375 in. polyurethane foam (2 lb/cu ft) + 1/16" steel					38		52		55	64	77	
11	Same as 10 above but 2 1/2" glass fiber (3 lb/cu ft) instead of foam					37		51		56	65	76	
12	1/4" steel + 1" polyurethane foam (2 lb/cu ft) + 0.055 in. lead vinyl composite (1.0 lb/lb/sq ft)					38		45		57	56	67	
E	Masonry												
1	Reinforced concrete	4	53	37	33	36	44	45	50	52	60	67	
2	Brick — common	12	121	45	49	44	52	53	54	59	60	61	
3	Glass Brick—3 3/4 x 4 7/8 x 8	3 3/4		30	36	35	39	40	45	49	49	43	

**TABLE 37-2**  
**Sound Transmission Loss of General Building Materials and Structures**

Item	Material or Structure	Weight Lbs/Ft <sup>2</sup>	Loss in Decibels at Indicated Frequencies, H <sub>z</sub>									
			128	192	256	384	512	768	1024	2048	4096	
E	Masonry											
4	Concrete block — 4" hollow, no surface treatment		27	29	32	35	37	42	45	46	48	
5	Concrete block — 4" hollow, one coat resin-emulsion paint		30	33	34	36	41	45	50	55	53	
6	Concrete block — 4" hollow, one coat cement base paint		37	40	43	45	46	49	54	56	55	
7	Concrete block — 6" hollow, no surface treatment		28	34	36	41	45	48	51	52	47	
8	Concrete block — 8" hollow, no surface treatment		18	24	28	34	37	39	40	42	40	
9	Concrete block — 8" hollow, one coat cement base paint		30	36	40	44	46	48	51	50	41	
10	Concrete block — 8" hollow, filled with vermiculite insulators		20	29	33	36	38	38	40	45	47	
11	Concrete block — 4" hollow, no surface treatment		21	26	28	31	35	38	41	44	43	
12	Concrete block — 4" hollow, one coat resin-emulsion paint		26	30	32	34	37	42	43	46	44	
13	Concrete block — 4" hollow, two coats resin-emulsion paint		24	31	33	35	38	42	44	47	44	
14	Concrete block — 4" hollow, one coat cement base paint		23	30	35	38	42	43	44	48	43	
15	Concrete block — 4" hollow, two coats cement-base paint		34	38	40	42	45	47	49	51	46	
16	Concrete block — 6" hollow, no surface treatment		22	27	32	36	40	43	46	45	43	

**TABLE 37-2 (Continued)**  
**Sound Transmission Loss of General Building Materials and Structures**

Item	Material or Structure	Weight Lbs/Ft <sup>2</sup>	Loss in Decibels at Indicated Frequencies, Hz								
			128	192	256	284	512	768	1024	2048	4096
17	Concrete block — 4" hollow, no surface treatment		30	36	39	41	43	44	47	54	50
18	Concrete block — 4" hollow, one coat cement base paint on face		30	36	39	41	43	44	47	54	49
19	Concrete block — 6" hollow, no surface treatment	Dense Aggregate	37	46	50	50	50	53	56	56	46
20	Concrete block — 6" hollow, one coat resin-emulsion paint each face		37	50	54	52	53	55	57	56	46
21	Concrete block — 8" hollow, no surface treatment		40	47	53	54	54	56	58	58	50
22	Concrete block — 8" hollow, two coats resin-emulsion paint each										

**TABLE 37-3**  
**Sound Absorption Coefficients of Materials**

The absorption coefficient ( $\alpha$ ) of a surface which is exposed to a sound field is the ratio of the sound energy absorbed by the surface to the sound energy incident upon the surface. For instance, if 55% of the incident sound energy is absorbed when it strikes the surface of a material, the  $\alpha$  of that material would be 0.55. Since the  $\alpha$  of a material varies according to many factors, such as

frequency of the noise, density, type of mounting, surface condition, etc., be sure to use the  $\alpha$  for the exact conditions to be used and from performance data listings such as shown below. For a more comprehensive list of the absorption coefficients of acoustical materials, refer to the bulletin published yearly by the Acoustical Materials Association, 335 East 45th St., New York, N. Y. 10017.

Materials	Frequency	Coefficients					
		125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Brick — glazed		0.01	0.01	0.01	0.01	0.02	0.02
Sand — dry — 4" thick		.15	.35	.40	.50	.55	.80
Sand — dry — 12" thick		.20	.30	.40	.50	.60	.75
Sand — wet — 14 lb water per cu ft 4" thick		.05	.05	.05	.05	.05	.15
Water		.01	.01	.01	.01	.02	.02
Glass Fiber — mounted with impervious backing — 3 lb/cu ft, 1" thick		.14	.55	.67	.97	.90	.85
Glass Fiber — mounted with impervious backing — 3 lb/cu ft, 2" thick		.39	.78	.94	.96	.85	.84
Glass Fiber — mounted with impervious backing — 3 lb/cu ft, 3" thick		.43	.91	.99	.98	.95	.93
Steel (Estimated)		.02	.02	.02	.02	.02	.02
Brick, unglazed		.03	.03	.03	.01	.05	.07
Brick, unglazed, painted		.01	.01	.02	.02	.02	.03
Carpet, heavy, on concrete		.02	.06	.14	.37	.60	.65
Same, on 40 oz hairfelt or foam rubber (carpet has porous backing)		.08	.24	.57	.69	.71	.73
Same, with impermeable latex backing on 10 oz hairfelt or foam rubber		.08	.27	.39	.34	.48	.63
Concrete Block, coarse		.36	.44	.31	.29	.39	.25
Concrete Block, painted		.10	.05	.06	.07	.09	.08
Concrete, poured		.01	.01	.02	.02	.02	.03

**TABLE 37-3 (Continued)**  
**Sound Absorption Coefficients of Materials**  
**Coefficients**

Materials	Frequency	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
<b>Fabrics</b>							
Light velour, 10 oz per sq yd, hung straight, in contact with wall		.03	.04	.11	.17	.24	.35
Medium velour, 14 oz per sq yd, draped to half area		.07	.31	.49	.75	.70	.60
Heavy velour, 18 oz per sq yd, draped to half area		.14	.35	.55	.72	.70	.65
<b>Floors</b>							
Concrete or terrazzo		.01	.01	.015	.02	.02	.02
Linoleum, asphalt, rubber or cork tile on concrete		.02	.03	.03	.03	.03	.02
Wood		.15	.11	.10	.07	.06	.07
Wood parquet in asphalt on concrete		.04	.04	.07	.06	.06	.07
<b>Glass</b>							
Large panes of heavy plate glass		.18	.06	.04	.03	.02	.02
Ordinary window glass		.35	.25	.18	.12	.07	.04
Gypsum Board, ½" nailed to 2 × 4's 16" o.c.		.29	.10	.05	.04	.07	.09
Marble		.01	.01	.01	.01	.02	.02
<b>Openings</b>							
Stage, depending on furnishings				.25 — .75			
Deep balcony, upholstered seats				.50 — 1.00			
Grills, ventilating				.15 — .50			
To outside				1.00			
Plaster, gypsum or lime, smooth finish on tile or brick		.013	.015	.02	.03	.04	.05
Plaster, gypsum or lime, rough finish on lath		.14	.10	.06	.05	.04	.03
Same, with smooth finish		.14	.10	.06	.04	.04	.03
Plywood Paneling, ¾" thick		.28	.22	.17	.09	.10	.11
Water Surface, as in a swimming pool		.008	.008	.013	.015	.020	.025

**ABSORPTION OF SEATS AND AUDIENCE**

Values given are in Sabins per square foot of seating area or per unit

Materials	Frequency	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Audience, seated in upholstered seats, per sq ft of floor area		.60	.74	.88	.96	.93	.85
Unoccupied cloth-covered upholstered seats, per sq ft of floor area		.49	.66	.80	.88	.82	.79
Unoccupied leather-covered upholstered seats, per sq ft of floor area		.44	.54	.60	.62	.58	.79
Chairs, metal or wood seats, each, unoccupied		.15	.19	.22	.39	.38	.39

**TABLE 37-4**  
**SOUND ABSORPTION COEFFICIENT**  
**VS.  $12.6\alpha^{1.4}$**

Sound Absorption Coefficient	$12.6\alpha^{1.4}$
0.50	4.78
0.55	5.46
0.60	6.16
0.65	6.89
0.70	7.65
0.75	8.43
0.80	9.16
0.85	10.02
0.90	10.87

**Preferred Reading — Books**

1. BERANEK, L. L. — *Noise and Vibration Control*, McGraw-Hill Book Co., New York, 1971.
2. HARRIS, C. M. — *Handbook of Noise Control*, McGraw-Hill Book Co., New York, 1957.
3. HARRIS, C. M. and CREDE, C. E. — *Shock and Vibration Handbook*, Volume 2, McGraw-Hill Book Co., New York, 1961.

**Preferred Reading — Periodicals**

*Sound and Vibration* — Published monthly by Acoustical Publications, Inc., 2710 E. Oviatt Road, Bay Village, Ohio 44140.

*Journal of Sound and Vibration* — Published bi-monthly by Academic Press, Inc. (London) Limited.