

CONTROL OF INDUSTRIAL SOLID WASTE

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SCOPE OF INDUSTRIAL WASTE
GENERATING ACTIVITIES**The Problem of Definition**

In reducing to comprehensible terms the vast spectrum of residues of resource utilization which comprise solid waste, it is necessary to resort to some scheme of classification.

At the broadest level of definition, relating wastes to the general sector of human activity in which they originate has been the most common approach. Thus municipal, agricultural, and industrial wastes commonly appear in both the literature and the language of solid waste management as categories which by implication, at least, are essentially of the same order. That they are not in fact of the same order is of little significance when the primary concern is for municipal wastes. However, when industrial waste is the problem, some distinctions between the three classes must be clearly understood.

1. *Municipal Wastes.* The domestic and commercial activities which generate municipal wastes are characteristic of cultural and social patterns which are national in scope. Thus, with some variations in regional and climatological factors which result in ashes in one community and year-round grass trimmings in another, the term "municipal wastes" has an identifiable meaning without great refinement of definition.
2. *Agricultural Wastes.* In the case of agricultural wastes there is currently some confusion of definition. Some individuals still consider the term to include everything from crop residues left in the fields to animal manures and the residues produced in processing food and fiber grown on the land. However, much of agriculture is organized and managed in the same manner as are factories. Land is prepared, and many crops are harvested, with sophisticated machinery. Thousands of animals are concentrated in milk, egg, and meat production enterprises. The distinction between a processing plant utilizing farm products as its raw material and one processing crude petroleum, for example, is quite artificial. Therefore, except for plant residues left in the fields and animal wastes deposited in the pastures, it seems appropriate to include much of what is now classed as agricultural waste in the industrial waste category. In fact there is already a trend to consider animal manures as a source of industrial pollution.¹

3. *Industrial Wastes.* Although, as previously noted, there is a certain logic in classifying solid wastes as municipal, agricultural, and industrial, the logic breaks down when control of industrial wastes is the problem of concern. Consequently, in terms of control there is no way to define "industrial wastes" in the context of the simple classification cited. It is everything that is not included in "municipal wastes" and a large percentage of what is included in "agricultural wastes." Therefore, it can best be isolated only in relation to certain types of human activity.

**Nature of Human Activity
Involved in Industry**

The range of human activities which might be described by the word "industry" is so broad and varied that essentially the only thing all industries have in common is that they generate residues they do not want. Although in the aggregate these unwanted residues comprise industrial solid waste, no one approach can resolve the waste control problem it presents, for the simple reason that there is no single identifiable problem. There are, however, types of activity which generate broad types of industrial solid waste problems, each amenable to some typical approach although not to a universal solution. For the purpose of this discussion these activities are divided into three classes: 1) extractive industries; 2) basic industries, and 3) conversion and fabricating industries.

Obviously these three classes are not mutually exclusive. Processing, for example, may be a feature of any type of industry, but each class has identifiable characteristic waste generating features which differentiate it from the other two.

**INDUSTRY AS A GENERATOR
OF SOLID WASTES****Extractive Industries**

The normal concept of an extractive industry is, as the name implies, one in which raw materials are taken from the earth and marketed in essentially their original state with little or no value added by manufacture or processing. Consequently it is to be expected that the solid wastes generated by such industries are but components or products of the earth. Four extractive industries, namely mining, quarrying, logging, and farming are of particular significance as generators of solid wastes. A fifth, the petroleum industry, is a major contribution to industrial solid waste problems, but not in the extraction process itself.

1. *Mining.* In terms of the quantity of solid wastes generated, mining probably exceeds all other industries, estimates ranging as high as 1.6 billion tons per year.²⁻³ Shaft and tunnel mining of coal and metal ores necessitates bringing to the surface large quantities of earth materials associated with the particular mineral sought, or overlaying it. Convenience, economics, and sheer weight and volume of materials dictate that these tailings be discarded near the mine head. Thus the major waste problem is fundamentally the local creation of an extremely large pile of inert material which is usually unsightly, destructive of the land resource it occupies, and may contribute to water pollution by leaching over a long period of time. Sometimes this waste pile is a menace to human life as well, as a result of instability due to fine particles, which may run as high as 40 percent.² A notable example is the 1966 tragedy in Aberfen, Wales, where 150 persons (mostly school children) were killed by a slide of an 800-foot-high pile of coal mine waste.

Mine tailings are proving to be stockpiles of valuable resources, albeit by inadvertence rather than design.³⁻⁴ A major example is the early discarding of tungsten and vanadium ores in iron mining operations. When later a use was found for these metals, more wealth was extracted from the waste pile than was originally generated from iron. However, this secondary extraction did little to diminish the size of the original heap of wastes.

Concentration of solid wastes often occurs at locations which are relatively close to the mine where crushing, flotation, and other processing of ores is essential to the extraction process. Such secondary waste concentrations are generally smaller than those at the mine head but they are by no means insignificant in volume. For example, about 1.3 tons of wastes are generated for each ton of pelletized iron ore processed.⁵ However, they still represent materials taken from the earth's crust and simply relocated and concentrated on the land surface.

2. *Quarrying.* Quarrying is often classified separately from underground mining. Open pit, or strip mining and the quarrying of glass sand, stone, and sand and gravel are typical of this type of extractive industry. In comparison with other types of mining, sand and stone quarrying displaces and concentrates smaller amounts of unwanted materials (approximately 0.5 to 5.0 percent).⁶ Otherwise the solid waste problem is the same; i.e., inert earth materials piled on the surface. Although quarrying wastes may be deplored by citizens on the basis of effects on nearby property values, or of aesthetics or other emotional response, quarrying is more an environmental problem of noise, dust, traffic, and aesthetics than one of solid waste generation.
3. *Logging.* As a generator of solid wastes the harvesting of timber differs from mining and

quarrying in that its residues are organic. Hence, in a matter of years rather than of geologic time they are returned to the soil by the biochemical processes of nature. It is estimated that traditional logging procedures leave in the woods some 30 to 40 percent of the original weight of the tree, or about one ton of debris per 1,000 board feet of logs harvested.⁷ As a solid waste problem this material is scattered over a wide area, is unsightly, constitutes a fire hazard to the forest, may be a reservoir of tree-destroying diseases and insects, and represents a wastage of natural resources.

4. *Farming.* The solid waste generating aspects of farming include both plant and animal wastes, the estimated per capita production averaging 43 to 60 lb./day.⁸⁻⁹ Plant residues of significance include unharvested or unharvestable crops, vines, straw and stubble, and orchard prunings. Here a variety of solid waste control problems accrue largely as a result of air pollution and other environmental considerations. Unfortunately, burning of certain seed grass stubble is necessary to control plant diseases. Straw and stubble plowed into soil increase the cost of nitrogen fertilizer to offset the carbon surplus. Unharvested products such as melons and tomatoes produce unpleasant odors and may attract insects and rodents. Tree prunings are both a physical problem and a reservoir of crop and tree-destroying pests if burning is not allowed. Burning of sugar cane remains an economic and technological necessity in eliminating leaves prior to processing.

Disposal of manure and dead fowl constitutes an extremely difficult problem to the poultry and egg production industry. Although the wastes are organic and capable of incorporation into soil by natural processes, they are concentrated in location, 10,000 to 100,000 birds being housed in a single location. Moreover, they are aesthetically objectionable, uneconomical to collect, and unwanted by agriculturists. The same situation exists in dairy and animal fattening installations, the latter of which involve as many as 20,000 animals in a single operation and may soon involve 100,000.¹ Concentration of decomposable wastes, pollution of water, fly production, aesthetics, and economic and technological problems of collection and disposal are among the solid waste problems generated by animal husbandry as an extractive aspect of the farming industry.

In evaluating extractive industries as generators of wastes, the four examples cited have several things in common. They concentrate wastes at specific locations on the surface of the earth; the wastes are normal products of the earth and its living things; and they do little to multiply the basic value of the product. They differ, however, in nature, some being inert materials whereas others are biodegradable organic matter. Consequently, no single approach to solid waste con-

trol can overcome the problems man associates with the wastes of extractive industry.

Basic Industries

For the purpose of this analysis, basic industries are considered those which take raw materials from extractive industry and produce from them the refined materials which other industries convert into consumer goods. Basic industries differ from extractive in several ways, the most significant being in the value added by manufacture.

Products of the basic sector of industry are such things as metal ingots, sheets, tubes, wire, and structural shapes; industrial chemicals; coke; paper and paperboard; plastics materials; glass; natural and synthetic fabrics; and lumber and plywood. From the farming industry there is a tendency for fiber to go into basic industry, and food to conversion industries or directly into commercial channels. Exceptions might be the hulling of rice and the production of raw sugar from sugar cane, although these two might better be classed as conversion industries.

The solid wastes generated by basic industries may be said to differ from those generated by extractive industries in three major aspects: They are more diverse in composition; they differ markedly from the normal mineral and plant residues found in nature; and the industry itself generates a fraction of its own wastes. The solid waste generated by any type of industry in its business offices is, of course, considered a part of the normal commercial component of municipal wastes.

Eight basic industries are perhaps the major generators of solid wastes in their class: metals, chemicals, paper, plastics, glass, textiles, wood product, and power.

1. *Metals.* Blast furnace slag and ashes from the smelting of iron ore probably rank second only to mining wastes in volume of waste produced by industry. Slag produced in steel production is estimated to be more than 1,000 tons per day per furnace, or about 21 percent of the steel ingot production^{10,11}. Similarly, the smelting of copper and the production of aluminum result in significant amounts (more than 5 million tons each in 1965)^{10,12} of waste materials essentially of an inert nature, although subject to leaching if carelessly discarded in the environment. Like extractive industry wastes, basic metal wastes are concentrated at the points of generation. Here, however, the similarity begins to lessen. Mining wastes, for example, tend to occur in areas remote from any community which does not depend almost entirely upon mining for its livelihood. In contrast, smelting is more likely to be done in a community which through the years has diversified until it harbors many diverse urban interests. Thus both the physical freedom to create a large pile of slag at the smelter site and the willingness of people to accept it, become serious aspects of the problem of control of solid wastes from the metals industry.

At the second level of the basic metals industry, where ingots are formed into

shapes, smaller amounts of mill scale and spalls characteristic of the metal being processed appear as solid wastes. At this level of industry new types of solid waste appear: trimmings from the product itself; residues from the on-site use of other refined products associated with the process (e.g., lime sludges from the neutralization of spent pickling liquor); and miscellaneous wastes from the handling and shipping of the item produced.

2. *Chemicals.* For variety of wastes the chemical industry exceeds all other basic industries and generates some of the most economically and technologically difficult problems of solid waste management. The nature of these problems in any particular chemical plant, of course, depends upon the processes and the products involved. Producers of less exotic materials such as portland cement, carbon black, and lime have tended to locate in areas remote from urban communities. Their principal solid wastes have been air-transported particulates, deposited over a large downwind area, plus ashes and mineral residues accumulating at the plant site. In contrast, such industries as petro-chemicals have generally located in urban centers or have been overrun by urban expansion. The same may be said of producers of sulfuric acid, fertilizers, and many other basic chemicals.

The range of waste materials generated by the more complex chemical industries is too extensive to catalog in detail in this summary. However, it includes off-specification material, tars, process sludges, and a vast variety of chemical residues. Although roughly one-third of industrial wastes are generated by the chemical processing industries,¹³ the wastes are significant because of their particular chemical properties and their environmental effects.

Generally, solid wastes from the more sophisticated chemical processes are generated in a liquid stream which, in many cases, has been discharged to the ocean or to surface streams, or injected into deep underground strata. Nevertheless, some are generated directly in the solid state. These include chemical residues, precipitated sludges, and the miscellaneous refuse associated with the import of necessary processing materials and shipment of the finished products. In the environmental climate of the 1970's an increasing fraction of air-borne particulates and water-borne process brines and sludges will have to be collected as solids and controlled by solid waste management techniques.

3. *Paper.* Although much public attention has been directed to paper as a waste material, most of the problems associated with its original production have been in the context of water pollution rather than solid waste control. As a generator of solid wastes the production of paper and paperboard is similar to other basic industries in that residues of materials used in the process and residues of the product itself must be dealt with. In the first category

are such things as tree bark, wood fiber, paper pulp, and inert filler, which are not difficult to remove from transporting water; and process chemicals and wood extractives which can be isolated as solids only with difficulty, at considerable expense. As in the case of basic chemicals, both components of this first category of residues are destined to be controlled as solids if they are allowed to become wastes.

The second category of wastes — residues of the product — consists primarily of trimmings of paper or paperboard, plus wastage occasioned by malfunction of the processing equipment. Much of this material may be reprocessed; some may be incinerated or deposited in landfills as are similar residues from the paper fabricating industry and from commercial and domestic sources.

The total volume of solid waste produced by the basic paper industry, although not insignificant, is not as much of a management problem as is the separation of dissolved solids from liquids in the waste stream which has historically been a water pollutant.

4. *Plastics.* In the case of plastics, the residues associated with production of the basic material are essentially a problem of the chemical industry. Much of this material then goes directly to the conversion and fabricating industries, but some is converted by basic industry into sheets and other forms used by fabricators. Wastes from this segment of the industry are largely trimmings from the product itself. No estimate is available of the amount of such solid waste, but it is undoubtedly only a small fraction of the overall plastics disposal problem of a community.
5. *Glass.* Solid wastes generated by basic producers of glass include slag from the purifying of glass sand, plus miscellaneous containers and residues from products used in coloring and laminating glass, cullet (glass fragments) from breakage during manufacture and trimming of sheets, off-grade, resin coated fibrous glass, and residues from on-site crating of glass for shipment to conversion and fabricating industries. Except in situations where cullet of various colors becomes mixed, the major fraction of solid waste from the basic glass industry is reused and hence does not appear as a waste requiring control measures.
6. *Textiles.* Basic textile industries vary in the nature and spectrum of solid wastes generated, depending upon the type of material being processed. Trash from the ginning of cotton may be generated at the extractive industry level or as an intermediate step between extractive and basic industries. It is a fraction of the original cotton plant and is generally concentrated as a waste in comparatively small fractions of the total at a number of dispersed locations in cotton farming communities. Wastes specifically characteristic of the cotton textile mill are more commonly such things as strapping and burlap used in baling, plus comber wastes and fibers damaged during storage or

shipment which are generally reutilized in the industry.¹⁴

Linen textile manufacturers likewise must dispose of plant residues and materials used in shipment of the raw flax. Fiber, twine, dirt, and wool fat characterize the wastes from preparing wool for textile processing. In addition to waste fibers, synthetics generate special wastes in the form of containers used in shipping chemicals from the basic chemical producers.

Residues from spinning, weaving, and trimming operations occur with all types of fabrics. Dye containers and residues from on-site preparation of cloth for shipment are a fraction of the overall solid waste generated by the basic textiles industry.

7. *Wood Products.* Tree bark, sawdust, shavings, splintered wood, and trimmings constitute the major solid wastes of the lumber producing industry. In weight they amount to some 10 percent of that of the original tree in the forest, or about 1.26 tons per 1,000 board feet.¹⁵ Conversion of wood to plywood sheets contributes plywood trimmings, knots, and glue containers to the overall solid waste of the wood products industry at its basic level. Wood ashes are typical wastes of this industry as a result of on-site burning of wastes for power production or to dispose of sawdust and other wood wastes.

Typically, sawmills are located in smaller communities and are notable for their untidy appearance. Broken cable, discarded machinery, and miscellaneous debris often characterize the environment of a wood processing plant, albeit out of scale with the amount of such wastes generated.

Air pollution and aesthetic considerations may be expected to intensify the solid waste control problems of the basic wood products industry as particulates now discharged to the atmosphere by burning become converted to solid wastes in response to restrictive legislation.

8. *Power.* Fly ash, bottom ash, and boiler slag accompany the production of power by burning of coal. Production of these three wastes by the U.S. power industry in 1969 was 21, 7.6, and 2.9 million tons, respectively.¹⁶ Often such power plants are located in metropolitan areas, hence the objection to air-borne fly ash, dust, and ash heaps confronts the power producing industry with solid waste problems. Where high ash coals are utilized, the volume of ashes and clinkers may approach that of the original coal consumed, although, of course, its dry weight is generally appreciably less than 20 percent of that of the coal from which it was derived.

As generators of solid waste, basic industries such as those herein cited have several things in common. With few exceptions, they draw upon more than one extractive industry for raw materials; a fraction of the raw materials they refine appears as a solid waste; they utilize refined products of

other basic industries and of conversion industries, importing in the process things such as shipping containers which become wastes for which they must assume responsibility; a fraction of their own product must be handled as a waste; and a considerable value is added by manufacture, or processing by the basic industry. In comparison with a purely extractive industry, a basic industry produces more categories of solid waste, some of which it can recycle directly in its own processes. However, in comparing one basic industry with another, the things they have in common are not reflected in any similarity of waste generated. Hence no common approach to solid waste control characterizes the problem of basic industries.

Conversion and Fabricating Industries

It is beyond the scope of this chapter to attempt any listing of the myriad enterprises which convert the products of basic industry into the goods which characterize our economy and our standard of living. Value added by manufacture is a maximum in the conversion and fabricating industries. As generators of solid waste, such industries also have many things in common. Particularly significant is the extent to which the output of one type of industry comprises a combination of raw materials and solid waste for another. For example, one modest sized industry engaged in converting plate glass to windows and mirrors in the Los Angeles area estimates its cost of disposing of crating materials received from its suppliers at one thousand dollars per month.

A second common characteristic of the conversion and fabricating industries is that residues of the basic materials they utilize generally constitute the greatest fraction of the waste they generate. Moreover, unlike a basic industry which may directly recycle the trimmings and rejects of its own product, the conversion or fabricating industry must rely on some secondary enterprise to take such of its residues as are reclaimable. Thus broken glass, metal trimmings, imperfect castings, and similar salvable residues can seldom be utilized directly by the conversion industry which generates them.

To illustrate the type of solid waste problems associated with the conversion and fabricating industries, such broad categories of industry as packaging, automotive, electronics, paper products, hardware, soft goods, food processing, and construction may be cited as typical, though by no means all inclusive.

1. *Packaging.* For the purpose of this summary, production of packaging materials is classed as basic industry, hence only the conversion of packaging materials to containers is considered. However, the scope of this sector of the industry is itself extremely broad and varied as regards the nature and resource value of the waste it produces. Aluminum, steel, glass, plastics, cardboard, corrugated paperboard, plastic-paper laminates, and paper with or without any of a broad range of coatings are among the materials used by the container industry. Whether or not an appreciable num-

ber of these items appear in any industrial waste stream depends, of course, upon the range of activities engaged in by a single company or plant. Recoverability of residues often depends upon the cleanness and uniformity of the waste material. For example, conversion of glass to containers generates an appreciable amount of cullet; however, whether this is recoverable or useless, generally depends upon the extent to which colored and clear glass is mixed in the waste. Nevertheless it may be said that, at the industrial level, wastes from the packaging industry are primarily fractions of the material converted, although the range of possible materials is unlimited.

A secondary waste of any individual packaging plant is packages passed along to it by its suppliers, together with residues on its own on-site shipping preparations.

2. *Automotive.* There are two major waste-generating sectors of the automotive industry. One makes and ships specialty components; the other assembles the components into a finished vehicle. Conversion and fabricating industries in the first of these categories produce such things as tires, generators, carburetors, radios, speedometers, wheels, bumpers, hub caps, lamps, bearings, and other of the dozens of systems or devices that go to make up an automobile. In each of these the solid waste generated is a function of the special activity of the individual industry, and comprises residues of the materials used and the packaging received from suppliers.

Painting and upholstering of automobile bodies adds both container and material residues to the solid waste stream of the manufacturer. However, by far the greatest component of the automobile assembly plant waste is the discarded packaging and shipping materials associated with the delivery of components from other industrial suppliers. In fact, there is probably no other sector of industry which compares with automobile assembly in the amount of solid wastes it inherits from its relationship with other industrial activities.

3. *Electronics.* Like the automotive industry, the electronics industry includes both a components and an assembly sector. Plastics, glass, wire and sheet metal scrap and residues of a variety of other basic products appear as solid waste of the many industries associated with production of electronic components. However, in comparison with the waste from most other conversion and fabricating industries, the actual amount is relatively small.

Packaging materials, particularly cardboard, corrugated paperboard, polystyrene foams, and padding materials utilized in shipping electronic components is the major waste generating problem of the assembly activity of the electronics industry. Shipping of the assembled equipment is generally in specially designed containers, the manufacturing wastes of which are ascribable to the packaging industry.

4. *Paper Products.* Conversion of paper into products used in commerce and by the public largely results in solid waste in the form of paper trimmings. Facial and toilet tissue, paper towels and napkins, and similar products yield a high quality waste which may or may not be salvable through a secondary enterprise, depending upon whether white and colored paper residues are mixed together in the conversion process. Conversion of kraft paper into bags, for example, yields a readily salvageable waste. Publishing of books and magazines, which might be classed as a fabricating industry in the context of solid waste generation, is a major source of filled paper residues which are commonly disposed of as solid wastes.
5. *Hardware.* The term "hardware" rather than "hard goods" is used herein because the latter embraces many classes of basic as well as conversion and fabricating industries. "Hardware" is confined further herein to the metals industry which produces the machines and tools (with the exception of the automobile), and the utensils and gadgets used by all classes of industry and by the public. Solid waste from such hardware industry includes residues from boring and machining of metals; trimming and sizing of plates, tubes, and structural shapes; and miscellaneous residues from casting and forging processes. It also includes plating, etching, and similar liquid borne wastes which, like similar wastes from the basic chemical industry, must eventually be managed in the solid form.
6. *Soft Goods.* Conversion of such materials as textiles, leather, and plastics into articles of commerce constitutes the soft goods industry in the context of conversion and fabrication. As is characteristic of all industries in this classification, residues of the material processed represent the major item of solid waste generated, with incoming and outgoing goods yielding secondary wastes associated with shipping.
7. *Food Processing.* As a waste generating industry, food processing presents problems somewhat different from other conversion industries. Like extractive and basic industries concerned with material of plant and animal origin, food processing produces wastes which are subject to the normal recycling processes of nature. However, they are generated seasonally and in large amounts at locations which may be either urban or intermediate between farm and city. With the exception of a few residues such as rice hulls, food wastes are putrescible, attractive to insects, and occur in a semi-liquid or liquid state. Preparation of fruits and vegetables for canning yields a slurry of such things as leaves, soil, skins, peelings, pits, seeds, and cores, along with spoiled, out-sized, and damaged fruit. In California alone this type of cannery waste totaled 750,000 tons in 1967.⁷ Washing and cooking operations yield a companion stream of water-borne

dissolved and suspended solids. Because of water pollution problems, these solids increasingly are being removed from water for disposal by solid waste management techniques.

Processing of fish and animals for marketing or canning likewise generates putrescible liquid and semi-liquid wastes. The solids content of these waste streams, along with bones and other inedible fractions, are destined to be handled as solid wastes as water quality objectives become more restrictive.

Because the food processing industry is linked directly to extractive industry without an intermediate basic refining, containers coming to the plant are reused in the fields and orchards. Furthermore, shipment of the finished product makes use of containers already prepared by the packaging industry. Consequently, wastes from the food processing industry are predominantly fractions of the material processed.

8. *Construction.* Among the most significant generators of solid waste is the construction industry. In its purely fabricating activities its waste products are typical residues of the materials it employs — lumber, plasterboard, wire, paper, cement bags, sheet metal scrap, etc. However, unlike other industries in the conversion and fabricating category, most construction wastes result from peripheral activities essential to its production phase. Demolition of buildings, breaking up of pavement, and preparation of site produce very large volumes of such materials as earth; rock; broken concrete, tile, brick, lumber, and plaster; tree stumps, poles, and piling; and miscellaneous rubble.

The eight foregoing examples by no means cover the full range of activities which might be classed as conversion and fabricating industries. They illustrate, however, that the wastes generated by this class of industry are primarily residues of the materials they process or convert into consumer goods, and that the measures necessary to move products from one sector of industry to another impose a secondary solid waste burden on the receiver. More important, it is significant that at this most complex level of industrial solid waste generating activity the value added by manufacture is greatest. This suggests that the economic capability of conversion and fabricating industries should generally be greater than that of a basic or an extractive industry as such. Moreover, conversion and fabricating industries tend to be activities of a diverse urban community. Therefore, social pressure for solid waste control can be expected to be exerted most heavily upon such industries, especially since their products, along with the associated packaging, constitute the major solid waste which the citizen himself ultimately casts off.

MANAGEMENT OF SOLID WASTES

Earlier in this chapter it was found convenient to arrange industry into three categories, each having specific waste generating characteristics. These categories were presented in ascending order of magnitude of value added by manufacture,

responsibility for creating wastes, and degree to which their activities are conducted in urban communities. To evaluate each category, and type of industry within that category, as a generator of wastes it was necessary to treat extractive, basic, and conversion and fabricating industries as discrete entities. In the real world of industry, however, these three may be only sectors of a single large industry which owns and operates every aspect from raw material source to the finished consumer product. Thus the conclusion that no common waste management technique is applicable to all types of industry in a single category, although valid, is complicated by the fact that industry may be stratified vertically along ownership lines as well as horizontally along functional lines. To get at the general problem of solid wastes management in such a complex situation, it is convenient to consider waste control approaches in relation to the source of solid wastes rather than the composition of the waste itself.

Disposal as a Condition of Production

The simplest situation in solid waste control applies especially to an extractive industry in which the feasibility of operating at all is contingent upon satisfactory control of its solid wastes. In such a circumstance a mining, quarrying, or logging operation might be undertaken by industry only when waste control is not an economically overwhelming consideration. Feasibility may, of course, be based on geographic or topographic conditions, property holdings, access, or regulation by public law or public policy. It does not necessarily imply environmental perfection, although there is a tendency (1971) for aesthetics to be given increasing weight where public interest or public opinion is a factor. Uneconomical conditions, whether natural or man-imposed in a wastes management context, generally have discouraged an extractive industry operating entirely on its own resources. However, in an industry which covers the whole range from extraction to conversion, extraction of raw material may well be operated at a loss in order to produce profits at the higher industrial level where value added by manufacture is sufficient to offset losses. Moreover, control of solid wastes by an industry of this sort may be subject to considerable upgrading in technique and cost without causing the system to fail economically. Nevertheless, in such activities as mining there is no choice but to dispose of wastes upon the land, albeit under conditions acceptable to society.

In the case of farming as an extractive industry, constraints imposed by solid waste management have seldom been insurmountable unless urban environmental conditions are required of the farmer. Generally, he is not part of an industrial complex which can take a loss continually at the extractive level. Thus if society asks too much in the name of solid waste control or other environmental context, the agriculturist, unless subsidized, ceases operations and converts his land to urban development.

Incidental Residues Produced By An Industry

As noted in a preceding section, processing,

converting or fabricating activities within several types of industry result in slag, ashes, clinkers, and similar solid residues, as well as air-borne particulates or liquid carried process sludges, generated at the site of operation. For air and water-borne solids, control measures may include electrostatic precipitators, bag filters, wet scrubbers, sedimentation, chemical precipitation, or other conventional waste treatment processes. Disposal of bulky worthless solids involves simple deposition on the land in some location and under some conditions, acceptable to the public. More valuable incidental wastes may, however, be reclaimable or convertible to useful resource materials if the level of cost is acceptable. For example, about 14 percent of power plant solid wastes were utilized outside the power industry in 1969.¹⁶ Other measures which may assist in controlling the residues produced incidental to industrial output may include such expedients as abandoning on-site generation of power, or making changes in process. Abandonment of an entire plant, especially one with obsolescent processes, is a measure sometimes taken by industry confronted with solid wastes which are a by-product of its fundamental processes.

Product Residues Generated By A Basic Industry

When refinement rather than conversion of raw materials is the goal of production, product wastes occasioned by spillage, breakage, or malfunction of process may be managed by direct recycling within the plant. The same is true of metal trimmings, cullet, and paper trimmings in industries producing metal, glass, or paper as basic products.

Residues From Materials Conversion Or Fabricating

Cullet, metal trimmings, packaging materials, and other residues resulting from the conversion of basic industrial products into consumer goods cannot be directly reused by the waste producer. To him they represent a solid waste, some of which might be salvaged or reused economically; some of which he shall have to pay someone to remove for disposal. Metal scrap, clear glass, and uncoated corrugated paperboard are typical of the material which might be returned to more basic industries for reprocessing. Similar trimmings from plastics, fiberboard, laminated plastic-paper, lumber, cloth and a host of other materials are generally useless and are relegated to the landfill or incinerator.

Waste From Interindustry Transfer

Packaging and shipping of basic materials or finished products, a necessary part of industrial activity, require that most industries accept various amounts of materials, which immediately become a waste, in order to acquire the materials necessary to their enterprise. Thus each industry helps to create a solid waste management problem for those with which it does business. In general, the waste-to-product ratio goes up from basic to conversion industry, reaching its maximum value at the conversion industry-to-consumer level. Most of the waste generated by interindustry transfer of materials and components is waste, although there

are instances where intra- or inter-industry practices work to hold down waste production. Where producer and fabricator are favorably located with respect to each other, such things as cable spools and protective packaging for television tubes are commonly reused repeatedly for their original purpose.

Special Problem Materials

Waste materials which present especially difficult problems of management at present (1972) include both natural and synthetic products. Organic wastes, particularly food processing wastes, are a nuisance because they are putrescible, whereas plastics are a nuisance because they are not. Process sludges of a wide variety of activity, ranging from industrial waste treatment to saline water reclamation, present an unsolved problem both because of their high liquid content and because they are so newly recognized as solid waste problems that no economic technology for converting them to drier solids has been developed.

CONTROL OF INDUSTRIAL SOLID WASTES

In the preceding section attention is directed to the internal management of solid waste generated at various levels in the industrial scale. However, to determine what methods of control are needed in solving the overall problem of industrial solid wastes, it is first important to understand the relationship of industrial practice to the generation of society's total solid waste problem.

To a significant degree it is true that the entire industrial effort of the nation is dedicated to the production of solid wastes. The product of extractive industry is the raw material of basic industry; and the product of basic industry feeds the conversion and fabricating industry. Each sector of the system discards what it cannot pass along to the next in line. Finally, the entire product of the conversion and fabricating industry becomes the solid waste of all sectors of society — industry, commerce, and citizens. The rate at which the overall system functions governs the economy of the nation and depends upon the acceptance of goods by the consumer at the top of the scale. This encourages industry to mistake the act of physical acceptance of goods by the citizens for actual consumption of these goods. The next logical step is to create through advertising a dissatisfaction on the part of the consumer so that he discards his purchases on the basis of obsolescence rather than loss of utility. Thus it is clear that quite aside from any question of whether industry is giving the public what it demands, or the public is accepting what industry persuades it to demand, the overall waste generation of the commercial and municipal sectors of society is a function of what flows from industry into these sectors.

Carried to its logical conclusion, this system would eventually convert all nonrenewable resources into discarded wastes unless reuse and recycling are a matter of industrial practice and public policy. Therefore it seems logical to conclude that public agencies, industry, and education of the public each play a role in industrial solid waste control.

Role of Public Agencies in Industrial Solid Waste Control

In the absence of any public agency concerned with overall environmental quality, solid waste control would be a problem of individual enterprises in specific locations rather than one confronting the entire sector of human activity loosely described as "industrial." Thus, for example, a mining operation with land area for spoils would have no disposal problems, whereas waste disposal might be the most compelling problem of a less fortunately situated operator. Without public constraints, wastes generated incidental to production, and residues of materials conversion as well, might be hauled to some public or private dump and so pose no problem other than that of cost to the generating industry. The same may be said of particulates discharged to the atmosphere, or of process brines and sludges discharged to the water resource.

Industry would, of course, share in any ultimate disaster that wastes might bring upon mankind, but in the interval industry's wastes like those of everyone else would react only to degrade the general environment. In such a situation, responsibility for deciding what sort of a world society wants accrues to the public; and implementing public goals is the function of public agencies. Therefore, some agency of the public must decide what constitutes an environmental problem, at what level the problem is to be tolerated, and what measures should be taken to alleviate it.

In the context of problems associated with industrial solid wastes public agencies play a role in four distinct areas: public health, environmental quality, resource conservation, and economics.

1. *Protecting Public Health.* The concept that industrial solid waste poses a threat to public health apart from that of municipal refuse is of quite recent origin. It developed from a realization that air pollution is a menace to human health and that industrial pollution of water has health implications beyond that of historical water-borne disease. Constraints imposed on industry in the interests of health of workers and citizens in general are, therefore, currently reflected in the concept that air and water pollutants should be separated from their transporting media and dealt with directly as solid wastes. As with municipal refuse, however, industry is expected to handle its putrescible organic residues in such a manner as to keep down insect and rodent vectors of disease.

Thus, the role of the public health agency in industrial solid waste control is essentially regulatory.

2. *Attaining Environmental Objectives.* Environmental objectives which call for clean air, pure water, freedom from nuisance and affront to the aesthetic sensibilities of man, and a healthy ecological balance in nature are perhaps the major concern of public agencies in relation to industrial (and other) solid wastes. At the local level attainment of such objectives may be the responsibility of the health department, but at the federal level and in many

states protection of the environment is a role assigned to some agency with broader regulatory powers than the department of health. It is the role of this agency to determine where and under what conditions wastes may be deposited on land, burned, or otherwise disposed of by those who generate them. In carrying out this role the agency, in the long run, continuously must strike a balance between the environmental perfection desired by an emotional public and the industrial freedom considered necessary to an ever-expanding and changing civilization to arrive at a point at which environmental objectives are attainable at an acceptable reduction in our level of civilization.

3. *Implementing Resource Conservation Policies.* Resource conservation is a matter of public concern which has been assigned to numerous agencies with various powers and specific interests for more than half a century. In relation to solid waste, conservation has been interpreted^{17,18} in terms of both land resources and the value of resource materials in the solid waste. Thus, a public agency, alone or in concert with other public agencies, might decree in one case that a spoils dump or a slag heap in a certain location would be destructive of a land resource either by physical occupancy of land or by environmental degradation. In another case the conclusion might be that a properly constructed landfill in a particular location would create a new land resource.

Concern for the resource value of residues such as glass, metal, and paper wastes from the conversion and fabricating industries might lead a public agency to any of several alternate decisions. For example, the decision might be that enhancement of land resources is important enough to justify sacrificing resource residues as landfill material. In contrast, there might be reason to decide that resource residues should be stockpiled in a fill for reclamation at some future date; or that they should immediately be recycled in the interest of resource conservation regardless of cost.

Both the multiplicity of public agencies having interest in land use and in resource conservation, and the scope of possible policy decisions, gives the public agencies a broad and flexible role in determining the conditions industry must meet in managing its solid wastes.

4. *Overcoming Economic Constraints.* In the matter of economic constraints, public agencies may play either of two important roles. They may force industry into actions regarding solid waste control previously thought to be too costly by regulatory actions directed to resource conservation, environmental quality, or any other objective. At the other extreme, they may establish economic incentives for action by industry.

It is not likely that regulation of what conversion and fabricating industries must do with their solid wastes will be a deciding factor.

Instead, a requirement that resource materials be recycled will strike at the consumer-waste hinge of the system and so feed back through the entire industrial equilibrium. That is, it will change the kind of materials required by the conversion industry and, consequently, what basic industry produces and what amounts of specific raw materials are extracted.

In the matter of economic incentives, tax breaks or tax penalties,¹⁹ demonstration grants for exploring new processes, direct subsidy of recycling, and equalization of freight rates for new and scrap metal* are examples of actions which might be taken by public agencies under appropriate public policy. The result might be both a change in the nature of solid waste generated by industry, and in the ultimate fate of such wastes.

Role of Industry in Industrial Solid Waste Control

Because industry accounts for a very large fraction of the total solid wastes of society and the processes by which many wastes are generated are proprietary to industry, it is logical to expect that industry should play a significant role in the control of its wastes and, consequently, of the total waste load upon the land.

The Matter of Options. If all discarded material is considered as waste, the mining and basic metals industries appear as the major source of industrial waste. To deal with such things as mine tailings and blast furnace slag, however, man has few options. Thus at the lower end of the scale the role of industry in solid waste generation is relatively fixed. Similarly, the small value added by processing at the extractive level limits feasible disposal methods, unless higher levels of industry or government subsidize waste control.

Further up the scale, however, such rigidity no longer pertains. The material to be used for any given purpose, as well as the resulting waste-to-product ratio, is a function of the inventiveness and ingenuity of man. Competition for markets encourages the producer of consumer goods to use that ingenuity in finding better processes and cheaper materials and production methods. Constraints imposed by public policies concerning resources, environment, and waste management may likewise react to this same end. Therefore, at the higher end of the scale the role of industry in the overall waste problem is not fixed by circumstance.

Reducing the Amount of Waste. Better processes and cheaper materials do not lead necessarily to a lesser amount of wastes generated. In fact, it is possible that quite the opposite might result. Therefore, industry's role in controlling the amount of solid waste society generates is one of looking to its own design and materials selection activities with consideration for the final disposition of its product in the environment.

The concept that purchase is synonymous with consumption of goods leads logically to a limitation of the objectives of design to such traditional factors as ease of manufacture, saving in cost of fab-

*In Minnesota the 1970 freight rate for scrap was \$4.25/ton as contrasted with \$1.84 for raw material.²⁰

rication, appeal to the buyer, novelty, and obsolescence. Responsibility for solid waste control and for resource conservation, however, now requires that degradability of synthetic materials, ease of dismantling for segregating component materials, minimum number of types of material, and other materials recovery considerations or disposal objectives be among the specifications designers should seek to meet.

Role of Public Education

It is particularly important that people understand the inter-relationships within industry and the dependence of our level of civilization upon industrial activity.

An informed public plays an especially significant role in the control of industrial solid wastes, both because public opinion is respected by industrialists and because public attitudes are the basis of policy legislation which creates the institutions which carry out public policy. Public education is both important and urgent at such times in history as the 1970's when prophets of doom abound, and citizens are bombarded daily with propaganda and with naive and simplistic answers to complex environmental problems.

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CONTROL OF COMMUNITY NOISE FROM INDUSTRIAL SOURCES

*Lewis S. Goodfriend***INTRODUCTION**

There are many potential sources of community noise in an industrial plant. However, there are only six general classes of noise sources: a) power generating units, b) fluid control systems, c) process equipment, d) atmospheric inlets and discharges, e) materials handling, and f) plant traffic. Although not a source, architectural and engineering deficiencies also contribute to community noise by allowing plant noise to escape into the community.

Within each of the above classes, there are several types of machines or processes that create the noise. The actual noise source within each machine or process is due to one of a very limited number of physical noise generating mechanisms.

Before describing each of the major industrial noise source categories, the physical generating mechanisms will be outlined, after which the machines, processes and systems in industry that generate community noise will be described. This will be followed by a discussion of the response of people to noise in the community and the methods for delineating or comparing community noise levels. The chapter concludes with a presentation of methods of reducing industrial noise in the community and the outlook for future needs and methods of noise control.

NOISE GENERATION

The noise generating mechanisms which occur in industrial machinery are: impact, gas flow phenomena, perturbations in fluid flow, combustion, friction, dynamic imbalance of reciprocating and rotating machines, and magnetic excitation. Each type will be discussed briefly with respect to the types of industrial machinery and processes and their particular systems of noise generation, transmission paths, and radiators.

Impact

The most familiar of the industrial impact phenomena are probably those from the forge hammer and the punch press. These produce intentional impacts which occur as a direct result of the energy in a flywheel or force of gravity on a drop hammer's mass being expended on the workpiece.

Other sources of impact include: repetitive chipping and scraping, bulk handling of small parts, e.g., tumbling, and the use of negative clearances in some processes. Another class of impacts is unintentional. This occurs when poor machine design, installation, or maintenance permits over-travel of machine elements.

Gas Flow Phenomena

The sound of escaping air or steam is probably the most familiar gas flow noise. However, other conditions associated with gas flow, such as turbulent flow and flow around obstacles, can produce noise. Where the obstacle is a sharp edge, it is possible to generate intense tones. Similar intense acoustic signals are generated by flow across spaced obstructions such as stiffeners in a duct. Flow across the face of a cavity will produce noise which can be amplified by other parts of the mechano-acoustic system.

Air flow causes noise. The hissing noise made by a high-pressure air line open to the atmosphere and the swishing noise of the air flowing past the open window of a car are both examples of air flow noise. There are two separate mechanisms at work here. In the open air-line case, the sound is generated by the non-uniform flow. In other words, the eddies or turbulences within the air stream generate noise, and the larger the difference in velocity between the air stream and the stagnant surrounding air, the more noise which is generated. In the second case, the obstacles in the air stream cause vortices downstream of the obstacle. Since it takes time for the vortices to form, be shed and be followed by another, a periodic system, the sound generated is characterized by tonal quality. Noise from such air flow generators can be amplified many times to produce intense whistles as will be discussed later. The usual sources associated with noise generation by air flow include fans, obstacles in air streams, leaks and open bypass valves in the air handling system, whether of high or low pressure.

The siren effect is responsible for many types of gas flow noise. A siren basically is a device which emits puffs of air in a cyclic pattern. Classically, it consists of an air supply and a rotating disc with holes that match one or more holes in the air supply. When the holes of the disc are aligned with those of the air supply or "wind box," air can escape freely. At other times, the air is essentially cut off. The repetitive release of air makes a sound of tonal character. The volume of air released at each matching of the holes determines the intensity of the noise produced. The siren effect is responsible for the noise of compressor inlets and air turbine discharges. Also, a similar sound is made by a power saw's teeth which cause perturbations in the air near the blade as the teeth pass fixed portions of the saw.

A special type of gas flow phenomenon which generates flow noises is the production of large volumes of hot, turbulent gases as a result of com-

bustion of fuels, whether solid, liquid or gaseous. The expansion of the gas as it is produced and heated causes intense local acoustical disturbances. This gives combustion noise its distinctive low-pitch rumbling sound. Where combustion takes place unevenly, the noise is rough and uneven. In some instances the acoustic signal is so strong as to extinguish the flame which is reignited by a pilot flame or the heat of the burner, and this cyclic behavior can generate serious vibration, often resulting in structural damage. The noise is often an intense low frequency pulsation.

Friction

Another source of noise generation is friction. Although we generally associate energy losses due to friction with heat, friction causes two kinds of noise generation. The first is a series of miniature impacts as the imperfections in one surface are forced over another surface without any lubrication. The sound is somewhat like that from air noise and the sound output is a function of surface smoothness and speed. The second type of friction noise is stick-slip noise. Here, the friction causes a moving part to stop or slow down imperceptibly and as the driving force builds up, the friction is overcome and the parts slip by each other for an instant. Then, they grab again. This action produces high stresses in the parts and the sticking and slipping phases occur at high speeds, thereby producing an intense, high frequency phenomenon. Where the combination of part size and shape permit effective radiation of this type of sound, an intense sound will be radiated.

Dynamic Imbalance

Almost any kind of dynamic imbalance in high speed machinery will cause mechanical vibrations. Where the appropriate acoustical conditions exist, the vibrations will be converted into acoustical energy. This energy may be radiated efficiently by some machine parts and housings. Typical sources are fans, pumps, engines, (both reciprocating and turbine) and compressors. Imbalance forces may be transmitted through bearings. Although bearing noise is partly friction noise, bearings can generate noise by the impact of imperfections in the bearings on other bearing parts at high speed. This causes vibrations which are readily converted to sound by the castings and housings. Generally, bearing noise is not a major source.

Magnetic Excitation

Although electrical machines are not generally considered as noise generators, motors, generators and transformers are capable of being major noise sources. The magneto-acoustic forces occur as a result of the magnetic forces on conductors and rotor and stator. Since there is no magnetic bias field like that due to the permanent magnet in a loudspeaker, the magnetic fields developed at both the positive and negative swings of the power supply line voltage in AC machines cause an unidirectional force. Thus, for each cycle of the line frequency there is a magneto-acoustic force of twice the frequency. Because of non-linearities in the magnetic and mechanical systems, the acoustic output can have a high harmonic content. The

radiated sound can, therefore, be rich in mid-frequency components. In some transformers and motors, the maximum levels occur for signals at six and eight times the line frequency.

In addition to the magnetic excitation, motors and generators produce noise from the radial blade fans used to cool the device by forcing air through or across the casing, and from the shear produced in the air as the slots on the rotor pass those on the stator.

Noise Amplification and Radiation

Except for a few of the sources mentioned such as fans, sirens, and air hoses, little noise would be radiated from equipment if it were not for subsystems which may be resonant or are efficient radiators. The most familiar resonant subsystem is the organ pipe. Without the pipe tuned to a resonance frequency desired, the noise made by the jet edge would be weak and would have little tonal quality. The pipe causes sound which has traveled to the far end to be reflected and transmitted just in time to reinforce the pressure variation at the jet, where a new, stronger signal is transmitted from the jet. The process repeats until an equilibrium situation occurs and a tone is radiated. There are other factors influencing the sound output of an organ pipe type of generator, such as the spacing of the nozzle and jet and their relative angular positions.

Cavities with small necks produce the familiar whistle when air is blown across the mouth. Castings can "ring like a bell," and machined parts such as gears can produce bell-like tones. Sheet metal panels can resonate over a wide frequency range, vibrating as either plates or membranes. The theory for these subsystems is presented in most vibration texts. Some specialized subsystems include machine shafts at the critical speed, gas furnace burners, cup burners, in which the source is inside the resonant structure, and machine room floors consisting of lightweight structural members.

Efficient radiators, formed by large surface area flexible bodies, may be combined with resonant subsystems. A small acoustical resonant subsystem, one side of which is formed by a large steel sheet, will drive the steel sheet as the coil in a loudspeaker drives the paper cone. The steel sheet will radiate the noise very effectively.

EXTERIOR SOURCES OF INDUSTRIAL NOISE

Power Sources

Furnaces and heaters provide the energy for a variety of industrial processes including the refining and fabricating of metals, generation of electricity, petro-chemical processes and a variety of kilns. In some new combined cycle plants, the hot gases operate gas turbines and then the same gases at lower temperature and velocity heat water in heat recovery boilers, the steam from which operates one or more steam turbines. Also, fossil fuel boilers generate steam for a wide variety of industrial processes. The basic process in all cases is combustion which by its nature produces thermal and pressure perturbations in the air which propagate as sound waves. Because of the slow

rate of flame-front propagation and the high energy release involved in the combustion, the perturbations, and thus, the sound waves produced, are of low frequency and high intensity.

Furnace and boiler noise is often mixed with induced or forced draft fan noise, but where combustion is rough, the low frequency rumble is often clearly distinguishable. The pressure pulsations can readily shake windows and cause doors to rattle against their stops.

Both steam and gas turbine systems radiate considerable noise from both turbine casing and the connected ducts and piping. The gas turbine's inlet and discharge are often open to atmosphere. Without mufflers they generate noise which is generally unacceptable. The inlet radiates the intense noise at compressor blade-passing frequency and the discharge radiates the combustion noise. The inlet blade-passing sound is a high pitched signal like a siren. The exhaust noise is like the sound of jet aircraft exhaust.

Electrical power transmission systems can cause three types of acoustical noise that can easily be heard in many rural and suburban locations at levels quite high, with respect to the ambient noise. These are substation transformer hum, high voltage corona and switch-gear and circuit breaker operations. Transformer noise is usually highest in level at light loads occurring generally late at night. Transformer noise is characterized by the pure tone harmonics of 120 Hz. As the load on the transformer is adjusted, the signal changes character. In open country, substations can be heard for distances up to half a mile or more. The levels at 1000 feet can run in the 45 dB (A) range.

Corona noise which sounds like frying has a range of 50 to 70 dB (A) below the lines, and approaches these levels at houses along the transmission line right-of-way. It is highest in level when the corona discharge is most severe, during periods of high humidity, rain and fog.

The noise from air quenched circuit breakers is an explosive sound like a gunshot. When the circuit breaker operates, air at over 800 pounds per square inch gauge is used to cool and quench the breaker gap as the breaker opens. The result is a high pressure acoustic pulse which can run as high as 95 dB (A) at 1500 feet.

Fluid Control Systems

Pumps, both within and outside of buildings in industrial plants, generate high level noise. Generation of noise in pumps is caused by sudden changes in any of the flow parameters, volume, velocity and pressure, by turbulence, and by the mechanical noise generated by the bearings, seals, couplings and loose parts. The noise is transmitted along piping and conduit and is readily radiated from the pump casing, equipment enclosures and lightweight structural and building shell components.

Compressors generate noise at the inlet because of the rapid changes in velocity that occur as the inlet is either opened or closed in a reciprocating compressor or as the blades pass the cutoff in a centrifugal compressor. In axial flow compressors, the noise originates through the inter-

action of the fixed and rotating blades at the blade passing frequency. This noise is radiated from the casing of the compressor, connected structural members, and housing elements as well as from the downstream piping and ducting.

Fans and blowers generate noise in a manner similar to compressors, but work at lower static pressures. Many fans are exhaust or induced draft devices which are ducted on one side, but open directly to atmosphere on the other side. The noise generated by a fan will, in general, be a minimum at the most efficient operating point for the fan. Materials-handling blowers have an additional noise source, the interaction of the blade and the material itself, e.g., the scrap blower in a paper-board plant.

Any obstruction in a fluid flow system causes a change in velocity and can generate vortices at the trailing edge of the obstacle. In addition, many flow control devices obstruct the flow, e.g., fire dampers, and may generate severe turbulence downstream. This results in the generation of vortex noise, turbulence noise, and in some cases, intense pure tones due to the interaction of the vortices with some resonance condition in the pipe or duct.

Process Equipment

The term process equipment encompasses a wide range of systems and machines. Typical examples will be given, but it should be fairly easy to compare any process or machine to the list of sources, radiating systems and resonators in order to determine the acoustical system responsible for the noise associated with the particular device or system in question.

There are numerous sizes of mills ranging from table-mounted units to those enclosed by a large building, with basically the same process in each. A number of heavy hard rods, balls or knives within the mill, work upon the material to be milled, dividing the substance under the pressure of the balls, rods or knives until the material is reduced in size to the range desired. It may then be separated by size using vibrating screens, mechanical separation or flotation separation. In any case, the housing of the mill is acted upon by a large number of impacts. Because of the large relative area, the housing radiates the milling sound quite well. Connected with the mill are sets of gears, belts and bearings, which also generate large forces because of the energy being transmitted is high. Thus, a mill may generate bearing and gear noise in addition to the sound of the milling itself.

Crushers, particularly ore and stone crushers, require large amounts of power which is released in the destruction of the bonds holding together the particles of the material being worked. The result is a rapid series of high energy impacts. Crushers are often located out-of-doors or in lightweight sheds, and in either case radiate low frequency noise as well as bearing and drive equipment noise from the crusher structure, enclosure, or building.

Saws

Circular saws generate noise by siren action as the teeth pass fixed elements in the saw and as

they pass into and out of the material being worked. Saws also ring in the manner of a gong, due to a plate resonance which can be excited readily by the teeth as they strike the work and by the siren tone. Even if used indoors, saws can generate noise which radiates into the community.

Cooling Towers

Among the major outdoor noise sources are the cooling towers used as heat exchangers in industrial processes, power generation and air conditioning. The cooling water is sprayed into an air stream resulting from the action of a powerful fan or blower. The water flows over a "fill" material which enhances evaporation by providing a large surface area for contact with the air stream. The combined heat transfer due to evaporation and conduction provide the required cooling. The noise generated by the fans and blowers is similar to what can be effected from such fans. However, they often generate low frequency noise because of low speeds and few blades. These conditions are dictated by the fact that these are low static pressure, large volume devices of great physical size. Another component which generates cooling tower noise is the water splash. This contributes a distinctive high frequency sound to cooling tower noise. When the fans are turned off, the splashing noise can be quite annoying.

Flare Stacks

In the petro-chemical field the disposal of waste gases is often accomplished by burning them at the top of a tower where the products of combustion can mix with ambient air and can diffuse sufficiently to reduce both concentration and temperature. The result is that the combustion takes place in the open at the top of a tower, providing clear line-of-sight sound propagation to the neighboring community. The sound is generated both by steam injection often used to suppress smoke, luminosity and instability of combustion, and by combustion instabilities often related to moderate and high wind velocities, flowrates and port characteristics.

Mechanical Power Transmission

The transmission of mechanical power can readily generate high noise levels as a result of friction and impact noise sources. Slight imperfections in gear teeth cause acoustically significant perturbations in the force transmitted. These perturbations are often amplified by resonators in the gear-shaft system and are effectively radiated by the machinery housing. The mechanical perturbations also shock-excite some components such as gears which then are free to vibrate at their resonance frequency. Here again, the part and its associated structure and housing may radiate the sound into the community.

Belted systems can generate noise by several means, the most common of which is friction noise. In general, belt generated noise is not a major problem until other noise sources are eliminated. Chain drive systems are basically impact generators as long as they are well lubricated, but if not lubricated, they can become friction noise generators and in some cases, the friction load on the bearings increases the bearing noise.

Bearings in transmission systems are usually designed to minimize friction. However, poor maintenance and overloading can soon turn bearings into high level noise sources. Since they are attached to the structure and often the machine housing, they can cause considerable noise to be radiated into the community.

High Pressure Atmospheric Inlet and Discharge

Rapid pressure fluctuations such as those occurring at the discharge of a diesel engine, or the inlet of a compressor, are radiated from the inlet or discharge as acoustic signals. The signal usually has a tonal quality or contains a pure tone (and harmonics) at the rate at which the port(s) open or close. At the engine discharge, the pulsations may have initial pressures at many times atmospheric pressure. In compressors, the large volume involved often leads to high velocities in attached piping. The pulsations from the compressor inlet are transmitted as high velocity perturbations down the pipe to the atmosphere where the pulses look very much like the exhaust pulsations from an engine.

Continuous flow discharge from steam, air and gas lines, and blow down from high pressure vessels and piping systems generate high level noise through turbulent mixing of the jet with the ambient air. At pressure about twice atmospheric, the flow from an air line becomes sonic; that is, the velocity at the outlet is at the speed of sound. At pressures above this, the velocity remains sonic, but the nature of the flow changes and can be supersonic downstream. In either case, high acoustic pressures are generated. The noise level is a function of the eighth power of the Mach Number below sonic velocity and depends mainly on the square of the pressure ratio across the opening above sonic velocity. The exact level is influenced, however, by the temperature (second power), molecular weight and compressibility factor for the gas (both inversely as the second power).

Materials Handling

The noise caused by materials handling is among that most often heard outside of many plants. Fork-lift trucks and front loaders and a variety of cranes moving around the yard generate noise with their motors and sometimes with their loads. Electrically operated cranes of large capacity can be heard over large distances late at night and are sources of complaint mainly because of the pure tone component. Conveyors make noise from two major sources, the material conveyed striking the sides of the chute or enclosure, and the bearings and rollers on which the moving belt, or in some cases, the material themselves move. Belt conveyors impose large loads on the bearings and rollers and these, in turn, can generate noise which is readily radiated by the enclosure and structure. The sound of the large number of wheels of the skate-wheel conveyor, because of the nature of the wheels and the structure, can radiate at levels which may exceed acceptable community goals.

Large vibrating shakers used to empty hopper cars radiate low frequency signals into the community by means of the large radiating area of the

side of the car. The noise is often a maximum level below 30 Hz and can rattle doors, windows and the china and glassware in a house at several hundred feet. The noise level at the house is usually 80 dB or more at the exciting frequency. At this level, no earth vibrations will be measured and the signal may only be heard by a skilled observer when the area is noisy at higher frequencies. This is due to the reduced sensitivity of the ear at low frequencies, as well as the masking of low frequency noise and tones by high frequency noise. However, the low frequency acoustic waves cause the walls of the building to vibrate and, in turn, cause relative motion between doors, windows and shelves and the rest of the structure. High frequency vibrators (actually 60 and 120 Hz) will also radiate effectively when attached to large sheet metal hoppers. However, the noise level can be six to 15 dB higher when internal springs and rubber dampers break or slip out of position.

Other out-of-doors noise sources are the impact of large parts on other parts of loading platforms, the operation of dockside and platform elevators, and the use of powered material handling tools.

Plant Traffic

One of the most difficult noises to define and control in a modern industrial plant is traffic noise. The sources are trucks for the delivery and shipping of goods, rail cars in the shipping and classifying yards, and the employee automobile traffic. These sources might be only a moderate contributor during the day, but at night they may stand out against a much quieter ambient noise level. This will be particularly true where the plant operates a second shift and plant noise drops in level just before the outward flow of cars. Also early morning deliveries, before plant opening, can cause distinctive and annoying noise.

Architectural Deficiencies

The design of industrial plants must take into account the types of noise that will be generated within the plant. Openings made in the plant to install new equipment create a problem to be dealt with carefully. Among the most important items to consider are the adequacy of the basic structure and enclosure, and the prevention of any openings through which noise can escape inadvertently. Plant ventilation must be accomplished without allowing the vent openings to act as transmission paths between the internal noise and the community.

THE RESPONSE OF THE COMMUNITY TO INDUSTRIAL NOISE

The noise which is heard in a given location from sources far and near, including readily identified noises such as passing cars or barking dogs, is the *ambient* noise for that location. Removal of, or shutting down, all local sources under investigation leaves the only sound arriving at the measuring location the *background ambient* noise. The background ambient noise in a community usually consists of distant transportation noise.

Acceptability of Noise in the Community

Noise in the community may or may not be

acceptable to the workers and citizens in the area. Without some "acceptable" noise to mask the more distant sounds and day-to-day activities of our neighbors, we should find life intolerable. Thus, the ambient noise serves a useful social function, as long as it stays within certain bounds. Noise becomes unacceptable in any particular situation when it is distracting, especially during creative activity and when it interferes with sleep or with speech communication. It is also unacceptable when it interferes with the ability to hear speech or the sound portion of television, radio or recorded programs. Industrial noise can probably be acceptable at these relatively high levels, 50 dB (A) or more, out-of-doors when it meets certain criteria:

- a) it is continuous,
- b) it does not interfere with speech communication (on the patio, at the dinner table, or in the office),
- c) it does not include pure tones or impacts,
- d) it does not vary rapidly,
- e) it does not interfere with getting to sleep, and
- f) it does not contain fear-producing elements.

There are many other parameters which influence the acceptability of noise by individual residents or groups of residents exposed to any particular noise. Thus, although physical measurement of the sound level is important, it cannot effectively predict the response of any specific neighborhood or community to a particular noise source. In fact, the relationships as will be determined later, between the community and the operator of the noise source, and the responsiveness of the local political authority, may have a greater influence on acceptability of a noise than the noise level or quality.

Measurement and Evaluation

Both the A-weighted sound level and octave band analyses have been the major physical methods for measuring noise for purposes of evaluating its effect on the community. Octave band analysis permits the comparison with contours such as the noise rating chart or a municipal code. Studies have shown that even though it was designed for another purpose, the A-weighting does rank human response to noisiness and loudness quite well over a wide range of levels. Other schemes using manipulation of octave band data such as the Perceived Noise Level (PNL or PNdB)¹ or loudness² in sones have been used with some success for particular applications. The PNL is derived from equal noisiness contours similar to equal loudness contours but with a sharp increase in sensitivity in the range 1500 and 8000 Hz. In an effort to provide a single reading comparable to the A-weighted measurement, the D-weighted curve based on the 40 Noys perceived noisiness contour has been used.

None of the methods used except Composite Noise Rating (CNR),³ based on the Noise Level Rank Curves (Figure 46-1) have shown any relation between noise and the community response.⁴ Recent efforts to use single number

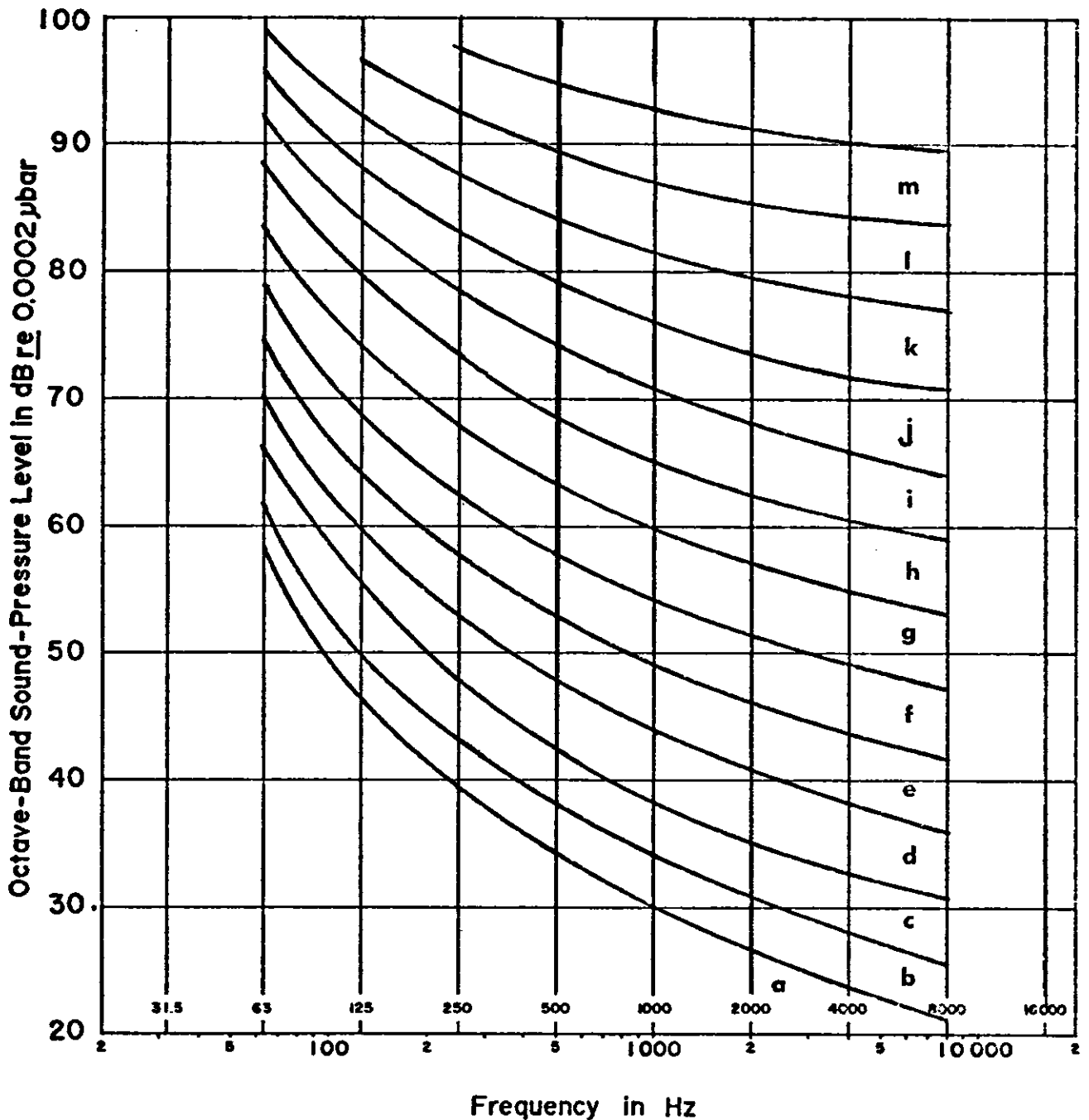


Figure 46-1. Noise Level Rank Curves.

measures such as the A-weighted level alone or Noise Pollution Level (NPL) have not been successful.⁵⁻⁶ A new effort using the A-weighted level modified by the same factors used in CNR has been proposed by Eldred and tested in a number of situations. Called "Normalized Community Noise Equivalent Level (NCNEL), this measure is based on the daily time history of the noise exposure expressed in terms of the A-weighted reading occurring in three periods: day, evening, and night. A table of adjustments covering the nature and extent of the exposure, the ambient

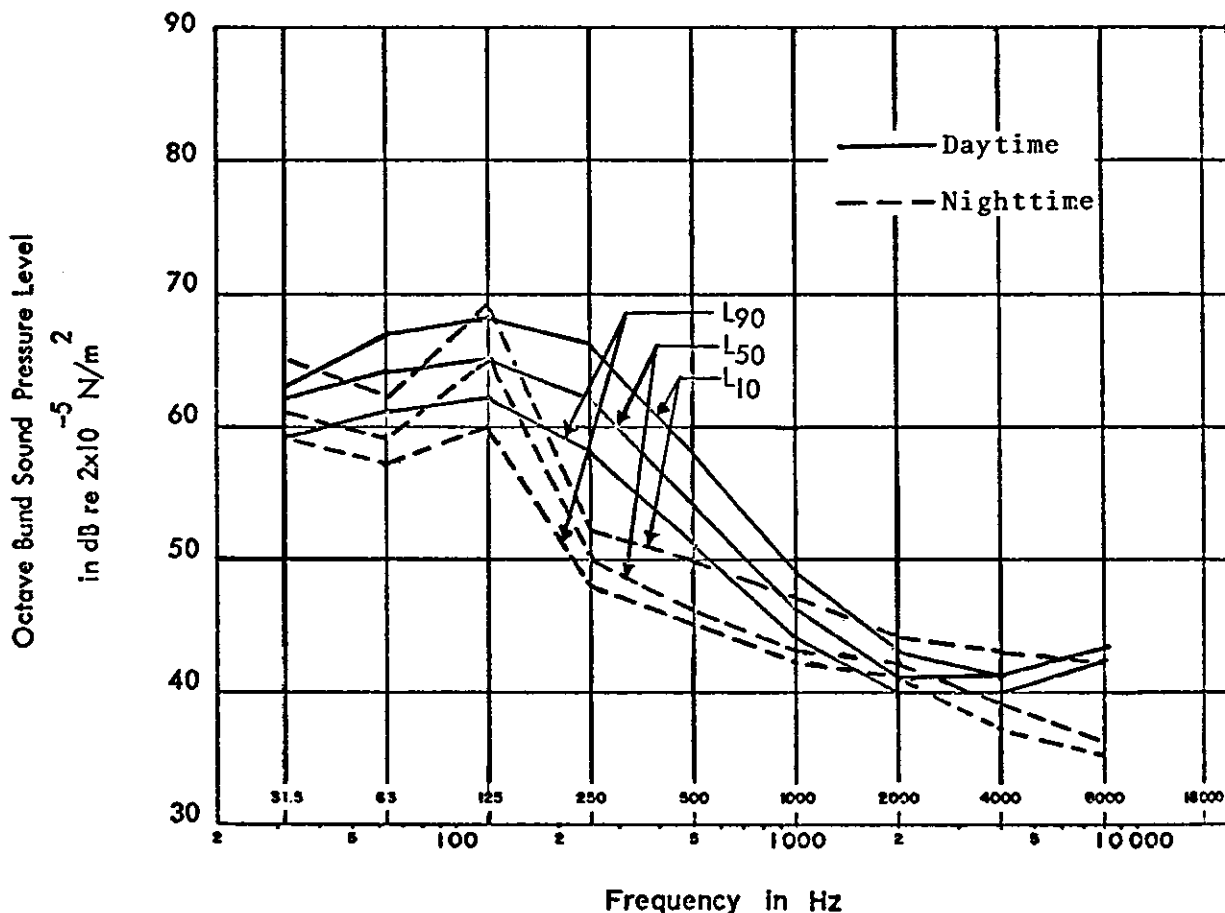
levels against which the noise is heard and the attitude of the persons exposed, is used to adjust measured values, (Table 46-1). When the adjustments are made, the NCNEL may be plotted on a chart that indicates the expected range of response of those exposed.

Noise Pollution Level (NPL),⁵ which is currently quite popular, attempts to use the statistical properties of the noise exposure to describe its noisiness. NPL is defined as $L_{eq} + 2.56 \times s$ where L_{eq} is the energy average of the noise as indicated on a level recorder or on a statistical

analyzer. Here, s is used as the standard deviation of the noise levels from a large number of one second samples taken during the measuring period. Unfortunately, NPL does not distinguish between the quiet residential background on which are superimposed many children at play and passing neighbors' cars versus the rather steady but high noise level of a downtown commercial area. There is not enough information in the statistics alone to describe the noises that do or do not cause a large standard deviation. One common treatment of data is the use of the tenth and ninetieth percentile of the measured levels to indicate the nature of the noise exposure. The 90 percentile values are considered to be the background ambient (the noise levels are above this value 90 percent of the time, while the 10 percentile values are those of the intrusions). The spread between the two is related to the standard deviation, but the absolute levels indicate its effect on speech communication.

Effect of Social-Political Environment

The response of a community or neighborhood to an industrial noise is, as has been noted above, not necessarily related to the level of the noise. There are many influences, not the least of which is an interaction between the industry and the municipal council and the citizens. It is sometimes two-sided and sometimes three-sided, but it is invariably a process of accommodation on each side. Whenever an industry proposes to locate a plant in a municipality, it has decided to do so on the basis of at least a preliminary investigation of the site. Corporate officials will have talked to local officials and there is some anticipation on both sides that the industry will provide jobs and tax income to the community and that the municipality will welcome the industry by accepting the gaseous, particulate, and liquid wastes and the increase in street traffic. However, after the initial decision to build a plant is made, the company must submit plans for zoning approval at one or



U.S. Environmental Protection Agency: Noise from Industrial Plants, Report NTID 300.2. Washington, D.C.

Figure 46-2. Example of Community Statistical Noise Spectra Obtained from Daytime and Nighttime Surveys. L_{90} , L_{50} , and L_{10} percentile values were obtained from 100 samples with one second integration time.

TABLE 46-1

Level Rank Chart. To Obtain Composite Noise Rating of a Noise Exposure (CNR), the Sound Spectrum is Plotted on the Chart and the Highest Level Rank Band Penetrated, Determine the Level Rank. The Level Rank is Then Adjusted One or More Steps According to the Table.

LEVEL RANK CORRECTIONS FOR CNR

a) Very Quiet Suburban	+1
Suburban	0
Residential Urban	-1
Urban Near Some Industry	-2
Heavy Industry Area	-3
b) Daytime Only	-1
Nighttime	0
c) Continuous Spectrum	0
Pure Tone(s) Present	+1
d) Smooth Temporal Character	0
Impulsive	+1
e) Prior Similar Exposure	0
Some Prior Exposure	-1
f) Signal Present: 20% of Time	-1
5% of Time	-2
2% of Time	-3

more public meetings. Officials must answer questions from municipal officials and the public. The process may have to be repeated four or five times. Finally, the plans must go to the municipal governing body where public and local officials can repeat the process. Some citizens groups have been known to arrive with lawyers and experts, while the company arrives with top officials and its experts. After appropriate parrying, each side offers some accommodation, and then the governing body may decide to approve the plans or ask for resubmittal. In all of these proceedings, noise is likely to be an important consideration. When the decision to accept the plant is given, the company involved may withdraw its plans and seek another site in a different municipality because it has sensed the hostility of the community that it will have to live with for many years. Even where the approval is granted, the municipality still maintains control. When the plant is completed it cannot be occupied without a certificate of occupancy. This must be issued by the building inspector who will have been monitoring construction. If he and the other officials are not satisfied, no Certificate of Occupancy will be issued until the "deficiencies" are "corrected." Finally, the municipal and state health officers and the state labor department must approve the plant and its operations.

Thus, the process of accommodation works to maintain some moderation of the noise radiated into a community neighboring an industrial plant (Figure 46-3). Even where a plant has existed for many years in reasonable harmony with its neighbors, a change in the plant that allows an increase in sound levels in the neighboring community is likely to cause an immediate response on the part of the neighbors. In some cases this results in demands for lower noise levels than ex-

isted prior to the change. In some cases the interpersonal relations between plant officials and neighbors may result in continuing skirmishes that preclude any satisfactory accommodation on the part of the parties involved. Even when the plant offers to buy neighboring homes at a premium, some neighbors may refuse, even if almost all of the remainder of the neighbors have left what was a substandard housing area.

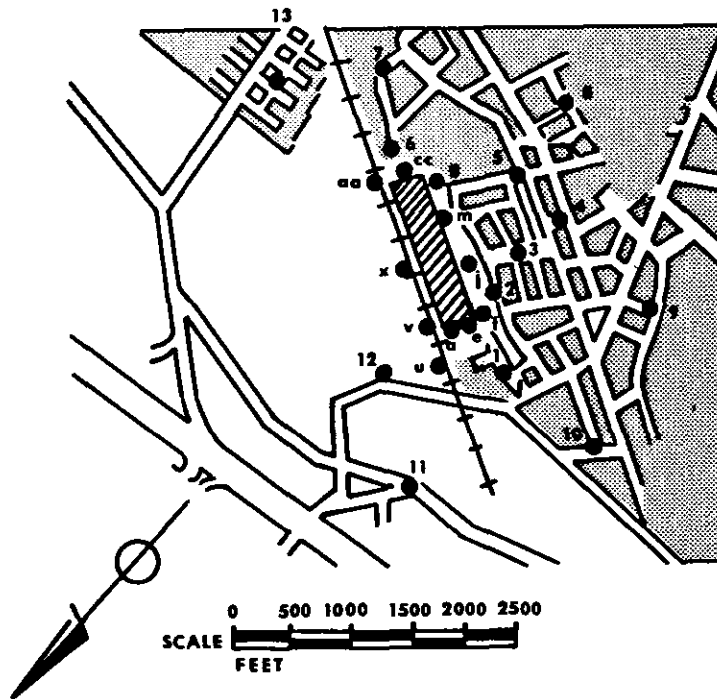
In some locations, single individuals have kept up such fights with major industries and have forced local officials to take legal action for violations of local health statutes even though the enforcement results from a personal vendetta. In general, the accommodation process has maintained the noise levels in communities across the country at levels just below that at which neighbors will complain (Figure 46-4). These noise levels may be higher than is socially desirable, but often they are also just below the noise from transportation noise sources, nearby highways, truck routes, and parkways.

The current effort to abate transportation noise may leave industrial noise as the major noise source in some areas. With the industries now clearly setting the ambient level, it may be that a new round of accommodation will occur.

THE CONTROL OF INDUSTRIAL NOISE SOURCES

Industrial noise sources expose both the employees within the plant and the neighbors in the community. Often the same machine producing levels of 90 to 100 dB (A) around the machine indoors can be heard in the nearby residential neighborhood at levels from 40 to 60 dB (A). Some industrial noise sources as outlined earlier are out-of-doors and may or may not expose employees to hazardous noise levels, but because they can generate high levels of noise they can be heard at distances up to a mile from the plant. Close to the plant the noise levels may be well above the ambient, and can be unacceptable. The following section discusses the general methods of quieting industrial noise sources, and in some cases, mentions specific hardware.

The first requisite for a noise reduction program is a carefully done noise survey. Made at or near the plant boundary or closer, it should be possible to identify the major contributors to the noise in every direction around the plant. It may be necessary to make some measurements during a shutdown, and others close to small machines, to examine how much noise they might contribute to the total sound level in any given direction. With this information, the amount of noise reduction required at each machine may be evaluated. From the physics of the situation it is clear that if three or four different sources contribute about equal energy at a given point at the plant boundary, and thus, in the community beyond, all must be quieted to some degree. Clearly, if four machines generate roughly the same noise with about the same spectrum, eliminating the noise from two will only cause a three dB drop in level, and shutting down three would yield about



	Community Noise Levels in dB(A)												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Weekend	46	54	45	39	41	43	-	-	48	41	41	51	43
Weekday	50	59	44	42	42	40	44	40	41	44	39	53	43
Weeknight	52	61	46	40	43	45	43	40	41	41	42	49	42

	Plant Property Line Noise Levels in dB(A)										
	a	e	f	j	m	q	cc	aa	x	v	u
Weekend	50	62	59	68	55	41	44	40	60	65	52
Weekday	49	64	61	68	59	49	50	49	66	68	55
Weeknight	51	64	63	69	58	48	41	46	61	65	54

Key	
	Industrial Noise Source
	Residential Area
	Railroad Track
	Highway
	Measurement Location

U.S. Environmental Protection Agency: Noise from Industrial Plants, Report NTID 300.2. Washington, D.C.
 Figure 46-3. Example of a Noise Survey around an Industrial Plant. Levels were measured directly with a sound level meter.

Community Reaction

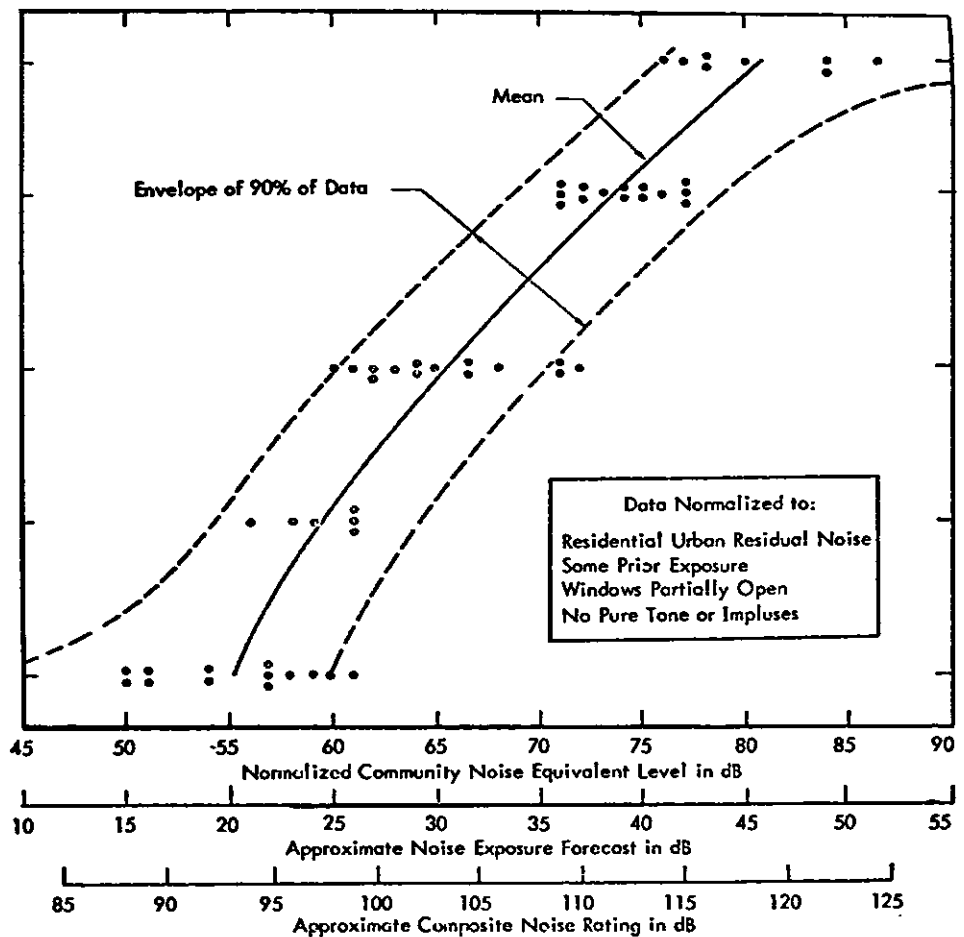
Vigorous community action

Several threats of legal action, or strong appeals to local officials to stop noise

Widespread complaints or single threat of legal action

Sporadic complaints

No reaction, although noise is generally noticeable



U.S. Environmental Protection Agency: Noise from Industrial Plants, Report NTID 300.2. Washington, D.C.

Figure 46-4. Relationship of Normalized Community Noise Levels and Other Human Response Scales and the Expected Community Response. (From Community Noise, U. S. Environmental Protection Agency Report NTID 300.2).

six dB reduction. Thus, a careful examination of the options is in order after the data are assembled.

Once the decision to quiet a given machine is made, detailed sound measurements and a study of the entire machine on a systems basis is in order. The sources within the machine must be identified, the various transmission paths for acoustic energy must be found by both inspection and measurement (acoustical and vibration), the radiators must be located, and finally, the resonators or feedback mechanisms must be found. When this study is completed, it will probably be clear what measures will provide the most noise abatement at the least cost. It may be possible to modify the source, leaving the path and radiators alone, or it may be possible to operate on two, three, or more of the system elements to varying degrees yielding an optimized-cost treatment of the system to produce a specific minimum required noise reduction.

Source Noise Reduction

Intentional impacts are used in forging, shearing and stamping. The desired result is achieved

only by an impact. Source reduction is difficult, although in shearing and stamping, die design and rate of operation do have a major influence on the noise. Also, the nature of the metal being worked strongly influences die design and noise output. Increasing the total time for the actual work on the material will usually reduce the sound output. This may reach a limit when the total stroke time is used for work. Any further change leads to a reduction in output. Many parts of presses and shears radiate the noise unnecessarily. It is possible to enclose partially some automatic presses; and large radiating surfaces, including belt and chain guards, can be damped as described below. The use of plastic shields and snap-out barriers close to the stamping dies should permit a reduction of several dB at the operator's position.

Unintentional impacts can be found by inspecting the clearances with the machine operating with illumination from a stroboscopic light source just off synchronism with the machine. Extreme care must be used not to touch parts that look like they are "standing still." It may be necessary to provide viewing ports or to use

mirrors to make the required inspection, but the results may be surprising. Rods and levers that appear to clear other parts when the machine is "turned over by hand" will whip at high speed with some being in mechanical resonance. Others may just be inadequately designed for the task. Rattling case parts can also be spotted by use of the strobe lamp. The obvious answer is redesign of the part, either using a more suitable section to prevent flexure or better connection at "crank-to-lever arm" connections that whip sideways. Each situation is different, and some will tax the designer's ingenuity. The problem is basically mechanical design, not acoustical.

Gas flow noise sources can often be controlled through the use of mufflers. Mufflers for high pressure lines are made in sizes for pipes from 1/8 inch diameter up to 60 inches in diameter. They can provide extremely large reductions in noise level when correctly designed and made. The sizes from 2 1/2 inches up are often called snubbers and are offered in a wide range of styles including steam and water separator units. Units for compressor inlet and engine discharge are designed to operate in the appropriate temperature range while handling the pulsations encountered in the respective services. These differ from units designed to quiet continuous high pressure supersonic gas flow discharges where a special inlet diffuser section is required. In every case the muffler must be designed to withstand the high forces that occur both on the casing and on the internal baffles and tubing. Also, they must be fabricated from appropriate materials for the service intended.

Small and miniature mufflers find application on production line valve discharges. Spool valves are particularly easy to quiet using small units. The number of unintentional discharges through disconnected lines or bypass valves is surprising. In some cases these can be capped, thus preventing wastage. In other cases slight changes in process control can be made to eliminate the discharge.

Another solution to valve discharges to atmosphere is to manifold the discharge lines to a header which may serve as a muffler because of the large expansion ratio from the inlet pipe to the header. In other cases the collected discharge can be piped away to an outlet where the residual noise will be no problem or a single muffler of appropriate size used.

In some instances it is clear that the use of high pressure air is unnecessary, but it is used because it is available. A pressure reduction device (regulator) at or near the machine can reduce the sound output considerably.

Valve noise in high pressure systems and the noise from centrifugal compressors radiated by the piping can best be eliminated by "lagging" the piping or valve.⁷ The use of a two- to four-inch thick medium density mineral wool or glass fiber "spacer" covered by a one lb./sq. ft. jacket of lead can yield high frequency noise reductions of 30 to 50 dB. Higher reduction values may be obtained, but it is difficult to cover every valve and

pipe support. Actually, flanking transmission usually begins to predominate beyond about 50 dB of reduction. The jacket may be sheet metal or any appropriate weather resistant material providing the required weight. Asphalted roofing felt, leaded vinyl and leaded neoprene have been used in some applications.

The control of perturbations in fluid flow is usually a job for the machine designer. This involves the design and spacing of the fixed and stationary blades in compressors, the blade shape and cutoff design in centrifugal pumps and blowers and fans, and the nature of flow control in positive displacement pumps. In general, these devices lose efficiency rapidly when changes are made from the optimum design. However, casing design to minimize cavitation in pumps can yield lower noise output. Use of pressure equalization chambers, snubbers and mufflers in both liquid and gas systems and lagging have been the accepted methods to date.

In fans and blowers every effort made to reduce the tip speed of the unit does help to reduce noise, but tip speed alone is not an adequate index of fan noise output. Noise in fans and blowers may be increased by having struts or braces in the air stream such that, with axial flow units, the blades cut the wakes made by the obstruction. This can produce intense tones when the blade-passing frequency coincides with the vortex shedding frequency of the air-flow obstruction system. In low pressure air handling systems noise generated by turbulence at turns, dampers and mixing boxes can usually be avoided by good design. However, air conditioning style mufflers can be used. These are usually a series of sound absorbing baffles on six to 12 inch centers. The sheet metal work is relatively light for residential and commercial building use. Special industrial grade mufflers are available, fabricated from heavier gauge metal with better assembly. Here again, material of construction is governed by the environment and the gas handled. These mufflers have sometimes been applied to cooling tower inlets. Cooling tower discharges may be equipped with mufflers, but their effect on the fan characteristics may be so great as to raise the source noise and yield no net effect on the sound output.

One way to eliminate noise is to get rid of the source by modifying the process or system. Many industries faced with problems related to cooling tower noise use wells and return the water to the ground after passing it through a heat exchanger. In many cases local streams used for process water have been used for cooling, but current and proposed restrictions on thermal pollution will keep cooling towers in the picture for some time to come. The use of natural draft cooling towers solves most of the noise and discharge temperature problem, but these are large and costly structures.

A change in design and operation can often effect the appropriate noise reduction, sometimes at a cost in efficiency. In one case, when night operation of one cell of a three cell cooling tower caused neighbors to complain, the electrical cir-

cuits were modified, the motors rewound for two-speed operation and two cells were operated at about half-speed at night. The fan noise varies as the fifth power of velocity and operating two units only brings it back up three dB. This yields a net drop of about 12 dB.

Another case of changing processes is to switch from deep drawing to spinning for fabrication of large objects of circular section. A change from oil fired combustion with high pressure air for atomization and combustion to gas firing with a totally-enclosed muffled burner has been used successfully on single and multiple burner furnaces. Also, the switch from induced draft operation where muffling hot stack gases is difficult, to a forced draft system with inlet mufflers, results in considerable noise reduction. The noise radiation formerly from the top of the stack now takes place at ground level where buildings act as barriers.

Mechanical damping, most familiar as automobile undercoating, can reduce the amplitude at resonance frequencies in a panel or even in structural members, thus reducing radiation and feedback to the source, and in turn, reducing the driving forces. Damping can be effected by applied coatings of mastic or fibrous materials such as jute or wood fibers and foams. Also, friction between two metal surfaces not adhered to one another over their entire surface is used. Air trapped within the space between two plates may provide added damping. The most effective damping may be obtained with a thin layer of elastomeric damping compound between the sheet to be damped, and a thin constraining layer, such as metal foil or a lightweight metal sheet. Although damping is conventionally applied to large metal enclosures, it may also be used to control resonance of gears and sheaves by applying damping to the web or "spokes" as a constrained layer or a filler compound for hollow parts. With some components it may be possible to apply a damping disc or other mating form on one or both sides of a resonant part.

Considerable noise is generated by loose parts, rattling covers, worn bearings, and broken equipment. Reductions on the order of six to 10 dB may be achieved through maintenance alone, and in some cases, spectacular results are possible when cases are resealed or even just screwed back onto the structure.

Transmission Path Noise Control

It is sometimes difficult to determine what part of a system is the source and what is the transmission path. Sometimes the decision is arbitrary. In any case, a muffler may be used along the path or at the end of a line to eliminate not only noise generated at a given machine, but flow discontinuity noise generated at turns, dampers and valves along the way. It is sometimes necessary, especially in the case of high temperature exhausts, to split the muffling between a unit near the engine and one near the discharge. The unit near the engine will reduce the input to the exhaust pipe and minimize the possibility of shock wave formation, and the discharge unit will remove any noise

signals introduced along the way and clean up any small shocks formed. As mentioned above, manifolds are useful for collecting the discharge from several small lines and can act as mufflers. This does not always work because of resonances with the header or manifold. Appropriate baffles and inlet diffusers inside the header or manifold will prevent problems with resonance.

Inside plants, and out of doors, large barriers⁸ and partial enclosures provide considerable attenuation of noise, provided the barrier or enclosure is located close to the source and is not negated by reflections from a wall behind the equipment. Barriers with acoustical material on the surface facing the source with similar material on the wall behind can be quite effective. Enclosures are similar to barriers until they are fully sealed. Fully sealed enclosures provide varying degrees of noise reduction determined by the frequency of the noise and the transmission loss (TL) of the panel material. The TL is generally higher for more massive materials. However, even a one-to-four pound per square foot material such as damped sheet metal or cement asbestos board will yield a reduction in the A-weighted sound levels of 20 to 30 dB. If the seal on an enclosure is broken for ventilation, the TL will be reduced greatly, unless a vent muffler is installed. Such mufflers are produced as standard hardware by several manufacturers who also manufacture complete enclosures, and duct and blow-off mufflers. The vent mufflers may be equipped with fans having explosion-proof motors as required.

The use of acoustically absorbing material similar to acoustical ceiling tile can provide some reduction for interior noises heard out of doors and for some out-of-doors operations such as at loading docks. The materials used for industrial application must be fire resistant and should be applicable to large areas. Spray-on materials were popular for some time, and the recent trend away from asbestos fibers toward open cell urethane foams and cellulose materials should also provide appropriate results. Sheets of mineral or glass fiber board with perforated or decorative open-faced material (expanded metal) are also useful although they require structural support. The perforated metal must have relatively small holes on close centers, typically no more than one-half inch centers and holes from 0.06 to 0.15 in diameter. The holes and spacing should yield an open area of more than 15 percent, preferably 30 to 40 percent. The most effective acoustical materials will have high sound absorption coefficients in the frequency range in which the noise levels are highest. However, good high frequency absorption is usually desirable. For industrial applications it is not sufficient to look at the "Noise Reduction Coefficient" because this is the average of the individual coefficients for the test frequencies 250, 500, 1000, and 2000 Hz, and since the noise to be controlled is in the 2000 to 4000 Hz range (air discharges and cleaning jets), the sound absorption values at 2000 and 4000 Hz are critical to the noise reduction.

An interesting and useful facet of area noise

control with acoustical material is that the entire ceiling and walls of the plant need not be covered. A coverage of 60 percent spread over the entire area of the ceiling is almost as effective as the entire ceiling and usually a lot less expensive. Wall treatment near the source of noise is always effective. Examples have indicated 12 dB reduction at remote locations due to corner treatment close to a machine.

There are some situations where muffling, enclosure, or machine modification are not readily feasible, but moving the machine is quite simple. Moving a small positive displacement blower from one side of a plant building to another can yield 20 to 30 dB reduction at the fence on the side of the building facing its original location. This works as long as the other side does not face a residential area also. This uses the plant as an acoustical barrier. There are numerous applications of this barrier effect, and they are an economical way of accomplishing the desired purpose. It may take some ingenuity. As an example, many plants face highways and other transportation complexes, while the rear faces nearby residential zones. Although routine plant design does not locate major items of equipment along the face of the plant, it may turn out to be a reasonable design; suitable decorative screening is a low price to pay for the acoustical benefit.

Because plant buildings are designed for the protection of employees and equipment from the weather, they often do not include noise control considerations. Louvers, windows and doors may all serve to provide effective ventilation and materials flow. However, they also permit noise flow from the interior to the neighboring community. There is much to favor gravity flow ventilation, and employees in some plants resist the use of mechanical ventilation unless it is accompanied by air conditioning. However, closing up the louvers or using acoustically treated louvers and forced draft ventilation with muffled fans will solve many noise problems. Curtain wall plants using corrugated sheet skins that are not sealed, or damped, may let sound out through both the wall and leaks. Plant design must account for the high noise levels inside and the large radiating area provided by the walls. Also, loading dock and plant storage yards where active materials handling is carried out at night may require some planning in order to control noise. The use of perimeter storage sheds as barriers can effect noise control.

Administrative Procedures for Noise Control

Traffic noise, especially for the end of the second shift and early morning arrival, can readily be effected through an education or training program for the employees. This must be a positive and continuing program and make use of appropriate traffic control systems within the parking lot and around the plant. In some cases the use of multiple exits help. The problem of employees' talk at side yards adjacent to neighboring residential property can also be controlled through a continuing education and internal public relations program.

PLANT NOISE ABATEMENT

A number of sources discussed at the beginning of this chapter require a multistep approach or multielement approach in order to quiet the entire system. Steam power stations, for instance, require noise control of fans, blowers for forced and induced draft, materials handling systems, burner noise in fossil fuel systems, and steam and gas turbines when those facilities are used. Heaters and furnaces in petro-chemical and process industries may require mufflers for the high pressure blowers, cooling blowers and the burners themselves.

Transformers are extremely difficult to quiet internally, although premium transformers are available which provide a modest amount of noise reduction. The most common technique today is to build partial enclosures around the transformers using special sound absorbing concrete blocks which are "tuned" to absorb the transformer generated signals.

Circuit breakers have received moderate attention with respect to quieting, but because they are not activated frequently they should not be a consistent problem. Location in an appropriate area is probably the most convenient method of handling them. Corona noise is currently under study.

Another area in which a multielement approach must be used is in process industries where each machine or process element must be examined for noise generating capability and then quieted according to need. Large mills located inside buildings may cause no community noise problems so long as the building is well sealed. In some cases, the building supports the mill and radiates the noise. On the other hand, rock crushers located within a sand and gravel operation may be totally exposed to the neighbors. In this situation, a partial enclosure of appropriate sound absorbing and transmission loss material combined in one shell would reduce the noise sufficiently to eliminate community complaints. Such materials are commercially available. Items such as switch valves, blow down lines and high pressure air or gas bypass lines should all be equipped with appropriate mufflers.

Material handling devices such as fork lifts, motors, and cranes can be quieted by attention to the engine inlet and discharge mufflers. Electrically operated overhead cranes may require a small motor enclosure with forced air cooling if the unit is to operate out-of-doors at night and not be heard by neighbors. Conveyors are subject to both quieting through maintenance and improvement in bearings, or they may require partial or total enclosure. Conveyors that carry materials adjacent to or through a community overhead, may require a partial enclosure with only the top open.

These are but a few examples of the application of noise reduction techniques to the outdoor noise generators discussed at the beginning of this chapter. However, an examination of each piece of equipment or each process in the larger system or process being studied should make clear

those methods of noise control which are applicable and those which *may* be applicable if the effort is warranted.

FUTURE OUTLOOK FOR INDUSTRIAL NOISE CONTROL

As the citizens in the community become more conscious of noise and more aware of the noise in their environment, it appears that there will be an increasing demand for a quieter environment. Not every community today wants to increase its tax base at the expense of new industrial plants and their prospective noise sources. It thus appears that more stringent noise control requirements currently exist and are becoming commonplace.

In the light of the potential need for more stringent requirements, it is heartening to note that the knowledge in the field of industrial noise control is increasing and that a large body of technology is available to industrial machinery and industrial plant designers to achieve the desired acoustical goals. The payoff is an economic one. It costs money to carry out the design and development work for quieter machines and plants. The cost is not reasonable unless all industries within a given product area are required to meet the same criteria. This is discussed in detail in studies by the Environmental Protection Agency

in its report to Congress. For a discussion of the Environmental Noise Control Act of 1972 as passed by the House of Representatives see the October 18, 1972, issue of the Congressional Record, p. #10287.

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