EVALUATION OF COMMUNITY ODOR EXPOSURE

report of

A Symposium sponsored by the

ENVIRONMENTAL PROTECTION AGENCY

at

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASSACHUSETTS

APRIL 26-29, 1971

Arthur D. Little, Inc.

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Edited by

David A. Kendall
Thomas Lindvall, M.D.

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PREFACE

As a result of the Clean Air Act of 1970, the Environmental Protection Agency (EPA) of the U.S. Government is committed to a program of improving the quality of the air from the standpoint of odorous air pollutants. Both in the U.S.A. and in Sweden research studies have been carried out with the objective of defining the dose-response relationships of odorous air pollution. There is particular concern for the Evaluation of Community Odor Exposure.

In June 1970, a symposium sponsored by the Karolinska Institute took place in Stockholm to discuss Methods for Measuring and Evaluating Odorous Air Pollutants at the Source and in the Ambient Air. Prior to that meeting, the EPA (then the National Air Pollution Control Administration) had undertaken to sponsor a complementary symposium in 1971. Arthur D. Little, Inc., was given the responsibility for organizing this symposium with the cooperation of the chairman and vice chairmen from the Karolinska meeting (Drs. E. R. Hendrickson, Lars Friberg, and John Goldsmith). Mr. Jerry Romanovsky represented the EPA during the initial phases and was assisted by Mr. Richard Dickerson. Mr. David Kendall was in charge of the program for Arthur D. Little.

The meeting was opened with a brief statement of welcome from Dr. Howard O. McMahon, President of Arthur D. Little, Inc., and an introductory statement from Dr. John T. Middleton, Acting Commissioner of the Air Pollution Control Office, EPA. Dr. Lars Friberg was elected chairman of the conference with Dr. Thomas Lindvall and Mr. Kendall to act as reporting secretaries. Drs. Trygg Engen, John R. Goldsmith and E. R. Hendrickson were appointed as panel moderators and group leaders for the working sessions. A list of participants in the program is included with this report. This report is a result of the discussions during the meeting and is based on the prepared working papers. It represents as much as possible the consensus opinion of the participants.

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EVALUATION OF COMMUNITY ODOR EXPOSURE

1. INTRODUCTION

Because of growing concern about living standards, annoyance reactions resulting from exposure to odors have become of increasing importance to advanced countries. The Air Pollution Control Office (APCO) of the U.S. Environmental Protection Agency (EPA) has explicitly stated that airborne odorous substances constitute a threat to the quality of human life at many locations and considers it imperative that they be brought under control under the provisions of the Clean Air Act. However, before an optimum control strategy can be achieved, much more specific information on dose and response needs to be developed.

In June 1970, the Third Karolinska Institute Symposium on Environmental Health (Stockholm) contributed valuable information, with primary emphasis on methodology, and stressed various aspects of the measurement and evaluation of doses. A second conference, held at Arthur D. Little, Inc., Cambridge, Massachusetts, in April 1971, was sponsored by the EPA to deal particularly with the evaluation of the effects of odorous exposure in the community, as well as to review recent studies of dose, response, and dose-response relationships. No attempt was made to replicate the material presented in Stockholm. Therefore, the reader is advised to consider this report as an extension of the Stockholm report (35)* and to review that work.

Both while planning this meeting and currently, the Air Pollution Control Office has been seeking answers to such broad basic questions (3) as the following:

(1) What are the relative contributions to U.S. odor problems by motor vehicles, aircraft, and the most important stationary sources?

(2) What approximate degree of control will be required to abate adverse effects in each of these source categories?

(3) How should emissions standards be stated for each of these source categories?

(4) What reference measurement method(s) should be adapted for emissions from each of these source categories to attain high quality ambient air?

*For this and succeeding references, see the similarly numbered sources listed in the Bibliography.

It was obvious at an early stage of the Cambridge meeting that these questions could be given only very limited answers. This report does, however, hopefully present some clues to underlying problems and their potential solutions. In Section 10 of this report, the conferees have presented formal responses to each of the above queries. These, with the recommendations for research (Section 8) and on the scientific basis for performance standards (Section 9), summarize the consensus of the conferees based on the information presently available.

To present a comprehensive catalog of odor sources would have been beyond the scope of this four-day conference. Even a casual review would reveal that almost every major industrial operation has at some time been accused of being an odor nuisance source although the relative importance of the various odor sources has not been established. Generally considered especially important, because of the number of complaints about them or for other reasons, are diesel exhaust, pulp and paper industries, refineries, meat packing and rendering plants, certain chemical processes, waste disposal, and animal refuse.

Moreover, a systematic analysis of all such sources would have been impossible since, in most cases, factual information is virtually lacking. Thus instead, emphasis was placed on odors from the pulp and paper industry and diesel engines because most of the available information is on these sources. Wherever possible, however, questions concerning dose, response, and dose-response relationships relating to other sources were considered.

At the Stockholm meeting, odor was defined as "The product of the activation of the sense of smell, an olfactory experience," as opposed to the odorous materials (odorants) which activate that sense. This definition also was considered useful when discussing odors at the Cambridge symposium. In addition, it was thought essential to make a further distinction between odorous substances which primarily elicit responses to odors as such and those odorous materials whose major adverse effects on humans are not caused by odor response. Many odorous substances (such as hydrogen cyanide and sulfur dioxide) produce irritant, toxic, or other undesirable effects at concentrations below their sensory thresholds. (For example, high ambient air concentrations of hydrogen sulfide have acute and severe effects on the central nervous and respiratory systems.) They are already controlled for reasons other than odor. In general, therefore, for the purposes of the symposium, odorous substances were defined as those materials whose most common adverse effect is the annoyance reaction caused by the odor itself. The adverse effects and dose-response relationships caused by direct toxic action of particular substances are and, of course, should be considered separately under other procedures, such as those utilized in the Air Quality Criteria Documents for sulfur oxides and oxidants.

2. HUMAN REACTIONS TO ODORS

2.1 Adverse Human Effects

The following types of adverse human reactions to odor in the ambient air are known or suspected on the basis of either laboratory or community studies:

- Disease states, including either causation or aggravation of disease;
- Annoyance reactions, including action taken to abate perceived annoyance; and
- Social and economic reactions.

2.2 Human Effects of Unknown Importance

In addition, several effects of unknown importance have been observed in humans:

- Physiological responses in human populations observed in laboratory studies; and
- Postulated interference with positive reactions to nonambient odors, such as those associated with food, sexual behavior, and avoidance of danger.

2.3 The Sources of Variation in Human Reactions to Odor

Variation in population response to odor exposure is caused by demographic variables (such as sex, age, marital status, income, and occupation) and differences in attitudes toward the pollution source which result in tolerance toward the odors or anxiety concerning the effects on health and property. Annoyance at odor exposure is reported more frequently among those with a propensity toward neurosis, sensitivity to aircraft noise, and displeasure with other aspects of community life. Also, persons who fail to detect or be annoyed by odor could have deficiencies related to clinical conditions, such as upper respiratory infections, as indicated in the Karolinska report (35). The contribution of these "extraneous" factors is probably least when the exposure is very strong (or so weak as to produce no reactions at all), but their effect on dose-response relationships must be taken into account in any report on exposure-reaction relationships.

3. DATA ON ADVERSE HUMAN REACTIONS TO ODOR

3.1 Disease States

The evidence presented at this conference could not demonstrate a relationship between odorous air pollution and the increased incidence of disease states. The work cited below may be suggestive of some relationship; however, questions have been indicated in each case.

The Eureka study (29) suggested the association of headache, sinusitis, and respiratory conditions with odor exposure. However, according to the Karolinska report, the study design was inappropriate to test this possibility.

An Anderson, California survey (7) also showed that the reported frequency of chronic respiratory, headache, and other symptoms was highest in the population living in the area with the greatest exposure to odor. However, the study did not define a disease state, and the reported symptoms could have been related to other atmospheric pollutants or other characteristics of the study populations.

Hyatt has reported that pulmonary emphysema patients have been found to react to exposure to perfumes. (25) Increased frequency of asthma attacks in susceptible individuals has also been described as a result of odor or odorant exposure. (11, 21, 24, 52) However, these reports were not reviewed during this conference. Thus, although none of the data presented at Cambridge demonstrate a correlation between disease states and odorous air pollution, it appears possible that future research might show an association between odorous air pollution and disease.

3.2 Annoyance Reactions

Although their possible long-term medical implications are not known, annoyance reactions have been documented in surveys of communities exposed to odor from pulp mills, manure, oil refineries, and motor vehicle exhaust. (17, 18, 44) Studies near Swedish pulp mills have elicited annoyance reports from 12% to 62% of the population, depending upon distance from the mill. Similar frequencies have been observed in Eureka, California, and in Clarkston, Washington. (33) Annoyance reactions due to air pollution have also been studied in urban areas of the United States, but the distinction between reactions due to odors and those due to other types of pollution has not always been clearly defined. (26)

Annoyance reactions are not easily evaluated. For example, one Swedish study found that the prevalence of annoyance reactions exceeded 20% near an older refinery while fewer than 5% reported annoyance near several modern refineries. (28) However, it is not known to what

extent the lower annoyance reaction ratio was due to reduced emission rates and to what extent to generally more aesthetic plant appearance.

Another form of reaction is petitions and spontaneous complaints. During 1969, the Japanese government received 40,000 petitions concerning a variety of environmental problems; of these, 8,000 were for odor, and a slightly smaller number for other forms of air pollution. (50) (This compares with nearly 18,000 petition complaints received for noise and vibration.)

However, while often the first sign of an important odor problem, petitions and spontaneous complaints are in some countries considered unreliable indices of the importance of the problem. In studies in the vicinity of a Swedish pulp mill, only about 50% of those persons who signed petitions reported annoyance in a subsequent survey. (28)

It has become obvious that, because of the influence of factors unrelated to dose, sociological studies may not yield data which remain valid over long periods of time. Community attitudes towards the source of emission seems to be particularly important. In a Swedish field experiment (42), annoyance reaction frequency caused by aircraft noise was about 50% less in a group preconditioned to have a positive attitude towards the source than in an untreated group. Springer's studies (43) have shown that, for the same exposure of diesel exhaust odor, differences in reaction occur not only between residents of different communities, but also over time. Attitudes towards protection against adverse effects from the environment may change considerably within the next 10-20 years. Odor exposures considered acceptable today may thus become unacceptable in the near future.

Sociologic survey methods thus need to be evaluated to determine the effects of variations in procedures as well as the comparability of annoyance responses measured over time. The impacts of different sampling densities on spontaneous social contacts within the community, and thus on survey results, should also be studied. Regional annoyance surveys have already been conducted to study the effects both of other air pollutants and of noise. The results of community odor annoyance surveys, physiologic experiments, health surveys, and systematic observations of behavior should be correlated and compared to determine the possibility of interaction and common factors.

3.3 Social and Economic Effects of Odor Exposure

It is generally presumed, on the basis of fragmentary information, that odor field is a factor in determining the social groupings within a community and the statuses of different communities. (8) However, there is no conclusive supporting data. Except for differences in property values, measurements of the social costs of odors have not been attempted.

Economic theory suggests that property values may be explained by neighborhood, occupant, and property characteristics. To the extent that odors are perceived as neighborhood characteristics, and to the extent that they are considered objectionable by both buyers and sellers of property, their presence is negatively capitalized into the value of lands and of improvements thereon. The results of studies by Ridker and Henning (38, 39) and Flesh (14) tend to support these premises.

Annoyance surveys have also included measurement of behavior related to social effects. For example, the Eureka questionnaire (29) includes questions about interference with daily activities, complaints to authorities, and various forms of individual action. No validation has been carried out for these measurements.

3.4 Laboratory Experimental Results with Unknown Effects on Human Populations

Studies with human subjects using two odorants, amyl acetate and tetrahydrothiophene, showed consistent changes in respiration rate, heart rate, and galvanic skin resistance and evidence of changes in blood flow. (30) Evidence from neurophysiological investigations in animals indicates that excitation patterns are elicited by the interaction of odorous substances with the olfactory receptors and that these patterns are conveyed to the centers within the central nervous system from which various physiologic effects as well as psychological effects can be mediated. (1)

3.5 Interference by Community Odor with Odor-Dependent Reactions

Odor in the ambient air may interfere with the positive effects of other odors, such as warnings against fire and unwholesome food or water. For example, mercaptans, among other agents, are added to natural and liquefied gases in order to ensure awareness of gas leaks.

4. EMPIRICAL DATA ON ODOR EXPOSURE FROM DIFFERENT SOURCES

4.1 Chemical and Physical

Various control agencies, research organizations, and industrial associations have collected data on odorant emissions at different sources by physico-chemical analyses. The Air Pollution Control Office, EPA, probably has the most extensive catalog of data on odorant emissions from the wood pulping industry (20), refineries, coffee roasting, sulfuric acid plants, nitric acid plants, diesel engines, and incinerators. State air pollution control agencies, which require submission of emission data for permit applications, also have relevant information on file.

Until recently, techniques for physico-chemical evaluation of odorants in the ambient air were scarce and primitive. Advances in trace analysis techniques have now made possible measurement of near-threshold levels of some odorants in the ambient air.

It is believed, however, that source and emission characterizations, which would assist in relating dose to response, would provide more valuable information than simple listings of odorant emissions from various sources. These descriptions should provide guidance in evaluating the usefulness of existing data, in acquiring new data, and in designing models of transport phenomena and for odorant source monitoring and abatement strategies.

4.1.1 Description of the Source

Adequate description of both fixed and mobile odorant sources requires attention to details possibly ignored in investigation of other kinds of air pollution because odor nuisances require only very brief exposure times and very low concentrations (such as trace impurities) to evoke adverse reactions. Moreover, there is strong mediation of receptor reaction to the odor stimulus by attitudes developed or modified by other factors.

In description of an odor source, the particulars on the points of emission must be detailed. (27) Confined sources--those emitted from a specific duct or stack--obviously must be examined with care. The contribution of unconfined sources of odor, whether from such localized points as leakages around valve stems, or from such broad and ill-defined areas as the contaminated soil around tank farms, must also be evaluated. Otherwise, major expenditures on stack control may result in little or no reduction in odor nuisance.

Because of the very short time scale of responses to odors, even the relatively infrequent occurrence of eddies that carry concentrated stack plumes to ground levels can produce major adverse community reactions. Thus, the investigator must be alert to aerodynamic factors.

Neither manual nor instrumental monitoring methods usually have a time-resolution capability adequate to detect brief transients reliably.

In addition to the physical features of the source facility, plant operations and processes must be appropriately described, particularly factors leading to variability in operating conditions, such as annual cycles of product scheduling and the short-term transients associated with batch cycles. Some wide fluctuations may not be controllable by the operator. Examples are the qualitative and quantitative changes in diesel engine exhausts as a function of engine speed and load, sulfur recovery in petroleum refineries, and municipal waste incineration. In the latter cases, the problems created by storing wastes to enable physical control of feed rates may be far worse than those that would be generated by operating disposal facilities at rates higher than their designed capacities.

The extent and nature of interactions between a particular plant's emissions and those from other community sources is also pertinent to evaluation of its contribution to a community problem and to determination of the degree to which control of its emissions would ameliorate odor nuisances.

4.1.2 Characterization of Emissions

Although odorants may be dispersed as gases or condensed as particulate matter, equal distribution of odorous matter between gases and particulates is probably uncommon in hot effluent streams because the partition coefficient decreases with temperature rise. However, some odorants do concentrate in a condensed phase. An example is the solution of phenol in water droplets. In many cases, therefore, gas phase sampling for odorants is valid, but attention must be given to possible condensation or adsorption of odorous matter on particulates.

Odorants may appear to be the same although they differ in concentration. However, Stone found that, with five odors, two samples of the same odorant were just noticeably different in perceived odor intensity if their concentrations differed by at least 20% and in many cases by at least 50%. (49) Therefore, analytical precision may not be essential to the instrumental technique, but sensitivity, specificity, and accuracy must be adequate. Moreover, since the different substances in a given effluent source will differ very widely in their odor intensities and qualities (53), no qualitative chemical identification of the components of an odor source can be considered odor-relevant unless demonstrated by sensory methods.

4.1.3 Analytical Approaches

Complete chemical analysis may be difficult for complex mixtures, and analytical effort might be conserved by assaying only those components that contributed to the perceived odor, a class of components

that contributed to the perceived odor, or a component or class of components that served as an indicator of odor, even though odorless.

The assay of the specific odorant compounds is the most direct and, therefore, the most reliable of these alternatives, but is usually the most difficult because many components may be involved. Caution must be exercised, therefore, to avoid false assignments of odor to irrelevant chemical components by the use of sensory methods.

The second choice, the assay of a class of odorous components in a given source, presents much less difficulty in analysis, but is an indirect and, therefore, inherently less accurate method. Probably the most satisfactory analysis of this kind can be carried out when the odor source is of the character produced by those sulfur compounds in which sulfur occurs in its most reduced oxidation state, -2, as in mercaptans. (48) Another set of odorants which may respond to such a group assay is the highly odorous nitrogen compounds in which nitrogen occurs in its most reduced oxidation state, -3, for example, various amines (RNH_2, R_2NH, and R_3N). Assays of total aldehydes and phenols have been taken as a measure of odors, but the extreme differences in the odor intensities and qualities of these classes would make group assay extremely unreliable in the absence of rigorously demonstrated correlations.

The third possible choice, the assay of an odor indicator which is not necessarily odorous in itself, is apt to be the least difficult, but also the least valid of the analytical choices. When the odor source is derived from a process that involves oxidation, investigators have sometimes sought carbon monoxide, but both theoretical considerations and experimental findings militate against its use as an odor indicator. Another possible indicator, which is particularly easy to monitor, is total organic matter. An odor indicator for readily oxidizable odorants which merits some consideration is the reduction of potassium permanganate. (37) Such an assay might be an appropriate indication, but would not respond to more stable odorants, such as esters. Moreover, non-odorous oxidizable components could interfere and produce spurious results. Any relationship between such an assay and the odor of the source being examined must be demonstrated in the most rigorous manner.

4.1.4 Analysis Before and After Institution of Control Methods

Odor control is sometimes effected by a change that produces a uniform decrease in quantity or concentration of all of the components of the odor source. Examples of such odor control methods currently in use are partial shutdown of operations, adsorption by activated carbon, and incineration. In such instances, analytical methods may need only to be modified to take such quantitative changes into account. However, various new odorants, or new ratios of odorant concentrations may be produced by selective adsorption, partial oxidation, or other processes incidental to the odor control effort.

Other control methods, such as process modification, the use of ozone, chlorine, potassium permanganate, or hypochlorites, or the application of nonreactive agents, such as odor maskants, do not purport to be nonselective. In such cases, the analytical problem after the control method is instituted must be regarded as a new situation, and all of the above considerations as to what to assay must be reevaluated.

4.1.5 Data in the Ambient Air

Except for some compounds studied for other than odorant reasons, relatively few valid observations of odorant concentration in the ambient air have been made until recently. Limited physico-chemical data are, however, available for kraft pulp mills (41), rendering plants and synthetic resin plants. (9, 10)

4.2 Sensory Analysis*

4.2.1 Introduction

In general, sensory analysis is concerned with the hedonic characteristics, quality, and intensity of odorants. Intensity involves so-called thresholds, detectability indices, and suprathreshold intensity and psycho-physical scaling methodology. For purposes of illustration, this report concentrates on demonstrating use of sensory analysis methods related to pulp mills, diesel exhaust, and other odorant sources with which members of this symposium were particularly familiar.

4.2.2 Laboratory Studies

A number of studies by various laboratories on sensory analysis of single odorants have been useful in defining minimal detection levels as well as suprathreshold response of the human nose to a variety of odorous materials. Response to odor also involves quality and hedonics as well as the complex interactions of all three factors. Further research in each area is required to develop laboratory models for possible extrapolation to the air pollution situation.

4.2.3 Empirical Data at the Source

Pulp Mills. Sensory data on odor problems associated with pulp mills are scanty and are only available from a few laboratories. (31, 41) Investigations in Sweden include mapping out odor generating processes, study of various control measures, prediction of odor intensity, and forecast of odor distribution and frequency. To meet these needs, mobile odor laboratories have been constructed for field

*The definitions of sensory analysis and recommended strategies for sensory odor measurements presented at the Third Karolinska Institute Symposium form the basis on which related findings at this conference were built.

studies under controlled and standardized conditions. Use of these air-conditioned, odor-free units has made it possible to limit variations resulting from the ambient background, and their dynamic dosing systems have minimized losses due to adsorption and other factors. These standardized experimental conditions are not, however, necessarily comparable to normal conditions of exposure in the ambient air. Extensive studies on the reliability of the entire experimental procedure have been undertaken. (40)

Diesel Exhaust. Few studies have been made on odorous exhaust products from gasoline-powered cars and aircraft or turbojet-powered aircraft, but a number of ways of measuring and expressing odor response to diesel exhaust have been described in published literature. (References 2, 5, 6, 19, 40, 44, 46, 47, and 54 describe a few.) A Swedish study on gas engines using fuel comparable with that used in the United States shows that this exhaust is detectable at the same concentrations as diesel exhaust. Unfortunately, no data have yet been obtained on the qualitative characteristics of the odor or its objectionability. (16)

Though threshold methods gained popularity for a while in diesel odor research, emphasis now is on the evaluation of odor intensity and quality when diluted to the suprathreshold levels more typically encountered in urban areas. The U.S. Public Health Service Quality-Intensity kit developed for use in diesel odor research in the United States requires a trained panel of observers, housed in a special odor representation facility, to relate the particular exhaust odor to the kit's standard diesel-like odors. (15, 45, 51)

Other. There is little available data on odor exposure at the source for other possible odor contributors to the environment. Studies using the ASTM syringe dilution technique as a measure of odor control have been conducted prior to and after incineration on stack samples from a variety of industrial odor sources, such as glass fiber curing, wire enameling, and auto paint baking ovens and a pulp mill recovery system. (4)

4.2.4 Data in the Ambient Air

Pulp Mills. The odor coverage in the neighborhood of Swedish pulp mills is calculated by a prognosis method which utilizes known source strength of the gas, expected distribution of the gas mass over the investigation area, and observations of its dilution at ground level at different distances from the point source. The source strength has until now been evaluated by absolute odor threshold methods (with some measures possibly obtained by scaling techniques) to determine the frequency with which odors will be discernible at various distances from the plants. (22)

Although odor frequencies may be predicted by dispersion calculations basically like those used for other air pollutants, the sampling time is more critical since olfactory reaction times are fairly fast (at the most half a minute). Studies with the absolute odor threshold dispersion model with very short sampling times show that the concentration of odorous gas may exceed the odor threshold several times during an hour even though the hourly mean concentration is below the threshold. A method based on these principles is currently being used in Sweden to predict ambient air odor frequencies for pulp mills and other odorous sources. (23) Table 1 shows typical results obtained with a panel of trained observers. Near the source, the result of the theoretical computations is in very good agreement with the observations, but with increasing distance there is an increasing discrepancy. This may be due to an inadequate dispersion model, psychological factors, chemical reactions, and/or physical separations within the odorous plume, or it may even be explained as a pure statistical effect. (22, 31) (See also Section 7.1 for discussion of meteorological factors.)

TABLE 1

RESULTS OF A FIELD EXPERIMENT TO TEST A METHOD TO PREDICT ODOR FREQUENCIES WITH THE AID OF SENSORY ANALYSIS AT THE SOURCE AND METEOROLOGICAL DISPERSION CALCULATIONS

Distance from the source	2 km	5 km	10 km	20 km
Total number of observations	6426	7490	5528	6976
Numbers of positive observations	696	736	470	360
Observed odor frequency (%)*	10.8	9.8	8.5	5.1
Predicted odor frequency (%)*	9.1	5.7	3.2	1.7

*"Predicted odor frequency" (number of observations of odor expected per hour) is determined on the basis of dispersion model calculations. "Observed odor frequency" is based on actual observations.

Source: U. Högström, "A Method for Predicting Odor Frequencies from a Point Source," manuscript submitted to Atmos. Environment, 1971.

Moreover, the prognosis of the expected odor coverage, expressed as a mean frequency value over a considerable length of time, does not necessarily reflect the subjective experience of the population. One reason may be that, in addition to frequency and duration of odor exposure, contextual factors, such as adaptation and expectation, affect perception of odors. (32)

Systematic determination of occurrence and magnitude of supra-threshold odor has been reported for the vicinity of two pulp mills in California. (7, 41) A panel of two to four "trained" individuals visits predetermined locations at predetermined times and compares odors with continuously variable dilutions which range to nondetectability. Results are expressed in proportion of observations at which odor is detected and the dilution ratio when odor is present. Odor threshold determinations with methyl mercaptan are given to each subject before and after each day's series of tests. Similar supra-threshold methods may be applicable to other sources, provided a characteristic or single odorant may be chosen.

Diesel Exhaust. The extent to which exhaust is diluted behind and beside a diesel-powered truck or bus before being experienced by the public has been established experimentally. Addition of a tracer gas to the exhaust of a vertical stack-equipped truck and a city bus with a horizontal, below-the-bumper, exhaust pipe made it possible to compare diluted concentrations in the exhaust with atmospheric concentrations. These tracer gas studies and later work (6) indicate a seven-fold increase in dilution of the vertical stack in contrast to the horizontal pipe. (Dosage was also further defined by a small panel of observers in an open sedan.)

Recent pilot studies in Sweden indicate that signal detection methodology seems to be a realistic alternative in dose description when dealing with the contribution of diffuse sources to the ambient air, particularly such generalized pollutant sources as traffic arteries, where the question of frequency is less important. (32) The index of detectability, measured for odor levels in the ambient air in one of the main streets of Stockholm city during rush hours varied in an expected fashion, from 1.0 to 3.0, in relation to variations in the traffic load during rush hours. No significant correlation between odor index and concentration of carbon monoxide was found.

Other Sources. Field studies utilizing a vapor dilution technique (Scentometer) and a sensory evaluation technique ("trained" panelists--reference standard as described by Turk and Mehlman) (55) on odor in the ambient air from a variety of sources have been described. (36)

The extent of perceptible odors in seven American Cities (Table 2) was observed according to type of industry or major product. According to this study, refinery installation and chemical facilities were found to be the most significant sources of odor emissions from the viewpoint of range. Odorous areas in the selected cities were mapped to indicate their extent and intensity.

Sensory evaluations were carried out by a panel in the Philadelphia area on ambient odors from an oil refinery complex and adjacent meat rendering plants. The panel, consisting of 18 women, was given intensity training with reference standards prior to the observations. Results of this field survey are expressed in terms of dispersion

patterns for each observation period, utilizing two types of contours: (1) the main intensities of the observations of the individual panels; and (2) the percent of the total observations of each individual in which odor was perceived. (36)

TABLE 2

AREAL EXTENT OF PERCEPTIBLE ODOR
TWO-DAY TECHNICAL FIELD INVESTIGATIONS

Summary of Observations in the Principal Cities
of Seven Metropolitan Areas

Type of Industry or Major Product	Number of Observations	Areal Extent (square miles)	
		Average	Range
Refinery	3	10	1.5 - 23
Agricultural Chemical	1	6	-
General Chemical	3	5	0.6 - 8.4
Polluted Bay	1	4	-
Sewage Treatment	1	2.5	-
Granary	1	2	-
Electrical	1	1.7	-
Tall Oil	1	1.25	-
Meat Packing	1	1	-
Rendering	4	0.8	0.2 - 1.3
Paint and Varnish	1	0.4	-
Tanning	1	0.1	

Source: Engineering-Science, Inc. (36)

5. DOSE-RESPONSE RELATIONSHIPS

Dose is here defined as a concentration of odorant substance(s) as measured by chemical, sensory, or other analyses; and response, as adverse effects within an exposed population. Only a few points are known on the dose-response curve for certain odors--for annoyance around pulp mills and experimental response to diesel exhaust. As noted above, in a Swedish survey, 12% to 62% of the population (depending on distance from the plant, within a radius of about 10 to 15 miles) reported annoyance reactions. Odor threshold studies were not carried out in this community at the same time, but studies at another time indicate that odor strength, as measured by dilution of stack gases, would correspond to a dilution factor of about 10^5 times above threshold.

In the Eureka studies (29), annoyance reaction and odor threshold determinations were made in addition to chemical measurements in three areas at different distances from the plant. The chemical measurements did not show distinctive differences in odorant levels among the areas, but the frequency of annoyance reactions and the frequency and magnitude of suprathreshold odor detected by the method used (Sanders) did discriminate among the three areas with presumptively different exposure. However, it is not possible to use these data for a quantitatively exact statement of a dose-response relationship. (41)

Various levels of diesel odor, defined in terms of the U.S. Public Health Service Quality-Intensity kit, were presented to over 5,000 quota-sampled Americans in a mobile odor testing laboratory during 1969 and 1970. Participants indicated their response via identification with five cartoon figures that depicted different stages of odor objectionability from "pleasant" to "unbearable." This survey with controlled odor exposure resulted in a type of dose-response curve that could be used as a base for estimating what effects various levels of odor control would have on relative annoyance as expressed by a large population. (19, 44)

The data now available from long-term community studies do not show how much any adverse reaction within the population would change if the exposure were doubled or halved. Moreover, epidemiological data refer only to particular situations, and emitted gases can differ widely in composition from one plant to another and from time to time.

It would seem possible to carry out epidemiologic studies which could give more or less complete dose-response data for pulp mills or any other well-defined point source. Then expected magnitude of changes in response could be predicted for alterations of dose by certain factors for that source. The dose could be evaluated either by chemical or sensory analysis of stationary source emissions in combination with meteorological dispersion models, or by direct chemical or sensory analysis of the dose in the ambient air. Because of the difficulties

in obtaining valid measurements in the ambient air, the first approach to dosage estimation seems to be the more promising one for guidance of control strategies at present. The lack of valid dose-response data does not prevent use of the best practicable means for the guidance of certain air pollution control strategies while awaiting more exact procedures.

6. INTERACTION BETWEEN ODOR SOURCES AND OTHER ENVIRONMENTAL CONDITIONS

Two important problems are the classic effect of mixing odorants and related environmental conditions, particularly the impact of aesthetic factors.

6.1 Odorant Interactions

If one mixes odorants A and B, several alternative odor effects are possible: (a) the odor intensity of the mixture may be perceptually stronger than the odor intensity of either component; (b) the odors may cancel each other so that the mixture is odorless; (c) one of the odors may mask the other, so that its odorant provides the dominant quality of the perceived odor; (d) synergistic effects may result in one of the odors being stronger in the mixture than by itself; and (e) if the odorants are mixed successively, the odor intensity and quality of the second odor may be decreased or altered due to cross-adaptation or conversely, it may be facilitated (that is, seem stronger) through addition of the second odorant to the one already present in the olfactory system. The importance of being able to predict such effects for different mixtures in different environments is obvious. Unfortunately, almost no data are available on any of these forms of interaction beyond the findings from a few debatable laboratory studies. The problem of interaction thus represents a most important area for future research.(12)

6.2 Environmental Interactions

The effect of other environmental situations on the perception of odors is similarly an important research target. The potential effects of temperature, humidity, atmospheric pressure, and individual and social factors remain largely unexplored.

6.3 Psychological Interactions

The most important consideration might be the interaction of learning or experience and odor perception. Psychologists have repeatedly stressed the extent to which prior bias, either for or against an alleged odor source, can influence the emotional response to an odor dosage. Thus any other aesthetic insult from the source, whether in the form of visible emissions, noise, vibration, or glare, or even such non-specific factors as disorderliness or distasteful plant architecture, may largely negate any potential decrease in community annoyance from reduction in odorant dosage, however, achieved.

It has been established that the presence of visual cues, such as smoke, may increase the frequency of reports of the perception of odor. (13) It is not clear at this time whether such results can be explained as evidence of biased responding or of keener odor perception because of sensory input from another modality and thus increased attention and awareness (similar to facilitatory effects). (56) In any case, a visible emission, because it is viewed as an air pollution contribution, does appear to be a particularly potent evoker of negative emotional response. If a visual plume has been identified by the public as an odor source, a major reduction in odorant emissions unaccompanied by a corresponding reduction in plume visibility may fail to diminish the community resentment which may still be expressed as an "odor" annoyance. Awareness of these aesthetic factors by control agencies and by industrial managements can do much to minimize the frequency with which constructive abatement programs fail to secure the community appreciation and support that they deserve.

7. TEMPORAL PATTERNS

7.1 Meteorological Considerations

When discussing temporal patterns of odor in the surroundings of a source, it is necessary to distinguish between point sources and area sources -- the variation in odorous impact at a fixed observation point being very much larger for a point source than for an area source (provided its output of odorous compounds is constant over time). Because temporal variations in odorous impact are due to corresponding variations in meteorological factors it is, in principle, possible to predict the variations in odor if there is enough information available regarding (1) the relevant dispersion mechanism and (2) the local dispersion climatology. Concerning the dispersion mechanism, an extensive literature has developed, particularly over the last two decades. A comprehensive summary of the present status of the art is given in Meteorology and Atomic Energy, 1968 (34).

In typical temporal odorous patterns in the surroundings of a point source, odors are experienced in episodes, usually about one to several hours long. During such an episode, the odor may be continuous if the odorous source strength is high enough, but it is more likely to be discontinuous, which means short-term variations in the concentration of odorous compounds around the odor threshold. The odor threshold may be exceeded only during a minor portion of the time. Such rapid variations which are inherent in the atmospheric dispersion process are well borne out by a field experiment in the surroundings of a pulp mill in Sweden. (31) It is reasonable to believe that the perception of odor for such an episode within a population is somehow related to the detailed structure of the episode, but this has not been investigated so far.

The feasibility of predicting the absolute frequency of perceptible odor cycles in the surroundings of a point source on the basis of sensory analysis of the chimney gases and dispersion calculations has been demonstrated. (See Section 4.2.4.) The success of the calculations depends largely on the effect of local wind flow patterns on the fluctuating plume model. A dynamic flow pattern model like one being developed for Oslo, Norway, for air pollution in general might provide a practicable solution for some cases. (23) The absolute perceptible odor frequency concept may not be ideally related to the perception of odor within a population living in the surroundings of a point source. But if it is possible in the future to establish a description of instantaneous changes in dose concentration, this could be included in a dispersion model. Such a dose description could, for instance, be in terms of the percentage of time in which the concentration exceeded the odor threshold and could be generally experienced as "an odor episode".

7.2 Sensory Considerations

Perception of temporal patterns has up to now mainly considered problems of temporal integration, adaptation, and recovery. Important data are still lacking on how frequency and duration of odor exposure are perceived in the ambient air. Thus field research, as well as laboratory studies in this area, are strongly recommended. The determination of temporal patterns obviously requires sampling over time on a systematic basis. In the Eureka and Anderson studies (7, 29) observations by olfactometry were made systematically over a period of several weeks and at intervals of from one-half hour to one hour. In both cases, measurements were limited to the hours of the day when pollution was expected to be greatest on the basis of meteorological and topographical variables and to several weeks of the year when pollution was greatest.

8. RECOMMENDATIONS FOR BASIC AND APPLIED RESEARCH

The following recommendations related to the need for basic and applied research were developed through discussions at the symposium:

8.1 Of the many effects postulated to result from odorous air pollution, two--the perception or detection of odor and the degree of annoyance response as a result of this odor perception--cannot be refuted. The major weakness of current knowledge is that the bulk of systematically obtained information deals only with exposure from two sources, pulp and paper plants and diesel vehicles, using a standard odor measurement technique.

Odor perception of emissions from a variety of other sources, such as petroleum refineries, rendering plants, petrochemical plants, paint and varnish plants, and most importantly gasoline and aircraft engines, should be evaluated. In addition, possibly concurrently, methods should be developed to measure the degree of annoyance produced by these various types of odor exposure. The difficulty of accomplishing this scientifically should be recognized, and such studies should be carefully designed.

8.2 As a potential alternative to measuring annoyance, physiological changes should be studied to determine the dose-response relationships associated with odor perception so that alternative criteria may be developed as indicators of response to odors.

8.3 Further work should be carried out to explore the possible effects of odor exposure in aggravating certain pathological effects, particularly respiratory ailments.

8.4 A systematic comparison of methodological approaches to sensory measurement should be carried out to develop a preferred method(s) for measurement of odor in ambient air and at the source.

8.5 Recent developments in physico-chemical methods for analysis of odorants at the source and in the ambient air have resulted in greater confidence in their usefulness. Their application, however, can only be successful to the extent that they can be correlated with detectability or perception of odor and with the resulting annoyance reaction. There is a need for development of instruments of improved specificity and sensitivity which can be correlated with observations of odor detection and annoyance reactions. In addition, it would be desirable to investigate the possibility of developing nonspecific indicators of odor. It would be helpful to determine whether there are acceptable indices of odorant mixtures, such as the concentration of total reduced sulfur which has shown some promise.

8.6 It would be useful to define and elaborate the mechanisms of odorant transport and emission interactions which occur in the ambient air and result in changed odorant form or composition and, thus, a different odor exposure from that experienced at the source.

8.7 Further work on the economic costs of odor pollution would be of value in determining pollution control strategies. The cost of control must be given serious consideration, and the cost of odor pollution is not well documented.

9. SCIENTIFIC BASIS FOR PERFORMANCE STANDARDS

A firm scientific basis for establishing performance standards requires that each odor problem is clearly defined in terms of degree of annoyance produced, the size of the population exposed, frequency and duration of the events, the extent and nature of emissions, and the relationship of cost of control to its cost benefits. In order to establish emissions limits on a firm scientific basis, one must have substantially more information on the specific quantities of odorants and the types of odorant chemicals involved, as well as knowledge of how much reduction in concentration is required to produce significant changes in the degree of annoyance, in the number of people affected within an exposed population, and the total size of the exposed population. Even though it is not possible to establish standard controls now for the whole range of emissions that produce significant annoyance reactions, specific controls could be established for the most highly odorous, objectionable, and persistent odorant chemicals which can be detected at very low concentrations.

Data necessary for an adequate description of levels of odor in ambient air can be obtained through the use of human sensors (many untrained or a few trained individuals) to conduct consecutive observations of odor occurrence within a given area for a fixed period of time. Possibly such panels could be aided by a simple dilution device, such as a scentometer, which, if suitably calibrated, might serve as a supplement to more rigorous sensory studies. Used alone, however, results from such devices lack the validity needed in odor research. Generally a sophisticated study design is necessary to obtain data of value from the viewpoint of public welfare.

Another approach is to interview the resident population to find out their retrospective opinions concerning the average odor frequency and duration of a smell. One difficulty of this method is ensuring that answers reflect actual experience during the period under study. Also, the degree to which respondents may unconsciously exaggerate or depreciate the frequency of exposure as a result of negative or positive attitudes is not known.

For well-defined point sources, indirect evaluation of ambient air dosage based on a predictive type of method can be useful. Sensory intensity analyses at the source, supported by physico-chemical measurements and calculations, may be used to predict the frequency with which odors should be discernible in the ambient air at various distances from the source. In the dose desecription step required before establishing dose-response relationships in a single-source case, predicted odor frequency may be considered an adequate alternative to survey methods and direct measurement in the ambient air.

For ambient air measurements of odor caused by surface sources, signal detection methods are suggested to obtain an idea of the intensity with which odors are experienced. Detectability indices of this kind

do not measure perceived intensity above the barely perceptible level, but do provide valuable information regarding source control and the distribution of odorant emanations in the atmosphere.

Practical experience has also shown the value of modern psycho-physical scaling, based on standard references suitable for the specific odor, for ambient air measurement of surface source odors. No general odorant reference standard can be recommended for all types of odor studies. In each case, the reference should be chosen on the basis of a pilot project.

In technological evaluations, suprathreshold perceived intensity and quality are of interest since they concern changes in perception associated with reduction in the physical odor intensity. In studying intensity of odor, one should preferably use modern psycho-physical scaling methods.

10. CRITICAL QUESTIONS

In light of the proposed method of approaching the control of odorous air pollutants, Dr. Barth submitted for the conferees' consideration four critical questions. (See Section 1.) These were discussed by the working group in plenary session on Thursday, April 29, and the consensus responses appear in the following paragraphs.

10.1 On the basis of data available to the conferees, it is not possible to develop the requested specific ranking of the relative contributions to U.S. odor problems by motor vehicles, aircraft and the most important stationary sources because:

- Considerable variations in relative odor contribution can be expected in different local or regional jurisdictions. (In large cities, transportation odors may be deemed the major source of odorous emissions, while in a small mill town the carbon disulfide associated with rayon manufacture may constitute the overwhelming problem.)

- Certain process operations, regardless of manufacturing category, may constitute a problem where other factors, such as the local topography and meteorological conditions, act to augment the situation.

Thus, it would appear more practical to develop rank orderings of importance of various sources for specific local or limited regional areas.

However, to provide a rational basis for establishing such priorities, APCO should promulgate guidelines to assure uniform evaluation. The weighting of such factors as the numbers of people exposed, the frequency and duration of exposure, the relative strength and severity of probable exposure, and the objectionability or frequency of annoyance indicated by the affected population should be considered in measuring the odor contribution. Through application of such guidelines at local or regional levels, it may be possible to integrate the resultant local priorities to develop a national priority statement if this is desired.

10.2 It is not possible to state categorically the degree of control required for abatement for a given type of source since there are considerable variations within groups, both in odorant concentration and complexity. Because of the nonlinear relationship of odorant concentration to perceived odor intensity and objectionability, it is probable that control measures will require measurement of reductions in exponential terms rather than in terms of percentages.

10.3 Ultimately statement of standards of performance or emission standards for each source category will require an administrative decision formulated on the basis of definitions resulting from the best available technology. Ideally, standards for a maximum emission should be expressed in terms of odorant or odorant class per unit volume for some percent of time (i.e., ___ mg/m^3 for ___ hrs/month). The maximum emission rate should be based on the dilution required to attain a perceived odor intensity defined in terms of standard sensory measurement procedures. Examples of such standards are available from Sweden (1, 44) and similar principles have been followed in California.

10.4 Reference measurement methods, including present technology, were reviewed by the Cambridge conference report, and the recommendations summarized in Section 9 of this report represent the consensus of the working groups on applicable methods. The needs for further basic and applied research on odors where adequate information is not available are discussed in Section 8.

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