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a critical review of
REGULATIONS FOR THE CONTROL OF ODORS

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The APCA Critical Reviews Program is designed to stimulate thought and discussion on major issues of concern in air pollution control. It is in this spirit that this critical review is presented.

In the absence of federal regulations on odorous pollution, the development of odor control regulations has been left to state and local (regional, county, or municipal levels) air pollution control agencies. With the increased pressure by the public over the recent past to do something about pollution in general and odor pollution in particular, a variety of odor control regulations have come into being. Odor is the most "visible" form of air pollution in that it can be perceived through the sense of smell that we all possess. In spite of the fact that everybody has the equipment to sense odor, the measurement of odor in the air pollution situation is poorly understood. Although there is continuing controversy as to the extent to which odorous pollutants must be controlled, there is little or no argument that odors can be controlled.

Since the purpose of the critical reviews is to stimulate discussion, the approach we have taken is to survey the odor regulations that exist at the federal, state, and local governmental level. The latter are not exhaustively surveyed and only selected examples are given. The existing regulations can be classified into approximately nine types.

In reviewing the existing regulations, it became evident that their rationale was based on essentially five papers that found their way into the literature during the mid-1950's to the late 1960's. Our intent in highlighting these papers is to bring before this audience the rationale that has formed the basis for the existing regulations.

Since the problem of odor control regulations revolves around the issue of how odorous air pollution is measured, we have highlighted two symposia that were held in the early 1970's to discuss this issue and have included some recent developments in the measurement of odor pollution which in our opinion have an important bearing on this issue.

The basis for the control of odor should be sound measurement techniques. Unfortunately, the existing techniques upon which the regulations are based, at best, give only partial answers while, at worst, may seriously underestimate the problem.

Survey of Odor Control Regulations—1974

Federal Regulations

At the present time, there are no federal regulations for the control of odors. Odors have been classified as non-criteria pollutants by the Environmental Protection Agency.[1]

State and Local Regulations

Copley International Corporation[2] has reported in considerable detail the odor control regulations of 203 state and local air pollution control agencies that existed in the fall of 1971. In that study 256 agencies were contacted. Barth[3] and Prokop[4] have also reviewed regulations of state and selected local agencies. As these reviewers had indicated that a number of states had pending proposed regulations for the control of odors, an independent mail survey of all state agencies and selected local agencies[5] was carried out in early 1974 to ensure that the information is up-to-date. Of the 50 states, only Indiana and Louisiana failed to respond. The various regulations for the control of odors of the states including the District of Columbia and the Bay Area Air Pollution Control District, California are summarized in the Appendix. A cautionary note is appropriate here in the use of the information presented in the Appendix. The regulations have been condensed and it was the author's intent because of space considerations to prepare a concise summary of the essential points and statements contained in the various regulations in precis form. Where we have failed, an apology in advance is due.

52 Odor Control Regulations

The regulations of the 52 agencies listed in the Appendix may be classified into the following nine general types:

- No specific regulations.
- Air pollution/nuisance regulations.
- The use of certain criteria to determine objectionability of an odor in the ambient air.
- Scentometer measurements by control officials in the ambient air by measuring dilutions to threshold (D/T). Violations occur if stated D/T's are exceeded usually within specified time periods.
- The use of the highest and best practicable or reasonable and suitable control system is required at the source.

- Source emissions standards specifying the concentrations (as odor units/ft^3 or odor concentration units) of odor that are not to be exceeded. These are based on the syringe dilution technique.
- Regulations based on instrumental analysis at the source or in the ambient air.
- Control regulations that serve as statements of policy for handling odor problems.
- Both source and ambient standards specified.

Many of the agencies have incorporated one or more of the above listed types into their regulations.

No Specific Odor Regulations

The 16 agencies with no air pollution regulations that are specific for odor include Arizona, Georgia, Hawaii, Indiana, Iowa, Kansas, Louisiana, Maine, Nebraska, New Mexico, North Dakota, Oklahoma, South Carolina, Tennessee, Utah, and Washington. Although Washington has no specific regulations for odor control, the nine regional district authorities do have odor control regulations of which selected examples are described in a later section. Hawaii, Kansas, and Oklahoma indicated that odor problems can be handled on a public nuisance basis. It should not be construed that these states allow odorous pollution. Several of these states are actively seeking to promulgate odor control regulations.

Air Pollution/Nuisance Regulations

The 17 agencies that control odors which create a condition of air pollution or nuisance include Alabama, Alaska, Arkansas, California, Florida, Illinois (inedible rendering odors only are controlled by source and ambient odor standards), Maryland, Massachusetts, Michigan, Mississippi, Montana, New Hampshire, New Jersey, New York, Ohio, Rhode Island, and Texas.

The wording used can be quite varied as indicated in the Appendix. These can range from New Jersey's (No person shall cause . . . to be emitted into the outdoor atmosphere substances in quantities which shall result in air pollution); Montana's (No person shall cause the emission of gases, vapors, or odors beyond the property line in such a manner as to create a public nuisance); Florida's (Objectionable odor prohibited: Objectionable odor defined as any odor . . . that may be harmful or injurious to human health and welfare, which unreasonably interferes with the comfortable use and enjoyment of life and property or which creates a nuisance) to New Hampshire's (create a disagreeable or unnatural odor). The philosophy is based on the nuisance concept and codifies this concept into air pollution control rules and regulations. The intent apparently is to control odors that are perceived to be nuisances, malodorous or objectionable by a considerable number of persons.

Objectionability Criteria

Six states have based their regulations (either wholly or in part) to control objectionable odors in the ambient air. The various criteria that can be used for deciding when an odor is objectionable are:

Connecticut—A staff member of the state agency determines, following personal observations, that the odor is objectionable taking into account its nature, concentration, duration, and location (also has two other criteria: an ambient analytical standard and a source odor emission standard).

Nevada—An odor shall be investigated when 30% or more of a sample of people exposed to it believe it to be objectionable in usual places of occupancy, the sample size to be at least 20 people; or 75% of those exposed, if fewer than 20 people exposed. Scentometer is then used to determine if a violation has occurred.

South Dakota—Upon receipt of 5 complaints of objectionable odor or earlier, complainants and/or occupants are investigated by interview to determine if violation occurred. An odor is deemed objectionable when a majority of a panel of 5 (up to two Commission members and the remaining members from the Department of Health) exposed to the odor determine that it is or tends to be unreasonably injurious to human health or welfare, animal or plant life, or would unreasonably interfere with the enjoyment of life or property.

Vermont—An objectionable odor shall mean those odors deemed objectionable by 15% or more of a sample of 20 people exposed to them. For samples of 4–20 individuals (not from the same household), 75% must deem it objectionable.

West Virginia—In addition to odors generally recognized as being objectionable, an odor shall be deemed objectionable when in the opinion of a duly authorized representative of the Air Pollution Control Commission, based upon his investigations or his investigations and complaints, such odor is objectionable. No person shall cause . . . the discharge of air pollutants which cause or contribute to an objectionable odor at any location occupied by the public.

Wisconsin—An odor shall be deemed objectionable when either or both of the following tests are met:

1. Upon the decision resulting from investigation by regulatory authority based upon the nature, intensity, frequency, and duration of the odor as well as the type of area involved and other pertinent factors.
2. Or when 60% of a random sample (consisting of at least 9 persons selected by the regulatory authority) of persons exposed to the odor in their place of residence or employment, other than employment at the odor source, claim it to be objectionable and the nature, intensity, frequency, and observation of the odor are considered.

Scentometer Based Regulations

The seven agencies that have adopted the Scentometer approach to regulatory control of odor have set standards at the seven dilutions to threshold level, especially for residential-commercial areas (Table I). Huey[6] stated that *experience has been* that odors in the ambient air above 7 D/T (dilutions to threshold) will probably cause complaints while those above 31 D/T can be described as a serious nuisance if they persist for any length of time. This would apply to all odors and utilizes odor strength (as measured by dilutions to threshold) as the criterion. The attractiveness of this technique to regulatory agencies appears to be that only one person need make the observation, thus enforcement (determination of a violation) is simple and inexpensive. The table also indicates specific points in the regulations concerning time constraints (how often and within what period of time the observations should be made), and the number of observers required to make the observations. Although Minnesota is included in the table, it should be pointed out that the syringe dilution technique with 6–8 observers is specified. However, Prokop[4] has reported that in Minnesota (based on the syringe dilution technique), the ambient odor limits set are basically unenforceable and the stack emission standards are being used to determine compliance.

Colorado, Illinois, Missouri, Wyoming, and Nevada require that two determinations within 1 hour separated by 15 minutes be carried out while Kentucky and District of Columbia do not specify this. The Illinois Scentometer rule (for rendering odors only) specifies that three inspectors are required and that for a violation to occur at least two of the three must agree on each determination. The other states do not specify the number of observers and it may be assumed only one is necessary. Colorado requires that inspectors be selected by use of an intensity rating test. Colorado also stipulates that a violation does not occur when the two lower Scentometer readings are exceeded if the best practical treatment, maintenance, and control currently available is utilized in order to maintain the lowest possible emission of odorous gases. Nevada's regulation is unique among state agencies in requiring that objectionability criteria be met before the Scentometer is used to determine violations. As discussed

Table I: States with regulations based on ambient odor limits.

State	Type of area	Ambient odor limits[a]	Frequency-duration constraints[b]	No. of observers	Dilution device
		X			
Colorado	Residential-commercial	7[c]	Yes	n.s.	Scentometer
	Other	15[c]			
	All areas	127			
District of Columbia	n.s	1	(separate complaints of 3 or more persons required)		Scentometer
Illinois	Residential-institutional	8	Yes	3[d]	Scentometer
	Industrial	24			
	Other	16			
Kentucky	n.s.	7	n.s.	n.s.	Scentometer
Minnesota	Residential-institutional	1 odor unit	n.s.	6–8	Syringe dilution
	Light industrial	2 odor units			
	Other	4 odor units			
Missouri	n.s.	7	Yes	—	Scentometer
Nevada[e]	n.s.	8	Yes	n.s.	Scentometer
Wyoming	n.s.	7	Yes	—	Scentometer

[a] Expressed as dilutions (1 part odor: X parts odor free air).
[b] Two observations to be made within 1 hour separated by 15 minutes.
[c] No violation if best practical treatment, maintenance and control currently available is utilized.
[d] Two positive determinations in each series of three determinations required.
[e] Also has objectionability criteria.
n.s.—not specified.

Table II. States requiring odor control equipment.

States	Industry(ies)	Pretreatment	Incineration conditions	Incineration equivalent
Idaho	Reg. Q rendering	Condensation	>1200°F, >0.3 sec	No
	Reg. K other	Techniques approved by the agency		
Maryland	Reduction of offal and veg.	Condensation <160°F	>1400°F, >0.4 sec	Yes
Minnesota	Rendering	No	>1500°F, >0.3 sec	Yes
Montana	Rendering	No	>1200°F, >0.3 sec	Yes
	Other	"Control devices as specified by the director"		
North Carolina	All odors	Must use suitable control measures approved by the board		
Oregon	Rendering	Yes	>1200°F, >0.3 sec	Yes
	Hardboard tempering oven		>1500°F[a], >0.3 sec	No
	Other	Highest and best practicable treatment and control required		
Pennsylvania	16 processes	No	>1200°F, >0.3 sec	Yes
Vermont	Industrial processes	No	>1600°F, >0.5 sec	Yes
Wyoming	Rendering	Yes	>1200°F, >0.3 sec	Yes

[a] May be lower if odors shown not to be perceived beyond property line.

in a later section, a number of local agencies have combined objectionability criteria with the Scentometer findings.

Highest and Best Practicable Control

Nine states have regulations that require controls on specific industry sources. Usually these are expressed in terms of an incineration or equivalent control standard. Pennsylvania under 123.31 Section *a* (1) and (2) requires that "emissions from 16 specified industrial sources must be incinerated at, at least 1200°F for 0.3 second prior to emission to the outside atmosphere. Techniques other than incineration may be used to comply if it is shown to the satisfaction of the department that such techniques are equivalent or better than the required incineration in terms of control of odor emissions. Section *b* prohibits emissions into the outdoor atmosphere of any malodorous air contaminants, from any source whatsoever, including those in compliance with provisions of the above Section *a*, in such a manner that the malodors are detectable beyond the property line."

These states generally prohibit consideration of dilution and/or masking as control methods for odor. Virtually all of these states require the incineration or control standard on inedible rendering operations with Idaho, Montana, North Carolina, Oregon, Pennsylvania, and Vermont applying it on a wider basis. Table II summarizes the states utilizing the incineration or equivalent control approach, wholly or in part, the industries covered, and the minimal temperature and residence time required for incineration. There is considerable variation among these agencies in this latter aspect.

Source Standards Based on Sensory Methods

Three states—Connecticut, Minnesota, and Illinois—have stack or source odor emission limits relying on sensory methods of evaluation (Table III).

Minnesota, in addition to setting odor concentration limits at the source that are dependent on dispersion characteristics, has also included an odor emission rate that is not to be exceeded. All of these are based in part, on the work by Mills.[7] The Illinois rule applies when more than one rendering source may be emitting odor. As mentioned earlier, Scentometer readings are taken in the ambient air.

Analytical Measurements at the Source or in the Ambient

The Bay Area Air Pollution Control District (California) promulgated an odorous substances regulation effective August 2, 1973, that represents a new approach to regulating odor. (Division 15—Odorous Substances Chapter 1). The regulation sets a maximum allowable emission of 5 odorous substances (see Appendix) measured at a well-defined emission point (Type A) such as a stack or vent or a diffuse source (Type B) that is essentially a ground level emission. It is anticipated that additional substances will be added.[8]

Table III. Source odor emission standards—by state.

State	Standard	Method
Connecticut	<120 o.u./ft³	Mill's A.S.T.M.
Illinois	<120 o.u./ft³[a]	Mill's A.S.T.M.
Minnesota	<150 odor concn. units[b] <25 odor conc. units[c]	Sampling and presentation, ASTM D 1391-57 panel test by Benforado
	<1,000,00 o.c u./min[d]	

[a] For inedible rendering only.
[b] For sources 50 ft or more above grade and adequate dispersion characteristics.
[c] For sources less than 50 ft above grade or otherwise failing to create good dispersion conditions.
[d] Odor emission rate = scfm × no. of o.c.u. for the source (odor concentration units/minute).

Several state and local agencies have promulgated TRS (total reduced sulfur) source emission rules for the control of odorous emissions from the kraft pulp mill industry (Table IV). Total reduced sulfides includes such chemicals as hydrogen sulfide, methyl mercaptan, dimethyl disulfide, dimethyl sulfide, and any other organic sulfide compounds measured analytically as hydrogen sulfide. These are thought to be the major components associated with kraft mill odors.

Connecticut, in addition to other criteria, has an ambient analytical standard. An objectionable odor occurs when it can be demonstrated by analysis of the ambient air, for any period of time, that the recognition odor threshold concentration of 53 listed odorant chemicals is exceeded.

Control Regulations that Serve as Statements of Policy

Two states—Delaware and Virginia—have regulations that appear to be statements of policy for handling odor problems. Delaware's Regulation XX (proposed) states:

Regulation No. XX—Control of Odorous Air Contaminants

Section 1. General Provisions

1.1 The purpose of the Regulation is to control odorous air contaminants which significantly affect the citizens of the State outside the boundaries of the air contaminant source.

1.2 Methods for determining a condition of air pollution due to an odorous air contaminant may include, but are not limited to, Scentometer tests, air quality monitoring, and affidavits from affected citzens and investigators.

Section 2. Requirements

2.1 No person shall cause or allow the emission of an odorous air contaminant such as to cause a condition of air pollution.

Table IV. Comparison of rules and regulations to control odors from Kraft pulp mills.

Location	Total reduced sulfur rule[x]	Rule equivalent in lb/ton pulp	Source regulated	Averaging interval
Humboldt County APCD	a) 0.012 (Stack height)[y] lb/day or 60 ppm	a) 1.7 lb/ton pulp (Crown)[y] 1.4 lb/ton pulp (L.P.)[y]	a) Any single point	a) One day
	b) 0.8 lb/ton dry wood 0.6 lb/ton dry wood (1-1-75)[z]	b) 1.6 lb/ton pulp 1.2 lb/ton pulp (1-1-75)[z]	b) Total mill	b) One month
	c) 0.03 ppm—at ground level off premises		c) Total mill	c) One hour
	d) No non-condensible stream over 60 ppm for over 30 min/day			
Shasta County APCD	a) 70 ppm 17.5 ppm (1-1-75)[z]	a) 2.0 lb/ton pulp 0.5 lb/ton pulp (1-1-75)[z]	a) Recovery furnace	a) Undefined
	b) 2 lb/ton pulp 1 lb/ton pulp (1-1-75)[z]	b) 2.0 lb/ton pulp 1.0 lb/ton pulp (1-1-75)[z]	b) Any other source	b) Undefined
Bay Area APCD	a) 0.2 ppm, 0.1 ppm *mercaptans only*	a) 0.005 lb/ton pulp[y]	a) Well-defined stack Any other source	a) 15 minutes
	b) 0.1 ppm, 0.05 ppm *dimethylsulfide only*	b) 0.003 lb/ton pulp[y]	b) Well-defined stack Any other source	b) 15 minutes
	c) 0.06 ppm, 0.03 ppm *hydrogen sulfide* at ground level		c) Total mill	c) 3 minutes one hour
Oregon (7-1-75)[z]	a) 10 ppm—or—0.3 lb/ton pulp 40 ppm 15 ppm—or—0.45 lb/ton pulp	a) 0.3 lb/ton pulp, 1.2 lb/ton pulp, 0.45 lb/ton pulp (7-1-75)[z]	a) Recovery furnace Recovery furnace Furnace stack	a) One day One hour One day
	b) 40 ppm—or—0.2 lb/ton pulp	b) 0.2 lb/ton pulp	b) Lime kiln	b) Undefined
	c) Non-condensibles treated equivalent to thermal oxidation		c) Digester, multiple effect evaporator	
	d) Lowest practical level		d) Any other source	
Washington	a) 70 ppm—or—2 lb/ton pulp	a) 2.0 lb/ton pulp	a) Recovery furnace	a) One day
	b) 17.5 ppm—or 0.5 lb/ton pulp (7-1-75)[z]	b) 0.5 lb/ton pulp (7-1-75)[x]	b) Recovery furnace	b) One day
	c) Non-condensibles treated equivalent to thermal oxidation			
Alabama	a) 1.2 lb/ton pulp	a) 1.2 lb/ton pulp	a) Recovery furnace lime kiln, digester, multiple effect evaporator	a) Undefined
Florida	a) 17.5 ppm—or— 0.5 lb/3000 lb of black liquor solids (7-1-75)[z]	a) 0.5 lb/ton pulp (7-1-75)[z]	a) Recovery furnace	a) Undefined
Minnesota	a) 1.0 million odor units/minute	a) —0.003 lb/ton pulp[y]	a) Any source	a) Undefined
	b) 150 odor units	b) —0.04 lb/ton pulp[y]	b) Any stack over 50′	b) Undefined
	c) 25 odor units		c) Any other source	c) Undefined
Mississippi	a) 70 ppm—or—2 lb/ton pulp	a) 2.0 lb/ton pulp	a) Recovery furnace	a) Undefined
	b) Non-condensibles treated equivalent to thermal oxidation			
Texas	a) 0.08 ppm—*hydrogen sulfide* at ground level off premises		a) Total mill	a) 30 minutes
Virginia	a) 1.2 lb/ton pulp	a) 1.2 lb/ton pulp	a) Recovery furnace, lime kiln, digester, multiple effect evaporator	a) One day

[x] TRS means hydrogen sulfide, methyl mercaptan, dimethylsulfide, dimethyl disulfide, and any other organic sulfide compounds measured as hydrogen sulfide.
[y] Calculated for recovery furnaces only.
[z] Effective date of regulation.
Source: Reference 9.

Both Ambient and Source Standards Specified

As indicated earlier, although Minnesota has specified both source and ambient odor limits based on sensory methods, the ambient odor limits are unenforceable.[4] Huey also has indicated that measurements by the syringe dilution technique is not practical below ten odor units.[10] The Minnesota rule was uniform in that the same methodology-syringe dilution technique and a panel of 6–8 observers—was applicable to the source and ambient measurement.

Illinois' rule for the control of rendering odors relies primarily on the Scentometer device to determine if an objectionable odor nuisance exists. Further, Section b states "No person shall operate . . . for the inedible rendering of animal or marine matter unless all gases, vapors and gas entrained effluents from these processes shall be controlled in such a manner as to effectively abate any objectionable odor nuisance. In the event that the rendering processes of more than one company are contributing to the objectionable odor nuisance, abatement shall be deemed effective when the odor concentration from each process is not more than 120 odor units/cubic foot as determined by Mills adaptation of ASTM D-1391-57."

The relationship between the dilutions to threshold as measured by the Scentometer and the odor units/cubic foot as determined by the syringe dilution technique has never been established.

Thus, in practice, there is no existing regulation covering odorous emissions that can be related by sensory methods or analytically both at the source and in the ambient air.

Selected Local Regulations

It must be pointed out that local regulatory agencies can have substantially differing regulations than those of the parent state agency. As an example, although the State of Washington has no statewide regulations specific to odor, regulations for their control have been delegated to the nine local air pollution control authorities. In Washington, the Puget Sound, Olympic, Yakima County, and Spokane Air Pollution Control Authorities have nearly identical regulations (i.e., effective control apparatus and measures shall be installed and operated to reduce odor bearing gases and particulate matter emitted into the atmosphere to a reasonable minimum). These agencies also do not permit the concealment and masking of odors. The odor regulation for the Southwest Air Pollution Control Authority of Washington states:

(a) No person shall allow, cause, let, permit, or suffer the emission of odorous gases from any source, except as provided in this Regulation, in such concentration as to cause a public nuisance or exceed:

(1) A Scentometer No. 0 odor strength or equivalent dilution in residential and commercial areas.

(2) A Scentometer No. 2 odor strength or equivalent dilution in all other land use areas.

Scentometer Readings

Scentometer No.	*Concentration range No. of thresholds*
0	1 to 2
1	2 to 8
2	8 to 32
3	32 to 128
4	128

(b) A violation of Section 5.03 shall have occurred when two measurements made within a period of one hour, separated by at least 15 minutes, off the property surrounding the air contaminant source exceeds the limitation of Subsection (a).

(c) When the source is a manufacturing process, no violation of Subsection (a) shall have occurred provided that the highest and best practicable treatment and control currently available shall be provided in order to maintain the lowest possible emission of odorous gases.

In surveying the local regulations, it became apparent that a number of local regulatory agencies in addition to (or prior to using the Scentometer) have objectionability criteria. Selected agencies that utilize this approach are listed in Table V.

Typical of this regulation is:

REGULATION XV[11]
Control of Odors in the Ambient Air

A. No person shall emit odorous matter such as to cause an objectionable odor
   1. on or adjacent to residential, recreational, institutional, retail sales, hotel, or educational premises,
   2. on or adjacent to industrial premises when air containing such odorous matter is diluted with 20 or more volumes of odor free air,
   3. on or adjacent to premises other than those in 1 and 2 when air containing such odorous matter is diluted with four or more volumes of odor free air.

B. The above requirement shall apply only to objectionable odors. An odor will be deemed objectionable when 30 percent or more of a sample of the people exposed to it believe it to be objectionable in usual places of occupancy, the sample size to be at least 20 people or 75 percent of those exposed if fewer than 20 people are exposed.

If a local regulation is in apparent conflict with that of the state regulation, the stricter of the two would generally apply. There are exceptions to this and it is recommended that both state and local or regional regulatory agencies be contacted to ensure which regulations are applicable to a particular situation.

Rationale for Existing Odor Control Regulations

At the present time, virtually all enforcement of existing regulations for the control of odors relies on complaints by citizens. It has been amply documented that in the recent past, as many as up to 50% of all citizen complaints to local agencies are associated with odors. As an example, the Puget Sound (Washington) Air Pollution Control Agency (in its 1972 annual report) received 2324 odor complaints out of 5155 total logged complaints.[12] Total complaints increased 20% over 1971 levels. Undoubtedly, the increased publicity given by the media to pollution in general has increased the public's awareness of odor and an increased willingness to complain when in the past it may have not been reported. We have noted that there has been an increased tendency for a community or community group to circulate petitions to state the community's displeasure with the odor quality of the air.

Feldstein[13] perhaps best expressed the frustration of the local pollution control official in a metropolitan area "By definition a nuisance must involve a sizeable number of persons. The actual number depends on the size of the community affected. Officials find it difficult to get inconvenienced persons to come in to testify against an alleged odor violator. As a consequence, the enforcement of such a statute (nuisance) is at best difficult."

It is difficult to assess the effectiveness of the various control regulations as the literature on control techniques, aside from giving percentage reduction on a dilution basis at the source, has not given the extent to which complaints have diminished or a reduction in odor in the ambient air has occurred as a result of control action.

At the present time 33 of the agencies covered in this review rely explicitly or implicitly on the public nuisance concept to handle odor pollution problems. A variety of regulatory approaches have been taken by the remaining agencies and their rationale is discussed below:

Scentometer Approach

In 1960 Huey[6] wrote:

"The language of air pollution in ordinances dealing with odor nuisances is broad and subjective. Only in recent years has attention been given to an objective criteria for outdoor odor situations. However, to date, no community has written objective odor criteria into their Air Pollution Control Ordinance. Therefore, legal procedures are used to settle unresolved differences of opinion between citizen and source management and to establish whether or not a violation exists.

"To those engaged in air pollution control work either for the government or industry, it is readily apparent that more objective odor complaint investigative procedures must be developed. To accomplish this a device or instrument for the determination of odor strength is of prime importance. Techniques to point out the offender from among a number of potential sources are also needed. With the development of objective procedures and the enactment of reasonable ordinances containing measurable odor characteristics, the effort expended in odor pollution correction will be more beneficial to the community."

Huey continues,

"For the purpose of air pollution control *odors are classified in two categories, ambient and source odors.* Ambient odors are those existing in the general atmosphere and source odors are defined as those at the point of origin, or at their point of exit to the general atmosphere. If odors occurred, only at their source, and were immediately dissipated there would be no air pollution problem. However, this situation does not prevail, and the ambient odor problem arises. The specific ambient odor characteristics of concern to the air pollution control personnel are *quality, strength and occurrence.*

"From the standpoint of the air pollution officer, quality is a very complex issue and cannot be described in objective terms. For the present, it must remain in ordinances as broad-word definitions.

"Odor strength can be expressed objectively in terms of the amount of odor needed to dilute the given amount of odorous air to the concentration at which the odor is just detectable by the human olfactory system. Strength has been expressed in terms of odor units, an odor unit being defined as one cubic foot of air at the odor threshold. Other units of odor strength are the threshold concentrations and multiples thereof. The latter term is unitless and, therefore, has certain advantages.

"Occurence, for purposes here, will be defined in terms of duration and frequency . . . This points out the need for an expression of the interval of time during which the sporadic durations occur. Therefore, occurrence should be expressed as having occurred at intervals with a given frequency during a known period of time.

"After investigation of various instruments which might have been capable of measuring ambient odor strengths, and finding all to be lacking for this purpose, a new instrument called the "SCENTOMETER" was designed . . . The current model SCENTOMETER is capable of four different dilutions and thus divides odors by strengths into five groups. *Experience* has shown that odors above 7 D/T (dilutions to threshold) will probably cause complaints while those above 31 D/T can be described as a serious nuisance if they persist for any length of time."

Source Control

Three years later, Mills[7] wrote,

"The quantitative odor measurement used by the Los Angeles County Air Pollution Control District grew out of the A.S.T.M. method,[14] a dilution procedure which was developed by Fox and Gex.[15] It must be emphasized that the dilution method is purely quantitative and does not differentiate pleasant from unpleasant odors. The dilution method provides odor concentration data based on a *zero standard of no detectable odors.* Although the definition of the odor unit according to A.S.T.M. is 'one cubic foot of air at the odor threshold,' it would be more accurate and informative to define it as 'the quantity of any odorous substance or of any given mixture of odorous substances which, when completely dispersed in one cubic foot of odor-free air, produces a median threshold odor detection response in humans.' From this definition it becomes readily apparent that every cubic foot of any odorous gas is capable of contaminating odor-free air in proportion to the odor concentration."

Mills continues describing the Los Angeles situation in the late 1950's and early 1960's.

"A great number of the odor complaints received implicated two general areas: one, including the meat packing plants and rendering plants, and the other the fish canneries and fish meal reduction plants.

"The only enforcement measure then available to the district was the nuisance statute. When an odor nuisance may originate in any one or more of many pieces of similar equipment located in a relatively restricted area, however,

Table V. Selected local agency ambient odor control regulations.

Agency	Complaints required	Objectionability criteria	Vapor dilution method	Ambient limits
Polk County, Iowa	n.s.	Odor deemed objectionable by >30% of >30 people	Scentometer	7 D/T
Cedar Rapids Iowa	1	>30% of >30 people or >75% of <30 people	Scentometer or equivalent	Residential— 4 dilutions Industrial —20 dilutions Other areas— 8 dilutions
St. Louis Metropolitan Area Missouri	n.s.	>30% of >20 people or >75% of >20 people	n.s.	Residential— 0 dilutions Industrial —20 dilutions Other areas— 4 dilutions
Omaha, Nebraska	n.s.	Classified source[a] or substantial number of complaints	Scentometer[b] or Mills—ASTM procedure	Residential— 4 dilutions Industrial —20 dilutions Other — 8 dilutions
Chattanooga and Hamilton County, Tennessee	n.s.	>15% of >20 people or 3 people <20 people	n.s.	Residential— 0 dilutions Other — 4 dilutions
Milwaukee County Wisconsin	>3	Investigation or objectionable to >67% of at least 9 people		None

[a] "An odor will be deemed to be objectionable when the source of the odor has been classified as a producer of objectionable odors as designated Appendix B." 45.04.250.
[b] In event of dispute.
n.s.—not specified.

it is always difficult and sometimes impossible, to pinpoint the exact source of any particularly bad odor about which a specific complaint may be received. In such circumstances, proving specific equipment to be the source of the nuisance may be extremely time-consuming and is frequently impractical to attempt."

"In 1959, as a result of the period of particularly unfavorable weather conditions, a series of complaints brought about the enactment of the new odor control ordinance, Rule 64. This rule requires that 'all off-gases from heated reduction of inedible rendering . . . matter be incinerated at 1200°F for at least 0.3 second, or be processed in a manner equally or more effective for the purposes of odor control.' The standards were chosen because meeting them results in destruction of the odor rather than mere reduction of its effect. Regardless of the odor concentration at the inlet, it appears that the peak permissible odor level in the vented gases from any kind of odor control device should be about 150 odor units per cubic foot with the average preferably 50 odor units or less per cubic foot. The enforcement of Rule 64 over the past three years has resulted in an effective clean-up of odor nuisances from the animal matter reduction industries and the packing houses and rendering plant area."

In discussing the practical use of quantitative odor data at the source, and its relationship to evaluating and eliminating odor nuisance, Mills indicated there were four factors involved. It was indicated while odor concentration (odor units per cubic foot) appears to be the prime factor, it is not the sole criterion in evaluating an odor nuisance. The length of time over which an odor can be detected is probably of second importance. The factor of third rank in importance is the odor emission rate at the point of discharge. The factor of fourth importance was indicated to be the quality of the odor.

Mills continues,

"For these reasons the District does not attempt to evaluate odor quality in making measurements. If an odor causes complaints, it may be of nuisance regardless of its quality. The general significance of the threshold response, as found, with reference to the expected response of the populace is, of course, dependent upon how well the panel represents the populace. If the odor panel is large enough and chosen with significant care, the results of the odor tests can be extrapolated with relative accuracy in estimating public reaction. Total emission rates measured for odors have been found to correlate positively with the number of complaints received about odor nuisance."

These two papers account for the philosophy and strategy that was followed by most of the evolving regulatory agencies in developing the newer odor regulations or ordinances that have been promulgated since 1960.

Objectionability Criteria

Objectionability criteria for ambient odors can be traced to a mid-1960 study carried out in the St. Louis, Mo., area by the U. S. Public Health Service.[16] In that study, it was stated,

"Air-quality goals for odors pertain to 'objectionable' odors. An odor is considered 'objectionable' when 15% or more of the people exposed to it believe it to be objectionable in usual places of occupancy. The sample size needed to determine the 'objectionable' quality should be at least 20 people or 75% of the exposed if fewer than 20 are exposed."

The goals have been incorporated into the existing St. Louis metropolitan area odor control regulation described earlier. The study also suggested that source owners be encouraged to use the syringe dilution technique to determine their individual contribution to the overall problem; the use of the Scentometer was recommended for making ambient dilutions to threshold measurements.

Unfortunately, as is well known, the Scentometer does not have the capability to measure 4 and 20 dilutions mentioned in the regulation. This criticism may be directed to a number of additional state and local regulations that make use of the Scentometer.

Threshold Concentrations

In February 1969, the *APCA Journal* published an article containing the recognition odor threshold concentrations of 53 odorant chemicals that were carried by a panel of four highly trained analysts.[17] The Manufacturing Chemists Association asked Arthur D. Little, Inc., to make this determination utilizing a standardized and defined procedure to permit a comparison to be made of their relative odor importance. The prior literature had indicated wide variations in odor thresholds for the same chemical.

However, in the article, it was stated . . .

"the recognition odor thresholds reported in this study were developed under ideal laboratory conditions and are not recommended for air quality criteria and standards since no effort was made to define the degree of objectionability of the odorant chemicals."

In spite of this, two agencies have adopted these data as part of their regulations.

Instrument Based Regulations

The rationale for the Bay Area approach has been described by Feldstein.[13] Essentially, it can be stated as,

"Many odorous substances emitted from industrial and commercial sources are chemically identifiable and can be measured quantitatively. Among these are such compounds as trimethylamine, phenols, ammonia, mercaptans and dimethylsulfide. Odor threshold concentrations have also been established for these compounds. A regulation limiting the allowable emission concentrations of these materials from sources was adopted by the Bay Area Air Pollution Control District (in August 1973). The limiting concentrations were designed to prevent downwind concentrations from exceeding the odor threshold values under the most adverse meteorological conditions."

Discussion

Huey's work may be described as the Scentometer approach to odor control regulations and emphasized a measurement in terms of dilution to threshold in the ambient air by regulatory officials. Mill's influence resulted in the incineration or equivalent rule which has been directed primarily to the rendering industry (as indicated in Rule 64); the highest and best practicable control approach (odor must be reduced or eliminated at the source) and to a much lesser extent in regulations for setting odor emission limits at the source. Both Mills and Huey believed it was difficult to handle the question of quality of odor (as a descriptor or on a like/dislike basis) and relied exclusively on the threshold measurement with the aid of presentation systems to determine compliance. Other control agencies decided that it was inappropriate to ignore the objectionability (or like/dislike) aspect of odor and proceeded to incorporate it into regulations.

Instrumental/analytical approaches for regulatory control of odor have also depended on the availability of threshold measurements of selected chemical compounds thought or known to be present in the odorous emissions of selected industries and the availability of instrumentation and analytical techniques to detect these components at the trace concentrations at which they produce an odor response.

While it is known that odor control regulations have had an effect in controlling odorous pollution, there is a lack of evidence in the literature to indicate the extent to which the existing odor regulations of whatever basis have

succeeded in reducing complaints. Perhaps the regulations may give a clue. As an example, Pennsylvania even after requiring an incineration standard or equivalent for certain identified processes, has a further restriction in that no malodors are to be perceived beyond the plant boundary even if the incineration or equivalent standard is met. Colorado, in its Scentometer based regulation, prohibits all odors that are greater than 127 dilutions to threshold. Sources producing odors in greater quantity must install the best practicable approach to achieve the minimal emission of odor and to approach the lower specified Scentometer readings depending on the land use area.

Colorado's regulation (Subsection A (3) (a)) includes a provision:

> "In determining the best practical control methods, the Division shall not require any method which would result in an arbitrary and unreasonable taking of property or in the practical closing of any lawful business or activity, if such would be without corresponding public benefit."

Perhaps the reluctance of many of the states to adopt the "newer objective" regulations and their tendency to retain the nuisance concept is the recognition that odor pollution is not an easy thing to measure. The writing of a control regulation that is satisfactory from the standpoint of the interested parties involved—the public, the sources of odor and the regulator—is impossible at the present time. The difficulty in developing an odor control ordinance is perhaps best illustrated by Copley International's efforts in this area under the sponsorship of the U.S. Environmental Protection Agency.[2]

The problem with existing odor control regulations can be stated in terms of the broader problem of how can odor be measured objectively and reliably. There is increased pressure by the public on all the states and E.P.A. to do something about the odor pollution problem and, at the present time, perhaps the best response to these pressures is to promulgate an odor control regulation such as that proposed by Delaware which allows for the development of the best available data and does not limit itself to any one approach.

Symposia on Odorous Air Pollution

Two international symposia were held in 1970–1971 to discuss problems of odor pollution. The first symposium held on June 1–5, 1970, at the Karolinska Institute, Stockholm, Sweden, was supported by several Swedish organizations—the National Environment Protection Board, the Karolinska Institute, the National Institute of Public Health, and The South Swedish Forest Owners Association. The U.S. National Air Pollution Control Administration sponsored the participation of the American attendees. The subject of the symposium was "Methods for Measuring and Evaluating Odorous Air Pollutants at the Source and in the Ambient Air."

The second symposium was held at Arthur D. Little, Inc., Cambridge, Mass., on April 26–27, 1971, under the sponsorship of the U. S. Environmental Protection Agency; its subject was "Evaluation of Community Odor Exposure."

Each symposium has issued a report which is a result of discussions during the meeting of prepared working papers and represents the consensus of the participants. The two symposium reports have unfortunately not received wide circulation and it is highly recommended that the reports be obtained and perused. For purposes of brevity, these symposia will be referred to as the Stockholm[18] and Cambridge[19] symposia.

Stockholm Symposium

In a statement on general considerations on sensory methods of analysis, it was reported "From the point of view of air quality, a given odor sensation may be generally described in terms of four 'dimensions.' " These are the *pervasiveness* or *detectability* of the substance, its *intensity* at supraliminal levels, the *quality* or characteristic properties which distinguish one odor from another regardless of intensity or acceptability, and the *acceptability* or stimulation of annoyance or pleasurable reactions.

"In environmental health, the *most important dimension of an odor is probably its acceptability*, e.g., what percentage of the population is annoyed by the smell. However, this should not be interpreted as meaning that only odorants with disgusting odors are a source of annoyance. The acceptability of an odor is probably in part dependent on the intensity, frequency and duration of the experience as well as the conditions under which exposure occurs. This probably applies to pleasant odors. . . . At present, however, it is not possible to establish a quantitative objective measure of acceptability or the degree of annoyance by chemical or sensory methods of analysis. Public reactions of subjective annoyance can probably best be evaluated by sociological inquiry methods. This response can be related to the degree of exposure to odorous air pollutants to which the population is exposed (the dose)."

The report further states "In many cases, classical absolute threshold determinations are used to obtain an idea as to the intensity with which an odorous substance is experienced. *Threshold values do not give any measure of the perceived intensity above threshold levels*, . . . but threshold determinations do undeniably provide valuable information regarding the control of odor-producing processes, the effect of various odor-reducing procedures and the distribution of odorant emanations in the atmosphere. However, a decision must be made as to the type of psychophysical threshold to be determined. It is impossible to establish a general fixed sensory threshold for a particular individual since a real threshold in the usual sense probably does not exist but rather a gradual transition from total absence to definitely confirmed odor impression. Some methods of detection are based on the assumption that the momentary threshold varies from time to time and that this variation is normally distributed. The modern detection theories deny even the existence of a momentary sensory limit value and base their indices of detectability on a supposed individual probability evaluation."

These comments indicate quite strongly that threshold determinations either at the source, in the ambient air or on specific chemicals are of doubtful significance in measuring the intensity dimension of the odor problem.

Cambridge Symposium

The Cambridge Symposium was an extension of the Stockholm Symposium and was directed toward evaluation of the effects of odorous exposure in the community, as well as to review recent studies of dose, response, and dose-response relationships. In addition, at that time, the Air Pollution Control Office (APCO) of the U.S.E.P.A. was seeking answers to such broad questions[20] 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?

The symposium could give only very limited answers to these questions. However, the answers that were given are as follows:

(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.

(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.

(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 to 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 . . .

(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.

The conclusions and recommendations for research of both symposia are too lengthy to report here, and indicate the extent to which basic information is required in order to measure odorous air pollution. Reference should be made to the reports of the two symposia.

Recent Developments in the Measurement of Odorous Pollutants

Since the time of the two symposia, effort has been expended by a variety of researchers to explore various aspects of the odor problem.

Social and Economic Impact of Odors

Copley International Inc. has carried out a three-phase study for the U. S. Environmental Protection Agency on the social and economic impact of odors.[2,21] Phase I was concerned with a national survey of the odor problem and its principal findings are summarized below:

A survey of 184 local air pollution control agencies indicated that odor problems existed in many cities and counties throughout the nation and that odor problems affected a very large number of people. Four categories of sources were responsible for almost half of the odor problems reported. The identification and assessment of community odor problems was accomplished by a large number of the reporting agencies using the *unaided nose, common sense and number of complaints as criteria.* An equally large number of agencies reported that there are many inadequacies in such methods of assessment and expressed the need for assistance in establishing more effective procedures. Over 70 percent of the responding agencies took some form of abatement action. One of the most popular forms of abatement was persuasion. It was the general consensus that nuisance laws have been ineffective. In addition, evaluations of the use of the Scentometer and an odor judgment panel were described and a public attitude survey in various areas were carried out. It was stated that the probability of encountering community odor problems is greatest in the urban portions of the Appalachian and Rocky Mountain Regions and the California Coastal Zone. Projecting the results of the attitude surveys to the nation as a whole suggested that as many as 25 million residents perceived community odors as problems.[21]

The second phase was directed toward the development of procedures to identify community odor problems and to assess their social and economic impact.

The third phase was directed toward the development and evaluation of a model odor control ordinance. It was concluded "that a model ordinance cannot be drafted that is compatible with the legalistic approach to controlling air pollution preferred by every jurisdiction. It is further concluded that emphasis in the development of a model ordinance is best given to a conceptual framework that would promote the most efficient solutions under the existing state of knowledge. It is impractical to establish arbitrary limits merely because they are easy to enforce or to devote resources in constructing as many ancillary provisions as are felt necessary to meet all eventualities . . As a no-ill-effects ordinance (model control ordinance), it prescribes the measurement of annoyance due to odors which, . . . would serve as a convenient indicator of the existence of undesirable effects, and thus, would provide a basis for deciding whether or not a violation exists. Its adoption would tend to focus technological controls on the annoyance threshold rather than the odor threshold and, thus, would promote more efficient solutions in light of the societal consideration that the added cost of control should equal the added benefit derived from that control."

Evidence is cited to "conclude that odor complaints are not only unreliable, . . . but also insensitive as an indicator of where odor problems may exist."

The "Procedures for the Identification and Assessment of Community Odor Problems" (appended to the Phase III report) are "aimed at the measurement of the problem dimension—annoyance—rather than at arbitrary limits of odor intensity or odor quality."

Source-Ambient Odor Relationships

There is a need for sensory methods that permit odor evaluations to be made at the source and in the ambient air in such a form that the data comparisons are comparable.

Högström[22] demonstrated that a fluctuating plume dispersion model can be used to give realistic estimates of odor frequencies around a point source, when the odor thresholds of the chimney gases (sulfate pulp factory) are determined by sampling and sensory methods described by Lindvall.[23]

Sullivan and Leonardos have reported on a technique utilizing a highly trained panel to describe odor in terms of its quality (descriptive notes) and intensity at the source and in the ambient air.[24] The technique was applied to a complex coffee processing plant to assist the plant management in defining the extent to which control of odorous emissions from the several hundred sources at the plant that could contribute odor was necessary. The data obtained in the ambient and at the source were in terms of quality of odor and the intensity observed. The source data were used with dispersion

estimates to determine the predicted odor intensity of each source. The maximum predicted ground level odor intensity compared with observed intensity in the ambient indicated good agreement. The odor panel used in this study was not selected on the basis that it represents the general population's awareness to odor, but on the panelists capability to describe three of the four dimensions of the odor sensation.

Although there appears to be some usage of the syringe dilution technique[14] and as modified by Mills[7] and Benforado[25] to obtain odor data at the source for use with dispersion estimates, it has not been demonstrated that the predicted frequency of odor is relatable to actual field observations.

Instrumental Analysis of Odors

The alternative to the use of sensory methods to measure odor at the source is the use of instrumental techniques to measure the chemicals that may be present. Modern instrumental techniques such as gas chromatography and the mass spectrometer are powerful resources for chemically identifying the types of chemicals in a particular odorous emission. In the past, sensitivity of instrumental detectors and/or analytical techniques was a major limiting factor. This is still the case today, when one considers that the lowest "recognition odor threshold concentration" that has been found for an odorant chemical is 0.000001 ppm v/v for *o*-iodophenol.[26] The sensitivity issue is however of minor importance, the prime issue is how to measure the various dimensions of odor that are important from an air quality standpoint. An instrumental technique must be relatable to the human nose and as such is a complementary tool for measurement rather than standing alone.

At the present time, the regulations for the control of odorous emissions based on instrumental or analytical methods are the TRS (Total Reduced Sulfur) source standards for the kraft pulp mill industry and the Bay Area Air Pollution Control District's regulations that have been reported to be directed primarily toward the control of odorous emissions from petroleum refining and processing.

Total Reduced Sulfides (TRS) are thought to be the major components associated with kraft mill odors. However, a recent paper on kraft pulp mill odors by Berglund[27] stated . . .

> "The unknown odors in the effluents may also behave according to the vector model and in such a case the strength of these unknowns may be as strong as the effluent gas itself. Thus, selective elimination of all the known odorants from the effluents would not necessarily reduce the odor strength of the effluent. It might even cause a slight increase.
>
> "The results of the investigation emphasize that the perceptual aspects of odor interaction are important in monitoring odorous air pollutants. It has been explicitly shown that unknown odors play a major role in pulp mill odors. Consequently, an important task for future research must be to isolate and identify these unknowns (or synergistic substances) so that it will be possible to determine their odor characteristics experimentally. This conclusion points towards an urgent need for mutual efforts in sensory-perceptual and chemical physical research."

The major criticism that can be directed at the Bay Area approach is that five odorants selected are *thought* to be responsible for the odors resulting from the emissions that are to be brought under control rather than having been *demonstrated* as being responsible for the odor.

There is a tremendous need for isolation and identification programs to determine the chemical nature of the components responsible for odor from stationary sources. The only studies of this type that have been carried out have been on rendering industry odors and such mobile sources as diesel exhaust and jet exhaust odors. These studies have confirmed the great variety and complex nature of the components present that may contribute to odor.

Some chemicals that have been identified as being present in the odorous emissions from rendering plants (sampled before and after scrubbers and incinerators) include various sulfides, disulfides (and probably mercaptans), C_4 to C_7 aldehydes, trimethylamine, and various amines, quinoline, dimethyl pyrazines, and other pyrazines, and C_3 to C_6 acids.[28]

In studies on such mobile sources as diesel exhaust and jet engine odor, it has been estimated that about 200 different distinct chemical species may be responsible for the oily-kerosene (unburnt fuel) odor quality, while approximately 2000 species contribute to the smoky-burnt odor quality.[29] Based on this information, instrumentation for the routine measurement of the intensity of diesel exhaust odor has been developed. Kendall[26] and Levins[29] have described the sensory measurement aspects and the analytical aspects of the program. The successful development of this instrument was predicated on the close cooperation of skilled analytical chemists combined with the capabilities of an expert panel that could effectively describe the odor intensity and quality dimensions that are of importance.

The most efficient means to the development of appropriate odor control regulations is to provide instrumentation that has been correlated with the human experience of odor. The instrumentation would define the dose (i.e., the amount of odor) which is required to assess the acceptability or annoyance criterion of the general population.

Summary

Our concern with odor measurement techniques utilized in the field of air pollution and upon which the regulations are based is that they measure only one aspect of the four dimensions that the Stockholm symposium has identified as being of critical importance from the standpoint of air quality. Our position is that odor measurement for pollution purposes must include, in addition to "threshold," an assessment of the intensity and the quality of the odorous sensation. These dimensions can be measured effectively by calibration of the instrument—the human and his nose—by the use of appropriate reference standards both for intensity and quality. With more information on these three dimensions, the acceptability of an odor can be inferred from a consideration of all three dimensions (detectability, intensity and quality) and from none taken alone.

Preferably, these three dimensions should be correlatable to the acceptability or annoyance dimension of odor and should perhaps be carried out by public attitude surveys as outlined in the Copley study or other acceptable means.

The existing odor regulations are quite varied and appear to be satisfactory to few. Since the purpose of these critical reviews is to stimulate discussion, a discussion of the relative merits and disadvantages of the various existing regulations appears to this observer to be of minor importance and the important issue is, "How is odor to be measured in the air pollution situation?"

The methods of sensory evaluation upon which the existing regulations are based have failed to provide the appropriate information and we suggest the need for establishing a better basis upon which effective odor control regulations may be developed.

Unfortunately, the priorities at the federal level have relegated research into odor pollution to a low level of effort. In view of the complex nature of the problem, the individual state and local agencies do not appear to have the necessary financial resources to investigate the various aspects of the problem of odorous pollution measurement that have been identified in the Stockholm and Cambridge symposia. Perhaps a cooperative effort between industry and the various government levels would be the best approach. In addition, there must be continued dialogue between regulators, "polluters" and researchers in order to develop the basis for the development of the satisfactory odor control regulations that are needed.

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Appendix

Summary of Odor Control Regulations of 52 Agencies (States, District of Columbia and Bay Area)

ALABAMA—Air pollution is defined as presence of air contaminant (includes odor) in quantities and duration to injure human health and welfare.

ALASKA—Air pollution prohibited: No emission ... unreasonably interfere with enjoyment of life and property.

ARIZONA—No regulations.

ARKANSAS—Section 10. Emission of Air Contaminants such as to Constitute *Air Pollution*—odors mentioned.

CALIFORNIA—No discharge of air contaminants which cause injury, detriment, nuisance or annoyance to any considerable number of persons or to the public (agricultural odors exempt).

COLORADO—No person shall cause ... the emission of odorous air contaminants ... such as to result in detectable odors which are measured in excess of specified limits as determined by Scentometer or equivalent (Regulation 2).

CONNECTICUT—No person ... shall emit ... into the outdoor air any substance which creates an objectionable odor beyond his property line. Three methods for determining objectionable odor specified. (Sec. 19.508-23).

DELAWARE—No person shall cause ... the emission of an odorous air contaminant such as to cause air pollution. The purpose is to control odorous air contaminants which significantly affect the citizens of the state outside the source boundaries. Methods for determining air pollution condition suggested include Scentometer tests, air quality monitoring and affidavits from citizens and investigators. (Proposed Regulation XX).

DISTRICT OF COLUMBIA—The emission of an odor shall be deemed a violation, after three separate complaints when odor is detected at Number 1 odor strength (1 part odorous air to 1 part odor-free air) using a Scentometer or equivalent (Section 8-2:715).

FLORIDA—Objectionable odor defined as any odor...may be harmful or injurious to human health and welfare, which unreasonably interferes with the comfortable use and enjoyment of life and property or which creates a nuisance. Affidavits obtained from affected persons. Objectionable odor prohibited (Ch. 17.2).

GEORGIA—No specific odor regulation.

HAWAII—No specific odor regulation. (Nuisance laws can apply).

IDAHO—No person shall allow...the emission of odorous gases...into the atmosphere as to cause air pollution. No person shall allow...any plant engaged in processing... to be operated without employing reasonable measures (as approved) for the control of odorous emissions. (Reg. K).

TRS (Total Reduced Sulfides) emission standards for kraft pulp mills (Reg. O).

Inedible rendering plants—condensation and incineration (1200°F, 0.3 sec.) required. (Reg. Q).

ILLINOIS—Inedible Rendering Process Only.

(a) Exemption of human food processing and food service.

(b) No person shall operate or use any device...for the inedible rendering of animal or marine matter unless all gases...shall be controlled...to effectively abate any objectionable odor nuisance. If more than one company, abatement effective if not more than 120 odor units/cubic foot.

Provision is made for the existence and determination of an objectionable odor nuisance by use of Scentometer at specified dilutions depending on type of land use (3 indicated) (Part VIII Rules 801, 802).

Other odor cases in Illinois are prosecuted on a nuisance basis rather than on odor regulation per se.

INDIANA—No response.

IOWA—No regulation.

KANSAS—No specific odor regulation. For serious nuisance situation, Regulation 28-19-13, *Interference with Enjoyment of Life and Property* applies. Public hearing to determine this.

KENTUCKY—Ambient standard for odor. At any time, odor is not to equal or exceed 7 dilutions by use of a Scentometer.

LOUISIANA—No response.

MAINE—No specific regulation.

MARYLAND—No person shall cause...any discharge of gases, vapors or odors in such a manner that a nuisance or air pollution is created.

No person shall cause...the use of any installation primarily engaged in the reduction of offal or vegetable oil unless all gases, vapors and gas-entrained matter from said installation are:

(a) cooled to temperature of not greater than 160°F and then

(b) non-condensible fraction is incinerated at a temperature of not less than 1400°F for not less than 0.4 sec.

(c) alternate methods may be used if equally or more effective.

Additional provisions for odor control from these sources are listed (Reg. F).

MASSACHUSETTS—No person having control of any dust or odor generating operations such as, but not limited to (several operations listed) shall permit emissions therefrom to the extent that such cause or contribute to a condition of air pollution.

MICHIGAN—No person shall cause...the emission of an air contaminant (odor included by implication)...which causes or will cause detriment to the health, safety, welfare and comfort of any person...(R 336.46).

The rule (336.47) prohibiting the dilution and concealment of emissions does not apply to the control of odors.

MINNESOTA—Chapter 9 (APC 9 Control of Odors in the Ambient Air) specifies odorous source emission standards, a source odor emission rate limitation of 1,000,000 odor units/minute, as well as ambient limits in 3 land use areas that are not to be exceeded. Chapter 10 (APC 10) requires odors from the Processing of Animal Matter to be controlled by incineration (1500°F, 0.3 seconds) or equivalent.

MISSISSIPPI—Miscellaneous Chemical Emissions. No person shall cause the emission of toxic, noxious, or deleterious substances, in addition to those considered in these regulations, into the ambient air in concentrations sufficient to affect human health and well-being, or unreasonably interfere with the enjoyment of property or unreasonably and adversely affect plant or animal life beyond the boundaries of the property containing the air pollution source (Sec. 5.2).

MISSOURI—Regulation S-IX on Restriction of Emission of Odors applies throughout the state except for St. Louis City and 11 counties.

No person may cause...the emission of odorous matter in such concentrations and frequencies or for such durations that such odor can be perceived when 1 volume of odorous air is diluted with 7 volumes of odor-free air for 2 separate trials not less than 15 minutes apart within the period of one hour. Scentometer or equivalent is specified technique. One industry is exempted.

MONTANA—No person shall cause...any emissions of gases, vapors or odors beyond the property line in such manner as to create a public nuisance. Legal proceedings may be instituted for abatement. Additional provisions require use of control devices on any odor creating process. Reduction of animal matter requires incineration or equivalent.

NEBRASKA—No regulation.

NEVADA—No person shall discharge any contaminant that...is offensive to the senses... An odor is deemed objectionable if 30% or more of a sample of at least 20 people deem it so, or 75% if less than 20. A violation is deemed to occur if odor is detectable in the ambient air after dilution with 8 or more volumes of odor-free air on 2 measurements within one hour, at least 15 minutes apart. (Article 10.1.)

Reduction of animal matter emissions are to be incinerated at 1400°F for 0.3 sec. or equivalent. (Article 10.2.)

NEW HAMPSHIRE—Air pollution means one or more contaminant in sufficient quantities to among others, create a disagreeable or unnatural odor.

NEW JERSEY—No person shall cause...to be emitted into the outdoor atmosphere substances in quantities which shall result in air pollution (Ch. 6, Sec. 2.1).

NEW MEXICO—No regulation.

NEW YORK—Air pollution prohibited. Air pollution is the presence of an air contaminant, including odor, "which unreasonably interferes with the comfortable enjoyment of life and property."

NORTH CAROLINA—No person shall cause...any plant engaged in the processing of animal, vegetable or mineral matter to be operated without employing suitable measures for the control of odorous emissions including wet scrubbers, incinerators or such other devices as may be approved by the Board. Applies to all operations that produce odorous emissions. (Reg. 5.)

NORTH DAKOTA—Air pollution control regulations do not cover odor control.

OHIO—AP-2-07. Air Pollution Nuisances prohibited. The emission or escape into the open air from any source...of odors,...or is unreasonably offensive and objectionable to the public.

OKLAHOMA—No regulation specific to odor other than public nuisance law.

OREGON—The highest and best practicable treatment and control of air contaminant emissions shall in every case be provided so as to maintain overall air quality at the highest possible levels and to maintain contaminant concentrations, visibility reduction, odors, soiling and other deleterious effects at the lowest possible levels (20-001).

Registration and air-contaminant discharge permits required.

Emissions from animal rendering (by incineration 1200°F for 0.3 sec. or equivalent) and hardboard tempering ovens (incineration 1500°F for 0.3 sec) must be treated.

Additional odor control rules apply to the area covered by the former (Columbia-Williamette Authority).

PENNSYLVANIA—No person shall cause...at any time any emissions from the following processes (16 listed) unless the emissions have been incinerated at a minimum temperature of 1200°F for at least 0.3 sec prior to their emission into the outdoor atmosphere (equivalent techniques—if shown—may be used).

No person shall cause...the emission into the outdoor atmosphere of any malodorous air contaminants from any source whatsoever, including those in compliance with the above, in such a manner that the malodors are detectable beyond the person's property (123.31).

RHODE ISLAND—"create a disagreeable or unnatural odor." (Reg. 7.)

SOUTH CAROLINA—No specific regulation.

SOUTH DAKOTA—"When as many as five complaints of an objectionable odor situation are registered...the Commission is to interview the complainants and/or other occupants of the area to determine if violation has occurred and to determine the source or sources and circumstances of emission." If violation has occurred, that person shall take all steps required by the Commission to control the objectionable odor (Part II).

TENNESSEE—None

TEXAS—No person shall discharge from any source whatsoever one or more air contaminants or combinations thereof, in such concentration and of such duration as are or may tend to be injurious to or to adversely affect human health or welfare, animal life, vegetation or property, or as to interfere with the normal use and enjoyment of animal life, vegetation or property. (Rule 5—Nuisance.)

UTAH—None

VERMONT—A person shall not discharge...any emissions of objectionable odors beyond the property line of a premises. An objectionable odor shall mean those odors deemed objectionable by 15% or more of a sample of people (at least 20) exposed in a particular situation or 75% if panel of between 4–19 persons. Panel to be selected from those occupying or frequenting places closest to, but beyond the source property line. (Section 2 of 5-241.)

No persons shall operate...any device...or other contrivance for the industrial processes which as determined by the A.P.C. officer is an odoriferous process per se, unless all gases...are incinerated at 1600°F for not less than 0.5 seconds or by equally or more effective technique. (Section 3 of 5-241.)

VIRGINIA—No person shall cause...any source to discharge air contaminants (all operations that produce odorous emissions) which cause an odor objectionable to individuals of ordinary sensibility. The determination of an objectionable odor is to be made after review of all data and evidence gained by staff investigation and by public hearing to hear complaints. If in violation, control measures as approved shall be employed. Section IV, Rule 6, 4.06.00.

WASHINGTON—No specific regulations (see the nine local APC authorities which have regulations).

WEST VIRGINIA—Regulation IV—To prevent and control the discharge of air pollutants into the open air which causes or contributes to an objectionable odor or odors. An odor is objectionable based on opinion based on investigation, in addition to odors generally recognized as objectionable.

No person shall cause...the discharge of air pollutants which cause or contribute to an objectionable odor at any location occupied by the public.

WISCONSIN—No person shall cause...emission into the ambient air of any substance...in such quantities that an objectionable odor is determined to result unless preventive measures satisfactory to the department are taken to abate or control such emission.

An odor shall be deemed objectionable when either or both of the following are met:

(1) Upon a decision from investigation by the agency based upon nature, intensity, frequency and duration of the odor as well as the type of area involved and other factors.

(2) Or when 60% of a random *sample* (at least 9 persons) exposed to the odor in their place of residence or employment claim it to be objectionable and the nature, intensity, frequency and duration of the odor are considered. (NR 154.18–1 malodorous emissions.)

TRS Limitations for kraft pulp mills (NR 154.18–2).

WYOMING—Section 16 Odors.

(a) The ambient air standard for odors from any source shall be limited to:

(1) an odor emission at the property line from which such emissions occur of sufficient strength to be equal to but not greater than that detectable after seven dilutions with odor-free air as determined by a Scentometer or equivalent techniques.

The occurrence of odors shall be measured so that at least two measurements can be made within a period of one hour, these determinations being separated by at least 15 minutes.

(b) Control of odors from animal reduction (incineration 1200°F for 0.3 seconds or equivalent).

BAY AREA POLLUTION CONTROL DISTRICT (CALIFORNIA)—No person shall cause...the emission of any of the substances listed in Column 1 of Table A in excess of the concentrations shown in Column 2 of Table A for that substance.

Table A Maximum allowable emission of odorous substances.

Substance	Maximum allowable emission (ppm)	
	Type A Emission point	Type B Emission point
Trimethylamine $(CH_3)_3N$	0.02	0.01
Phenolic compounds calculated as phenol C_6H_5OH	5.0	2.5
Mercaptans calculated as methyl-mercaptan CH_3SH	0.2	0.1
Ammonia NH_3	5000	2500
Dimethylsulfide $(CH_3)_2S$	0.1	0.05

BAY AREA POLLUTION CONTROL DISTRICT—All sampling and analysis of exhaust gases for odorous substances listed in Column 1 of Table A shall follow the techniques prescribed in Chapter 2, Division 15. Tests for determining compliance with this regulation shall be for not less than 15 consecutive minutes or 90% of the time of the actual source operation, whichever is less. (Division 15—Odorous Substances, 15101, 15103.)

Cautionary Note: The information reported above has been condensed for brevity and it is hoped to convey a sense of the various odor control regulations that exist. Reference should be made to the appropriate agencies for the full wording of their regulations.

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