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DEVELOPMENT OF A STRATEGY FOR QUANTIFYING THE IMPACT OF ODOROUS EMISSIONS FROM STATIONARY SOURCES ON THE SURROUNDING COMMUNITIES.

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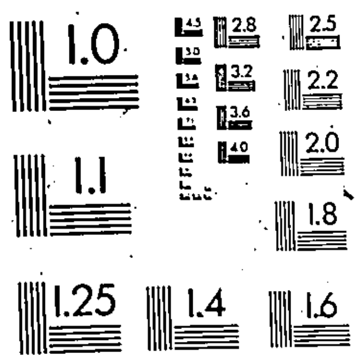

DEVELOPMENT OF A STRATEGY
FOR
QUANTIFYING THE IMPACT
OF
ODOROUS EMISSIONS
FROM
STATIONARY SOURCES
ON
THE SURROUNDING COMMUNITIES

by

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Dedicated to my family,

especially my parents,

Rana, Minou, Moni,

Maryam and Mehrzad

whose love and affection

never end.

ABSTRACT

Regulatory agencies are expected to deal routinely with community odor problems yet they have no objective methods for assessing the effects of odorous sources. A three step strategy has been developed for quantifying the impacts of existing or proposed stationary odorous sources on their surrounding communities. Successful implementation of the proposed protocols would establish

- whether there is a recognizable odor problem in the community
- "how bad" the odor is
- "how much" odor there is.

A public attitude survey has been designed to aid in the confirmation of recognizable odor problems in the community.

Quantification of odors with respect to "how bad" is done through an evaluation of the degree of offensiveness (DO) as the product of

- intensity; expressed as maximum dilution level at 100 percent probability of complaint (MDL @ 100 PPC)
- hedonics; evaluated in terms of predicted degree of annoyance (PDA_{100})

The various odor emitting sources are ranked in terms of potential level of source annoyance defined as product of the

- degree of offensiveness (DO)
- volumetric flow rate (V_o)

The odor impact on the surrounding community is assessed using a potential odor impact (POI) value, at downwind locations for various distances and elevations under a variety of meteorological conditions, as the product of

- percent probability of complaint (PPC)
- predicted degree of annoyance (PDA).

The PPC and PDA values are obtained from the Odor Impact Model following the application of appropriate dispersion models.

Since an odor free environment is not attainable some maximum acceptable magnitudes of POI, PPD, PPC AND PDA must be agreed to by the community, the associated industries and concerned regulatory agencies.

Application of this model to the odorous emissions from

- a wastewater treatment facility
- a paint manufacturing plant
- a municipal waste landfill site
- an automotive foundry

indicates that a POI = 20 could be a possibly acceptable standard for a community experiencing odorous insults from four stationary sources. Since a POI = 20 does not provide protection for the estimated 15 to 20% of society that may have developed hypersensitivities, regulatory agencies may be urged to adopt even lower POI values as a basis for development of standards and regulations.

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I. INTRODUCTION

Community odor pollution problems are very complex in nature. They generally start when a source (or a number of sources) such as

- a manufacturing plant
- a landfill site
- a wastewater treatment facility
- a fast food restaurant

situated close to a residential area, emits odorous gases or particulate matter.

The odor impacts are most obvious during the summer months, especially under unstable meteorological conditions when

- the emissions are not well dispersed or diluted in the atmosphere
- the plant is running at full load but is not equipped to control its maximum odorous emissions
- there is a malfunction in the operation of the plant or the control equipment.

A. Basic Problems

Although most stack emissions are visible in the form of white, black or grey plumes, many odorous discharges cannot be seen. Furthermore, a significant part of the odor impact may be the result of sporadic fugitive emissions from the open doors and windows of the facility or even from open field operations or the waste stream fed into the sewer system or to a nearby waterway.

The response from the community towards these impacts is initially that of indifference. In the beginning, it is the elderly, the allergic and the sick who feel the effect. Then the working section of the community begins to feel the impact during the early morning hours while going to work or in the evenings when coming home for supper or late at night. Generally, citizens may feel that there is nothing wrong with the air in their locality. However, it is when they find that

- episodes are repeated often
- the elderly cough more
- friends visit their homes less
- the value of their homes depreciate

that they realize there is definitely something wrong with the air in their community.

At this point in time, spontaneous complaints are made to the office of the air pollution control agency and the managers of the odor emitting sources in the area. However, most of these citizen reactions are treated as statistical information. Occasionally, an inspector from the air pollution control agency may visit the site of the complaint. The officer may or may not be able to detect the odor, depending upon the frequency of the emissions and changes in meteorological conditions. Even if he is able to detect the odors on the site of the complaint, he is not in a position to objectively determine the impact of the odorous emissions on the complainer. Although he may be prepared to issue odor violations, this approach does not solve the problem. The process continues to the point where complainers give up filing complaints. It is only when a large number of concerned residents in the community voice their views that regulatory agencies are able to ask the managers of the suspected odorous sources to call for a study of their emissions. At this point, public meetings and environmental hearings are held with the hope that, ultimately, some solution can be found. However, public hearings cannot be very fruitful without objective quantification of source and ambient odor levels and citizen responses.

B. Addressing The Problems

This research program was initiated in order to develop procedures for assessing the impact of odorous source emissions on surrounding communities. Many odorous pollutants, detected at parts per billion by the human nose, cannot be measured objectively by available analytical instruments. Perception of odors from person to person (and even with the same person) varies with time, place, concentration and context.

Odorous emissions are generally sporadic rather than continuous. The impact that a source creates is often the result of a large number of compounds being present rather than a single odorant.

Operators of odor emitting sources and sometimes regulatory agencies discourage environmental researchers from initiating studies in communities experiencing adverse air quality. They try to prevent the generation of, what they consider, unwarranted awareness among citizens who have not been concerned about odor problems earlier. Often, managers of residential apartments deny access to their buildings while surveys are being carried out. They do not want to have their current or potential residents upset by alleged odor problems in their neighborhood.

Citizen complaints concerning odor pollution problems are generally well documented but seldom verified. Very little has been done to relate odorous episodes to community health problems. Although laboratory studies with animals have shown that some odorants can cause marked physiological and morphological changes in terms of cardiovascular and respiratory performances, [1] there is very little information available about the toxicity or hazardous effects of odorous substances on man. In some cases changes can occur without being perceived by the person undergoing them. In communities close to odorous sources, there may not be excess disease or infirmity, but there certainly is not a state of complete mental, social or physical well-being. This follows from the recognition that prolonged exposure to foul odors usually generates undesirable reactions in people, which can vary from

- unease
- discomfort
- irritation
- anger
- depression
- headaches
- nausea
- vomitting.

To avoid future community displeasures, studies are needed [1] to predict the degree of odor control that will be demanded before a potential odor emitting source is constructed. Attempts should be made to develop dose-response information for a wide spectrum of odorous sources.

Successful verification that a suspected source (or sources) is or is not responsible for alleged odor problems in a community requires correlation of data from

- on-site
- off-site
- receptor response

studies. However, the present state of the art of odor regulations has left air pollution control agencies in a very difficult position when determining if a specific odor source is causing a nuisance in the community. In order to solve an odor pollution problem, it is necessary to

- evaluate the impact of the odor source on its surrounding community without causing any antagonism in the community towards the odor source
- find what is a fair degree of control
- determine if, indeed, the existing or proposed odor source is or would be a cause of annoyance in the community.

Reviews of technical literature [2] and government documents [3] as well as discussions with personnel from the Ontario Ministry of the Environment [4] indicate that there is a pressing need for the development of a technological basis for odor control in North America before effective odor compliance programs can be implemented. The technological needs include development of

- procedures for establishing the validity of spontaneous odor complaints
- methods for assessing the perceptions of the community without creating any adverse reactions to suspected sources
- relationships between odor levels and annoyance thresholds for different odor sources in communities
- guidelines for locating and defining the alleged source or sources causing an odor problem in a community.

Since people differ in their responses, it has become traditional to define the 50% thresholds as the minimal concentrations at which half the subjects in a population

- respond to
- discriminate
- get annoyed by an odorant.

This definition is in accordance with the mean effective dosage, ED_{50}, used in toxicological work.

The traditional sensory dimensions for describing any odor have been

- detectability
- intensity
- hedonics
- quality.

Only recently, have attempts been made to express odors in terms of real life dimensions which have direct impact on a community as

- probabilities of complaint
- predicted degrees of annoyance.

The ranking-plotting [5, 6] and ASTM E679 [7, 8] methods have been used to provide direct odor detection thresholds based on 50% panel responses as explained in detail in Appendix I.

The maximum likelihood estimator model [9, 10, 11] goes one step further by providing discrimination thresholds as outlined in Appendix II.

In order to account for and evaluate the real life odor dimensions, a fast, simple method of presenting an overall view of an odor impact on a community is necessary to facilitate the regulation of odorous emissions.

New approaches should provide practical procedures for routinely evaluating all the essential odor dimensions including percent probabilities of detection and complaint as well as predicted degree of annoyance profiles.

C. <u>Solutions to Odor Problems</u>

In order to achieve the basic objectives, a research program was designed

- to validate spontaneous odor complaints
- to determine perceptions of the community towards odor sources through a well designed and tested public attitude survey
- to develop and implement an odor impact model that would relate community percent probabilities of odor detection, complaint and predicted degree of annoyance profiles to the odor levels under investigation.

A preliminary examination of several odorous sources showed that

- citizen responses could not be readily collected without creating unwarranted antagonism towards the odorous sources in the community if a carefully designed questionnaire was not used
- many odorous emissions are too sporadic for routine ambient odor sample collection or real time instrumental monitoring of any key components.

In an effort to overcome these limitations a systematic search was conducted for odor sources where

- citizen complaints to a regulatory agency are well documented

- emissions are relatively constant rather than sporadic
- emissions may be discussed in terms of readily identifiable major components.

During the past 5 years, odor sampling programs and/or neighborhood public attitude surveys have been conducted at:

- a wastewater treatment facility
- a paint manufacturing plant
- several fast food restaurants
- a municipal solid waste landfill site
- an automotive foundry
- an automotive paint facility.

II. LITERATURE SURVEY

Of the various categories of air pollutants, odors are generally ranked as the major generators of public complaints to regulatory agencies in North American communities. It is estimated that more than 50% of the complaints related to air pollution deal with exposures to odors [1, 12].

A. Recognition of Odor Pollution Problems

Surveys of citizens living in the neighborhoods of odorous stationary sources indicate that odors can cause mental and physiological stresses on humans. Receptors describe their perceptions of odorous environments in terms of.

- tolerable
- unpleasant
- very unpleasant
- terrible
- unbearable

conditions. Typical human reactions are

- nausea
- headache
- loss of appetite
- impaired breathing
- in some cases, allergies [13, 14].

On the basis of a recent study [15], it appears that more than half of the people in the 65 to 80 year age category have major olfactory impairments. Consequently many senior citizens can experience adverse health reactions without being aware of their exposure to odorous environments.

In recent years, odorous sources have received considerable attention from the public and regulatory agencies. In practice, the existence of an odor pollution problem must be established before any steps towards control can be attempted.

B. <u>Community Annoyance</u>

Annoyance is a common reaction of residents in communities where unpleasant odors are encountered [16]. Reliable relationships between ambient odor levels and odor annoyance thresholds for different sources must be determined before ambient odor standards can be established.

The scentometer and ASTM syringe methods are considered to be inadequate for regulatory purposes [17]. There has been a general trend towards the dynamic olfactometric approach. However, there is still a basic need for the development of sensory methods that are capable of measuring odors objectively and reliably to yield results that can be related to community annoyance.

To be rated as a community problem, an odor must cause substantial annoyance by the standards of an ordinary, reasonable person living in that locality [1]. Consequently, an unusually sensitive person may find it impossible to establish a nuisance on the basis of odor pollution in an industrialized neighbourhood, partly because the odor is characteristic of the locality and because it is considered harmless by most residents of the area.

Since the most important impact of a majority of odor problems is community annoyance, objective measurement of annoyance is essential to the success of a regulatory strategy for odor control. Two approaches have been used to assess community reactions to odorous sources. One relies on spontaneous complaints and the other on social surveys.

C. Spontaneous Complaints

The use of odor complaints provides a simple and straightforward approach to exerting pressure on the people responsible for the sources of offending odors. Odor complaints are indicators that a potential odor problem may exist in the community [18]. In general, very few people register formal complaints with authorities with respect to any environmental problem [17].

A study of annoyance created by aircraft noise showed that the main characteristics distinguishing complainants from noncomplainants were related to education, value of their home and membership in organizations. On this basis, the number of complaints received by officials may reflect not so much the amount of discomfort experienced by the exposed population, but its social class composition and level of community organization [19,20].

However, studies have shown that persons who volunteer their opinions may tend to overstate their concern [21]. Some courts have indicated that the difficulty of relying on odor complaints to prove a nuisance lies in the possibility that the complainants do not represent the feelings of the community as a whole [22].

D. Social Surveys

Social surveys can be used to estimate the true feelings of a community by including controls for bias. Field procedures involve asking questions whether odors have been perceived, whether they have caused annoyance and under what conditions [23]. Questionnaires are the most widely used method for collecting information about people's attitudes and behavior [24]. Questions about the backgrounds of the respondents are added to facilitate correlation of data. Additional questions about other forms of pollution are included, if the main interest in odors is to be de-emphasized to those being surveyed.

The major objections voiced by enforcement agencies that have used this approach are generated by the cumbersome procedures involved [23].

E. Regulating Odorous Emissions

The basic goal of odor regulations is to eliminate or prevent the occurrence of objectionable odors in the community. An objectionable odor can be defined as one causing harm or discomfort to a person[s] with an average olfactory sense to an unreasonable extent [18]. The phrases, 'harm or discomfort', 'average olfactory sense' and 'unreasonable extent' may be difficult to define and often depend upon subjective judgements. This is the fundamental issue to the problem of odor regulations.

In 1982, the National Renderers Association conducted a survey of air pollution control agencies in North America, in order to classify their current odor regulations [25]. Of the 60 agencies approached, 17 had no odor regulations, not even an odor nuisance type although they had a general nuisance type regulation. Sixteen agencies specified odor levels in the ambient air [beyond property lines of a plant] that are not to be exceeded. Six agencies specified source emission or stack type odor limits which are not to be exceeded. Table 2.1 summarizes the results of the survey.

The San Francisco Bay Area Air Pollution Control Division pioneered the concept that a specified number of complaints must be received within a specified time period before compliance is required for a source [25]. These complaints are to be validated by the agency before any action is taken.

The Wayne County Air Pollution Control Division in Detroit, Michigan has adopted a similar but stricter approach. The Wayne County regulations specify that 3 or more complaints verified by the APCD must be received within a three-month period before emission limits are applied to the source [25].

In Ontario, odor nuisance type regulations for ambient air are applied, but no specified levels at the source or ambient

TABLE 2.1: A Summary of Odor Regulations for Different State or Local Air Pollution Control Agencies in North America [25]

Province/State or Local Agency	Ambient or Source Emission Standard	Odor Nuisance	Odor Level Specified		Incinerator of Equivalent Standard	Comments
			Ambient Air	Source Emission		
Alabama	Ambient	Yes	-	-	-	-
Arizona	None	No	-	-	-	-
Maricopa County (Phoenix)	Both	Yes	-	-	1300°F & 0.3 sec	Incineration temperature and residence time in seconds specified.
Arkansas	None	No	-	-	-	-
British Columbia (Canada)	Ambient	Yes	-	-	-	-
California	Ambient	Yes	-	-	-	-
San Francisco Bay Area	Both	Yes	Yes	Yes	-	Unit volume of ambient air sample diluted with 4 volumes of odor free air; odor dilution ratio measured with dynamic olfactometer. Odor dilution ratio of 1000 (less than 30 ft.) ranging up to 50,000 (greater than 180 ft.) varies with height of emission point above ground level; measured with dynamic olfactometer. The Bay Area regulations specify that 10 or more complaints must be received initially within a 90-day period before standards are applied to a source. These limits remain in effect until no complaints are received for 1 year. The limits become applicable again when 5 or more complaints are received during a 90 day period.

TABLE 2.1: (cont'd) A Summary of Odor Regulations for Different State or Local Air Pollution Control Agencies in North America [25]

Province/State or Local Agency	Ambient or Source Emission Standard	Odor Nuisance	Odor Level Specified		Incinerator or Equivalent Standard	Comments
			Ambient Air	Source Emission		
South Coast AQMD (Los Angeles)	Both	Yes	-	-	1200°F & 0.3 sec	Incineration temperature and residence time in seconds specified.
Colorado	Ambient	No	Yes	-	-	Scentometer method - 2 measurements within 1 hour but at least 15 minutes apart; 7 dilution ratio for residential or commercial and 15 dilution ratio for other land use areas.
Connecticut	Both	Yes	Limits in PPM 58 compounds	120 odor units ASTM method	-	-
Delaware	Ambient	Yes	-	-	-	-
Florida	Ambient	Yes	-	-	-	-
Dade County (Miami)	Both	Yes	-	-	1600°F & 0.3 sec	Incineration temperature and residence time in seconds specified.
Georgia	None	No	-	-	-	-
Illinois	Both	Yes	Yes	120 odor units ASTM method	-	Scentometer method - 2 measurements within 1 hour but at least 15 minutes apart; 8 dilution ratio for residential or commercial, 24 dilution ratio for industrial and 16 dilution ratio for other zoned areas.
Chicago	Ambient	Yes	-	-	-	-
Indiana	Ambient	Yes	-	-	-	
Iowa	Ambient	Yes	-	-	-	-

TABLE 2.1: (cont'd) A Summary of Odor Regulations for Different State or Local Air Pollution Control Agencies in North America [25]

Province/State or Local Agency	Ambient or Source Emission Standard	Odor Nuisance	Odor Level Specified		Incinerator or Equivalent Standard	Comments
			Ambient Air	Source Emission		
Polk County (Des Moines)	Ambient	Yes	Yes	-	-	Scentometer method - 2 measurements within 1 hour but at least 15 minutes apart; 7 dilution ratio for residential or commercial and 15 dilution ratio for other land use areas.
Kansas	Ambient	Yes	-	-	-	-
Kentucky	Ambient	Yes	Yes	-	-	Use of scentometer to detect sample of unit volume after dilution with 7 equal volumes of odorless air.
Louisiana	None	No	-	-	-	-
Maine	None	No	-	-	-	-
Maryland	Ambient	Yes	-	-	-	-
Massachusetts	Ambient	Yes	-	-	-	-
Michigan	Ambient	Yes	-	-	-	-
Wayne County (Detroit)	Both	Yes	-	50-150 o.u. based on stack	-	Both source emission limits expressed in odor units are measured by a modified ASTM syringe method. 150 o.u. applies to a stack based on good engineering practice (GEP). 50 o.u. applies to a stack not having GEP design which refers to the stack having sufficient height to avoid atmopheric downwash due to nearby structures or terrain obstacles. The Wayne County regulations specify that 3 or more complaints verified by the Air Pollution Control Division must be received within a 3 month period before the emission limits are applied to the source.

TABLE 2.1: (cont'd) A Summary of Odor Regulations for Different State or Local Air Pollution Control Agencies in North America [25]

Province/State or Local Agency	Ambient or Source Emission Standard	Odor Nuisance	Odor Level Specified		Incinerator or Equivalent Standard	Comments
			Ambient Air	Source Emission		
Minnesota	Both	No	Yes	25 & 150 o.u. million o.u./min.	1500°F & 0.3 sec.	3 odor dilution levels (1 o.u. for residential, 2 o.u. for light industrial and 4 o.u. for other zoned areas) for ambient air. Measurement by ASTM syringe method. 25 odor units specified for stack heights below 50 ft. and 150 odor units specified for stacks with height of 50 ft. or more. Measurement by ASTM syringe method. Odor emission rate of one million odor units per minute to not be exceeded (odor emission rate = odor units x cubic ft./min. volumetric rate). Incineration temperature and residence time in seconds specified.
Mississippi	None	No				
Missouri	Ambient	No	Yes			Use of scentometer to detect sample of unit volume after dilution with 7 equal volumes of odorless air - 2 measurements within 1 hour but at least 15 minutes apart.
St. Louis	Both	Yes	Yes		1200°F & 0.3 sec.	No objectionable odors in residential area, 20 odor dilution ratio for industrial and 4 odor dilution ratio for other zoned areas. No odor measurement method specified. Incineration temperature and residence time in seconds specified.
Nebraska	None	No				
Nevada	Both	Yes	Yes		1400°F & 0.3 sec.	To detect sample of unit volume after dilution with 7 equal volumes of odorless air - 2 measurements within 1 hour but at least 15 minutes apart. Incineration temperature and residence time in seconds specified.

TABLE 2.1: (cont'd) A Summary of Odor Regulations for Different State or Local Air Pollution Control Agencies in North America [25]

Province/State or Local Agency	Ambient or Source Emission Standard	Odor Nuisance	Odor Level Specified		Incinerator or Equivalent Standard	Comments
			Ambient Air	Source Emission		
New Jersey	None	No	-	-	-	
New Mexico	None	No	-	-	-	
New York	None	No	-	-	-	
North Carolina	Ambient	Yes	-	-	-	
North Dakota	Ambient	Yes	Yes	-	-	Prohibits discharge to ambient air of objectionable odor exceeding 2 odor units. ASTM syringe method is specified but scentometer is included as alternate method to measure odor intensity.
Ohio	Ambient	Yes	-	-	-	
Cincinnati	Ambient	Yes	Yes	-	-	2 odor dilution levels (15 dilutions of odorous air for heavy industrial zone and 7 dilutions for other zoned areas) - use of scentometer to make two measurements not less than 15 minutes apart in any 8 hour period.
Cleveland	Ambient	Yes	Yes	-	-	20 dilutions of odorous air for industrial zone and 7 dilutions for other zoned areas - more than 2 scentometer measurements to be made at intervals of 15 minutes or more during any 8 hour period.
Oklahoma	None	No	-	-	-	
Ontario (Canada)	Ambient	Yes	-	-	-	

TABLE 2.1: (cont'd) A Summary of Odor Regulations for Different State or Local Air Pollution Control Agencies in North America [25]

Province/State or Local Agency	Ambient or Source Emission Standard	Odor Nuisance	Odor Level Specified		Incinerator or Equivalent Standard	Comments
			Ambient Air	Source Emission		
Oregon	Both	Yes	Yes		1200°F & 0.3 sec.	2 dilutions of odorous air for residential and commercial zones; 7 dilutions for other zoned areas - use of scentometer to make 2 measurements within 1 hour but at least 15 minutes apart. Incineration temperature and residence time in seconds specified.
Quebec (Canada)	Source Emissions	No		Yes		Odor emission from rendering process to not exceed 120 odor units. Plant ventilating air emission to not exceed 50 odor units. Measurement by modified ASTM syringe method.
Montreal (Canada)	Both	Yes		99% reduction from process		99% reduction in particulate and organic substances emitted from rendering process.
Pennsylvania	Both	Yes	Yes		1200°F & 0.3 sec.	Prohibits objectionable odors being emitted which are detectable beyond property line. Incineration temperature and residence time in seconds specified.
Philadelphia	Ambient	Yes				
South Carolina	None	No				
South Dakota	Ambient	Yes				
Tennessee	None	No				
Knox County (Knoxville)	Ambient	Yes				
Texas	Ambient	Yes				
Houston	Ambient	Yes				

TABLE 2.1: (cont'd) A Summary of Odor Regulations for Different State or Local Air Pollution Control Agencies in North America [25]

Province/State or Local Agency	Ambient or Source Emission Standard	Odor Nuisance	Odor Level Specified		Incinerator or Equivalent Standard	Comments
			Ambient Air	Source Emission		
Utah	None	No	-	-	-	-
Virginia	Ambient	Yes	-	-	-	-
Washington	Ambient	Yes	-	-	-	-
Pudget Sound Area (Seattle)	Ambient	Yes	-	-	-	-
Wisconsin	Ambient	Yes	-	-	-	-
Wyoming	Both	Yes	Yes	-	1200°F & 0.3 sec.	Use of scentometer to detect sample of unit volume after dilution with 7 equal volumes of odorless air - 2 measurements within 1 hour but at least 15 minutes apart. Incineration temperature and residence time in seconds specified.

locations [26] are used.

In Manitoba, the specified maximum desirable level is less than the odor threshold based on two tests not less than 15 minutes nor more than 60 minutes apart. In residential areas, the maximum acceptable level is two dilutions to threshold and in industrial zones, seven dilutions to threshold [27].

The Province of Quebec specifies source emission standards for rendering plants and plant ventilating air emissions as shown in Table 2.1. Table 2.2 summarizes odor regulations in Canada.

The use of information obtained from spontaneous complaints about odors is a poor method [1] of measuring community reaction towards an odor pollution problem. A properly developed and implemented public attitude survey can yield results related to annoyance in the community.

TABLE 2.2: A Summary of Odor Regulations in Canada

Province or City	Ambient or Source Emission Standard	Odor Nuisance	Odor Level Specified	
			Ambient Air	Source Emission
British Columbia	Ambient	Yes	-	-
Manitoba	Ambient	-	Yes	-
Ontario	Ambient	Yes	-	-
Quebec	Source	No	-	Yes
Montreal	Both	Yes	-	99% reduction from Process

III. DEVELOPMENT AND IMPLEMENTATION OF AN ODOR ATTITUDE SURVEY

Regulatory agencies are often embarassed when environmental disputes between odorous sources and their surrounding communities are to be resolved through legal court proceedings or quasi-legal environmental hearings. To be successful in these encounters, a regulatory agency must be able to answer the three fundamental questions -

- is there a "recognizable" odor problem in the community?
- "how bad" is the odor?
- "how much" odor is there?

Considering, the first basic question, "Is there a recognizable odor problem in the community?", records show that over several years many residents in the neighborhoods of odorous sources have complained regularly and vigorously about odor problems. In certain communities, as many as 40 complaints have been registered by some residents in one year [13]. It is important to appreciate that one or two complaints per year have been generated by many other residents in the same communities during the same period. Generally the number of different complainers is less than 15% of the number of documented residences. Although many complaints are validated by members of air pollution control agencies, municipal engineering or fire departments, no corrective actions are usually taken. In fact, chronic complainers are treated with suspicion by odor emitting source owners and even some regulatory agency personnel.

The problem facing regulatory agencies is how

- to establish that there is a genuine odor problem in the community?
- to prove that spontaneous complainers are not just trouble makers?

Is it possible that chronic complainers are basically normal citizens responding to a definite community odor problem? To resolve this question it becomes necessary to determine whether people in the community under investigation are behaving normally, by comparing their attitudes towards commonly encountered odors with those of citizens in other neighborhoods or a control group. In addition, it is essential that they should be able to spontaneously identify any odors or odorous sources that are responsible for the alleged community problems.

To help regulatory agencies approach odor problems more objectively a public attitude survey was designed and implemented in a number of communities.

A. The Public Attitude Survey

The survey was designed to expose individual attitudes towards commonly encountered odors on the basis of past experiences or prejudices. The ultimate goal was to determine if there were any odors or odorous sources in the neighborhood that would seriously bother the people.

1. Formulation of Questions

Questions were modified several times during preliminary field trials to accomplish the objective of the survey. The final version in Appendix III represents the questions after a number of revisions.

The questions were worded so that they could be understood by both young and old as well as people with limited educational backgrounds. During preliminary trials, changes were made after

- people complained that the questions were not clear enough
- participants had difficulty completing the questionnaire
- individuals found it difficult to record responses
- complaints were made that the questionnaire was too long.

Questions 1 to 5 were included to provide data that might relate responses to the backgrounds of the participants. Although questions 6 to 31 were formulated specifically to de-emphasize the objective of the survey, they helped to establish the hedonic ratings [pleasantness-unpleasantness] of various odors commonly encountered in any community.

The basic objective was to be achieved from answers to the question "What smells in the air seriously bother you? Please list" which was introduced as Question number 32.

The format of Question 33 is flexible and is designed to determine the citizen reactions to changes in the character of the odor in the community as a result of implementation of specific odor control techniques to an offending odorous source. The example in Appendix III was formulated to assess the application of hypochlorite solutions to the control of odors from fast food restaurants.

The number of questions was limited to 33 in order to enable the participants to complete the questionnaire in 5 to 10 minutes.

2. Recording Responses

Every effort was made to simplify the recording of responses. Experience showed that individuals resisted quantifying their reactions numerically to any particular odor. In all the preliminary surveys, the young, old, educated and uneducated were prepared to respond in general terms using expressions such as 'OK', 'Not at All' and 'Very Much'. In order to simplify the field activities respondents were simply asked to circle the arrows that most closely represented their attitudes ranging from "Not At All to "Very Much" as illustrated in Appendix III. For statistical purposes, a scale ranging from -10 to +10 was used to quantify the responses varying from "Not At All" to "Very Much".

B. Implementation of the Survey

The optimized version of the public attitude survey was presented to people in the neighborhoods surrounding

- a fast food restaurant
- a municipal waste treatment plant
- an automotive paint application facility
- a foundry
- an active municipal waste landfill site.

An indoor shopping mall in Windsor, Ontario was selected as a control area since it provided responses from different parts of the city as well as from out of town visitors.

In each community, residents were selected on a random basis. The responses were obtained voluntarily, with no compulsion. Care was taken to ensure that the presence of the survey team would not create any feelings of antagonism towards any existing or potential odor emitting sources by emphasizing the scientific nature of the investigation. The survey teams were made up of individuals who had no knwoledge of the alleged odor problems in any of the communities under investigation.

In every neighborhood, many citizens refused to complete the survey because of apathy, defeatism or fear. Statements like "we have complained a number of times but nothing has happened", "this has been going on for many years", "I am very busy and have no time for that", were heard many times. In some apartment buildings close to odorous sources, the managers refused to cooperate. They claimed that they did not want tenants upset by such surveys. This was most common in areas where community action groups were organizing support against the suspected odorous sources.

C. Results of the Survey

1. Analysis of Hedonic Ratings

Table 3.1 compares the hedonic ratings, of twenty-six commonly encountered odors, as expressed by residents in the communities surrounding the five selected odorous sources with those in a control area and a similar study of 146 odor descriptors reported by Dravnieks et al. [28,29]. For comparison purposes, the Dravnieks data were multiplied by a factor of 2.5 to convert the ratings from a -4.0 to +4.0 scale to the -10 to +10 scale used in this investigation.

According to Table 3.1, the overall community attitudes toward different odors are essentially identical in all the areas surveyed. It must be emphasized that in every neighborhood there are individuals whose appreciation of several odors would be distinctly different from the community average. A detailed analysis of Table 3.1 shows that, generally, people do not like the smell of

- gasoline
- paint
- cigarettes
- locker/dressing rooms
- ammonia,
- car/truck fumes

TABLE 3.1: Hedonic Ratings of Odors Expressed by People in Various Communities, The Control Group and Those Published by Dravnieks et al. [28]

Odor Description	Control Group	Fast Food Restaurant	Sewage Plant	Paint Auto-Plant Upwind	Paint Auto-Plant Downwind	Landfill Site	Foundry	Dravnieks et al. [28]
cut grass	+2.6	+0.7	+ 3.7	+ 2.1	+ 2.2	+2.5	+ 2.8	-
car/truck fumes	-8.9	-9.1	- 9.7	- 8.7	- 9.6	-9.3	- 9.1	-
fried chicken outlets	-0.7	-1.3	+ 0.4	- 1.1	- 1.4	-0.8	- 1.4	-
sewers	-9.6	-	- 9.9	-10.0	-10.0	-9.9	-10.0	-9.2
vinegar	-3.9	-5.3	- 4.0	- 3.0	- 4.0	-5.3	- 2.9	-3.2
garbage	-9.8	-9.6	-10.0	-10.0	-10.0	-9.9	- 9.8	-9.4
hospital	-4.7	-5.2	- 5.7	- 4.1	- 6.4	-5.4	- 4.2	-4.0
fruit market	+2.0	-	- 1.0	+ 1.2	+ 1.1	+0.5	+ 1.8	-
gasoline	-5.5	-3.8	- 7.5	- 5.0	- 6.9	-5.6	- 6.4	-2.9
hamburger restaurants	-0.9	-2.2	- 2.1	- 2.6	- 1.2	-1.8	- 2.3	-
fresh popcorn	+4.7	+2.2	+ 4.2	+ 4.8	+ 5.0	+5.2	+ 3.9	+6.2
ammonia	-8.5	-8.2	- 8.2	- 7.6	- 8.9	-8.6	- 7.2	-6.2
paint	-5.9	-5.8	- 6.1	- 5.4	- 8.4	-5.1	- 5.5	-1.9
roses	+7.4	+6.0	+ 6.7	+ 7.3	+ 9.0	+7.3	+ 8.3	+7.7
beer	-1.6	-0.7	- 3.5	- 2.0	- 2.7	-2.9	- 4.3	-0.4
outside chinese restaurant	-0.7	-0.7	- 2.0	- 2.8	- 2.5	-1.8	- 2.7	-
locker/dressing room	-8.4	-7.4	- 8.9	- 8.2	- 9.0	-8.2	- 9.0	-
baking bread	+7.9	+6.0	+ 7.8	+ 7.4	+ 6.6	+7.7	+ 8.8	-
wood fire	+6.0	+1.8	+ 4.2	+ 5.8	+ 2.3	+5.0	+ 6.5	-
chocolate	+5.0	+3.2	+ 4.2	+ 4.2	+ 3.8	+3.5	+ 3.8	+4.1
cigarettes	-7.8	-6.5	- 7.2	- 6.5	- 7.1	-6.3	- 6.9	-
carnival	-1.5	-2.4	- 2.2	- 2.9	- 2.1	-3.0	- 2.3	-
peanuts	+2.8	+0.5	+ 2.2	+ 2.9	+ 2.9	+2.9	+ 3.0	-
barbeque	+6.2	+6.0	+ 5.0	+ 5.8	+ 5.2	+5.7	+ 5.6	+5.9
leather jacket	+1.3	+0.1	- 1.6	- 0.2	- 1.7	-0.7	- 1.9	-
coffee	-	-	+ 2.7	+ 3.3	+ 3.9	+4.2	+ 5.8	+5.8
Number of People	109	53	47	46	52	282	60	429

- sewers
- garbage.

On the other hand, they do like the odors associated with

- baking bread
- a barbeque
- roses
- wood fires
- chocolate
- fresh popcorn.

However, they are neutral with respect to the odors common to

- fried chicken outlets
- hamburger establishments
- Chinese restaurants.

From the survey results of 649 people, it is possible to separate the 26 commonly encountered odors into the three categories

- pleasant
- neutral
- unpleasant

on the basis of the hedonic ratings falling in the ranges 10 to 5, 5 to -5, or -5 to -10, respectively. Table 3.2 shows the three classifications.

TABLE 3.2: Three Categories of Odors Based on Their Pleasantness, Neutrality and Unpleasantness.

Pleasant	Neutral	Unpleasant
roses	cut grass	garbage
barbeque	fried chicken outlet	sewers
baking bread	hamburger restaurant	car/truck fumes
	vinegar	ammonia
	beer	gasoline
	fruit markets	paint
	outside Chinese restaurant	cigarettes
	carnival	locker/dressing room
	peanuts	hospital
	coffee	
	fresh popcorn	
	leather jacket	
	chocholate	
	wood fire	

Figures 3.1 to 3.7 compare the hedonic ratings expressed by the different communities and Dravnieks data to the ratings by the control group. Table 3.3 summarizes the results of statistical to test for paired data. The good agreements between the ratings from the various communities, Dravnieks data and the control group illustrate the consistency of people's responses to common odors. Such a generality suggests that citizen reactions to odors in the neighborhoods of various odorous sources are no different from those in the control area. Consequently their spontaneous complaints can be interpreted as honest responses to offensive odors and not simply as frivolous exercises by neighbors who may be antagonistic towards a particular facility.

The data from the community in the vicinity of the solid waste landfill site, where 282 people had responded, indicated that

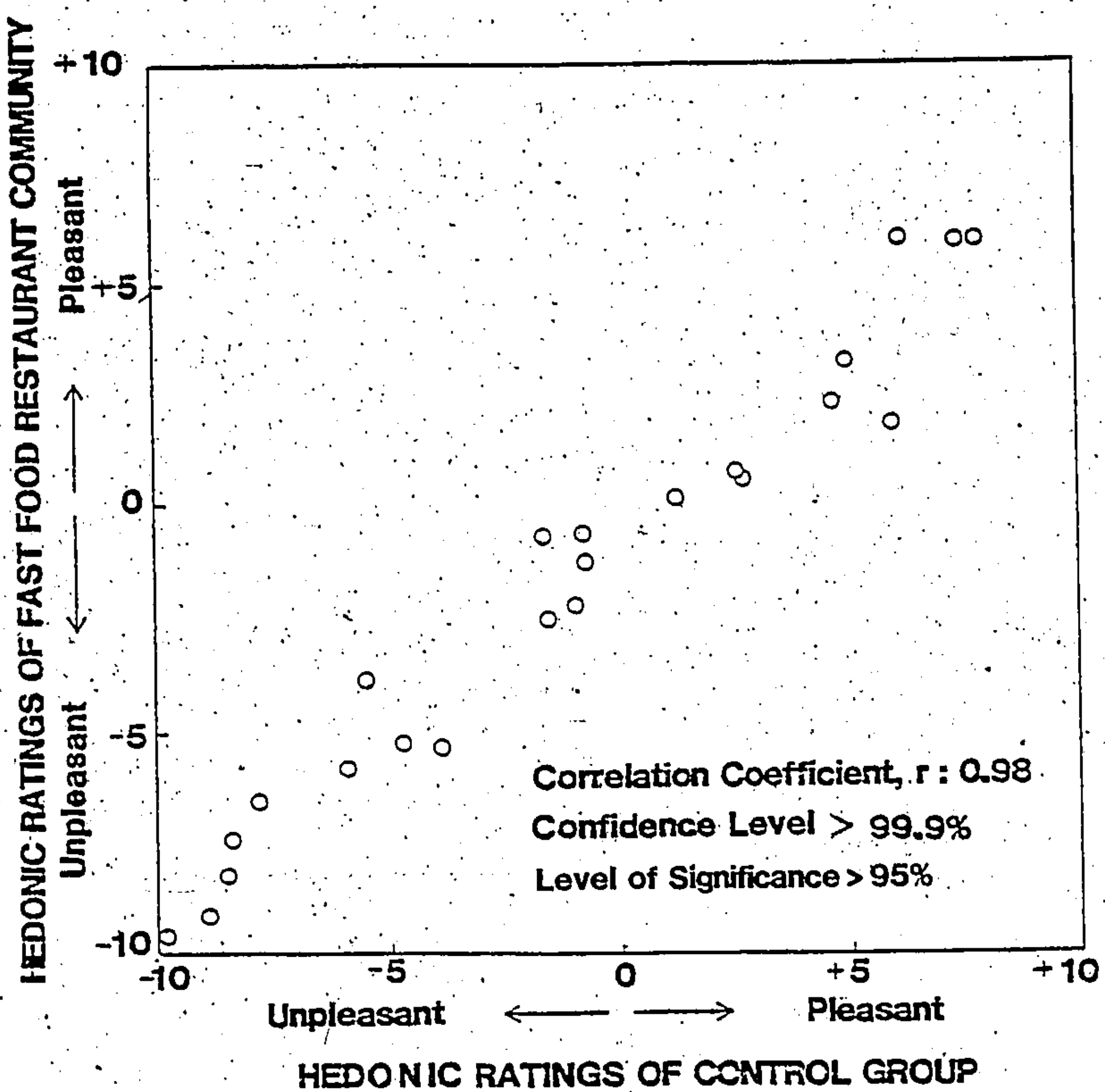

FIGURE 3.1: Correlation Between Hedonic Ratings of Odors Expressed by People in the Neighborhood of the Fast Food Restaurant and the Control Group

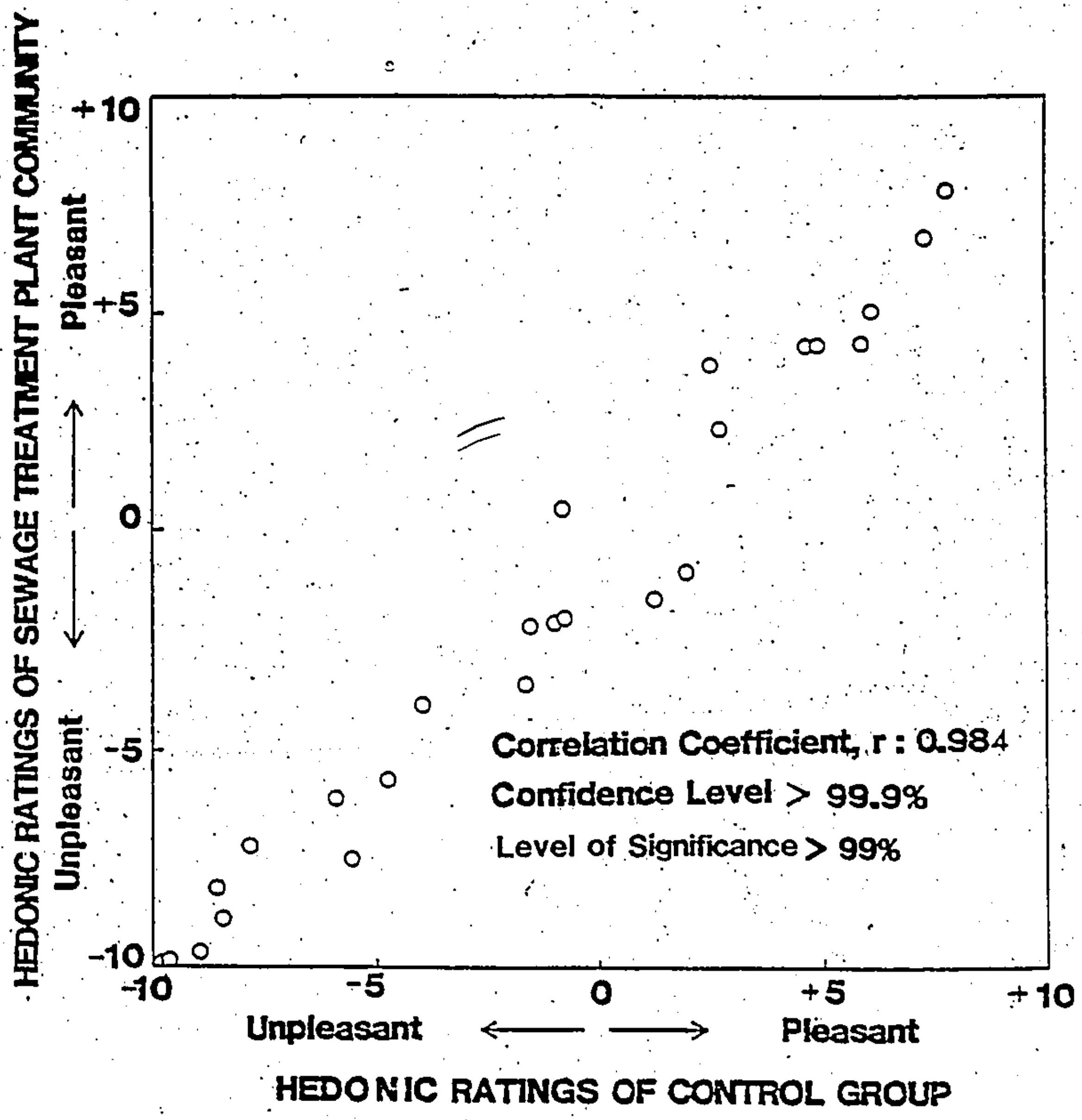

FIGURE 3.2: Correlation Between Hedonic Ratings of Odors Expressed by Residents in the Neighborhood of the Sewage Treatment Plant and the Control Group

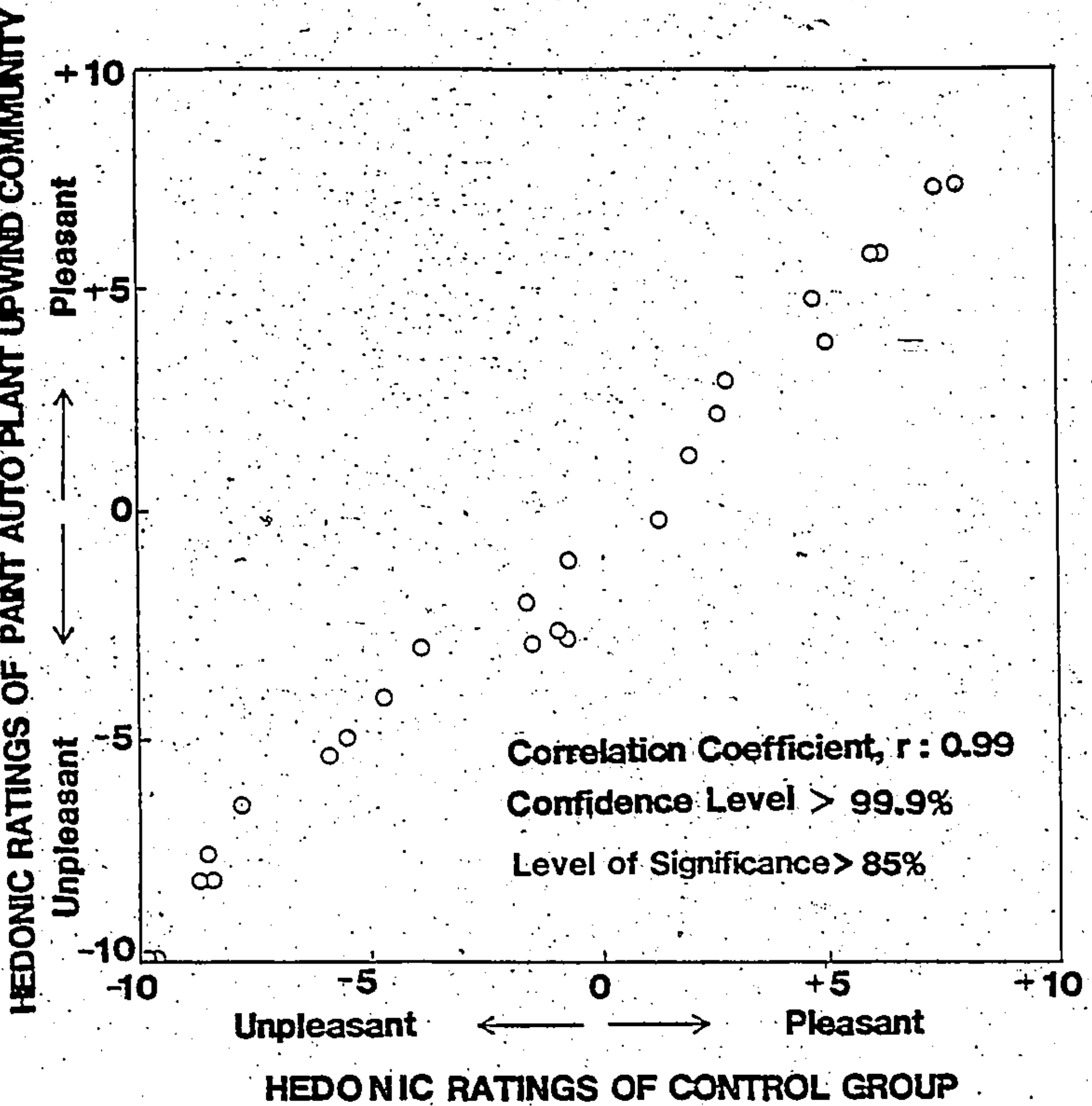

FIGURE 3.3: Correlation Between Hedonic Ratings of Odors Expressed by the Residents in the Upwind Community of the Paint-Auto Plant and the Control Group

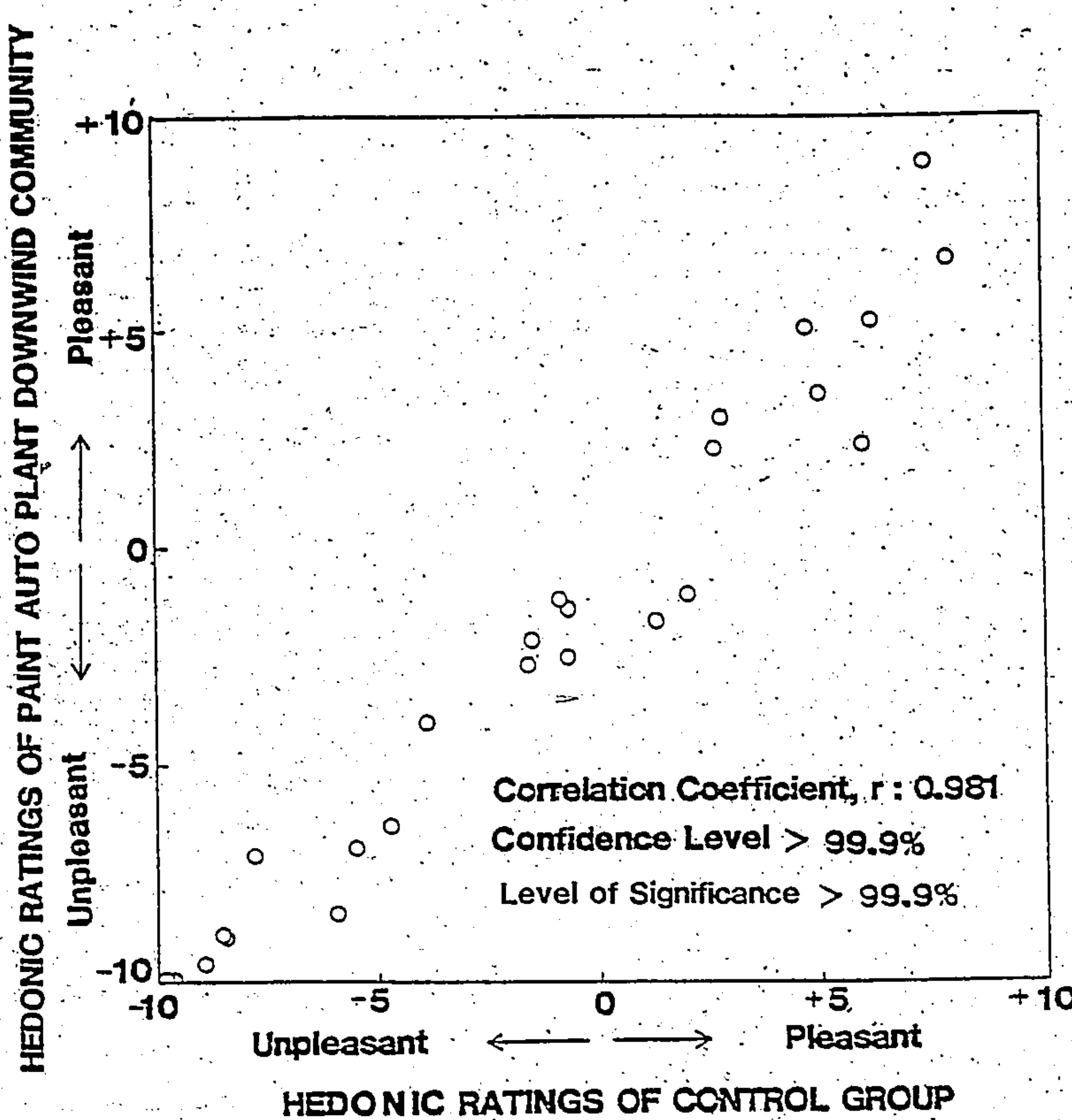

FIGURE 3.4: Correlation Between Hedonic Ratings of Odors, Expressed by the Residents in the Downwind Area of the Paint-Auto Plant and the Control Group

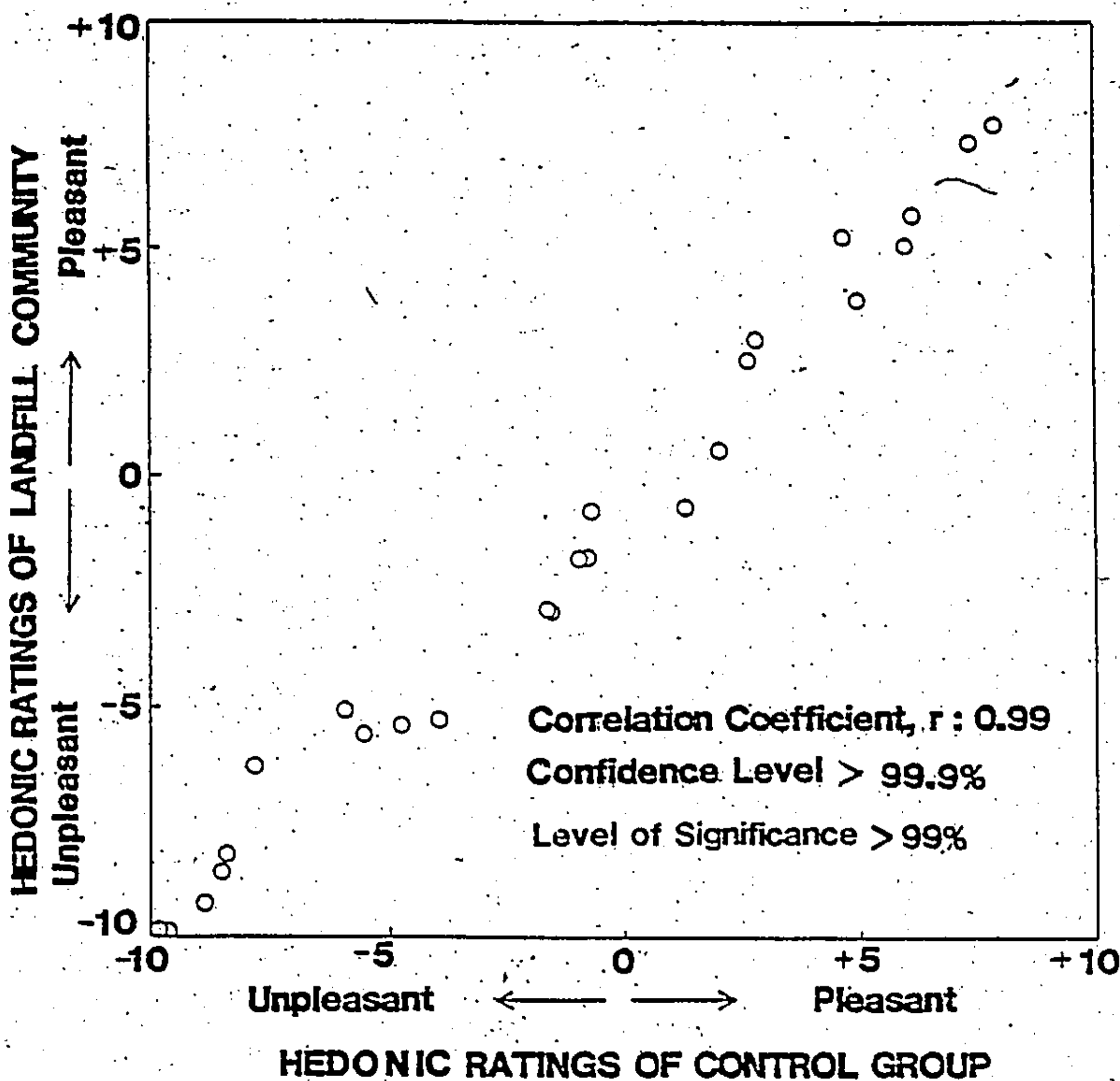

FIGURE 3.5: Correlation Between the Hedonic Ratings of Odors Expressed by the Community in the Neighborhood of the Active Solid Waste Landfill Site and the Control Group

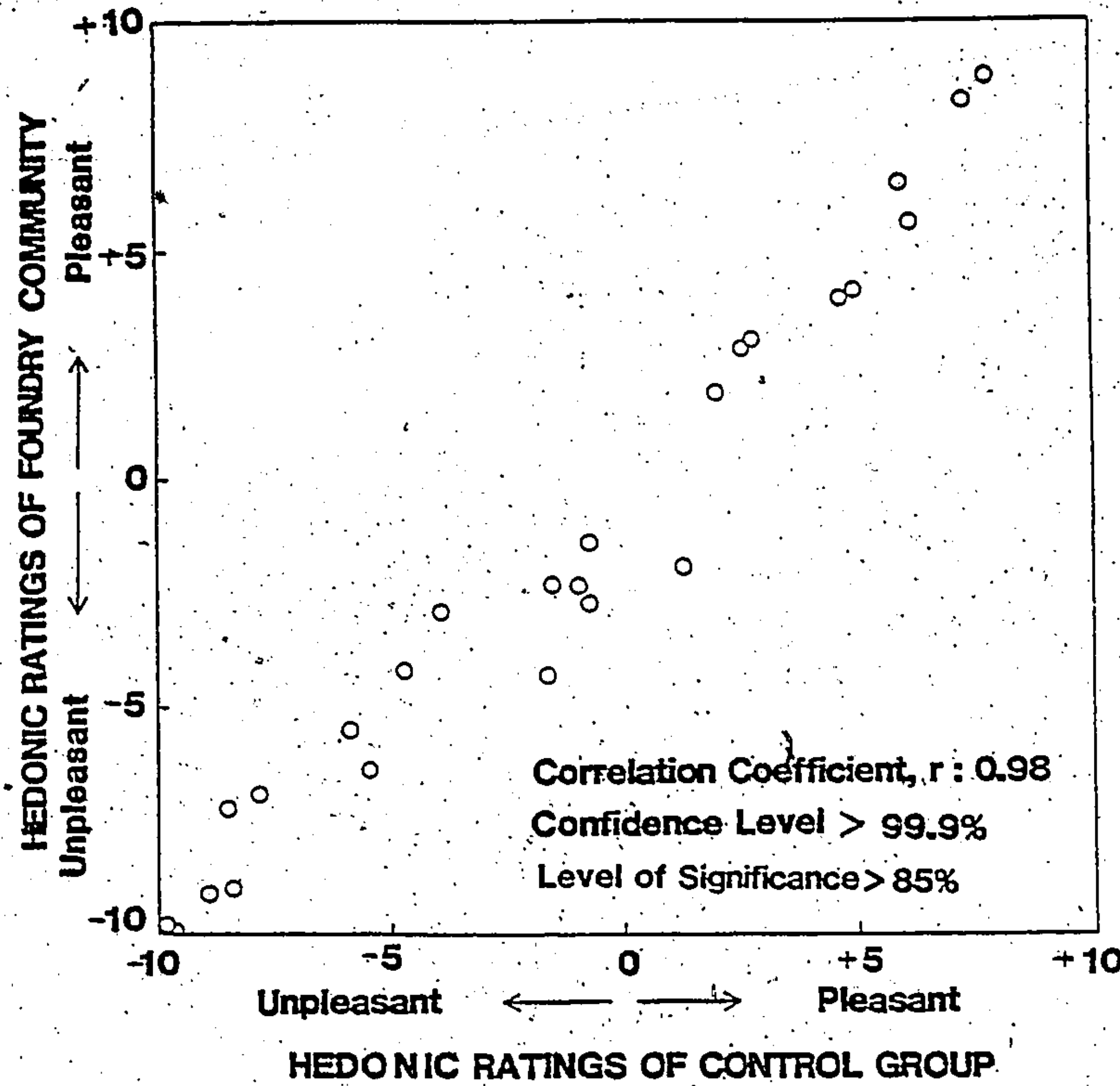

FIGURE 3.6: Correlation Between the Hedonic Ratings of Odors Expressed by the Residents in the Neighborhood of the Foundry and the Control Group

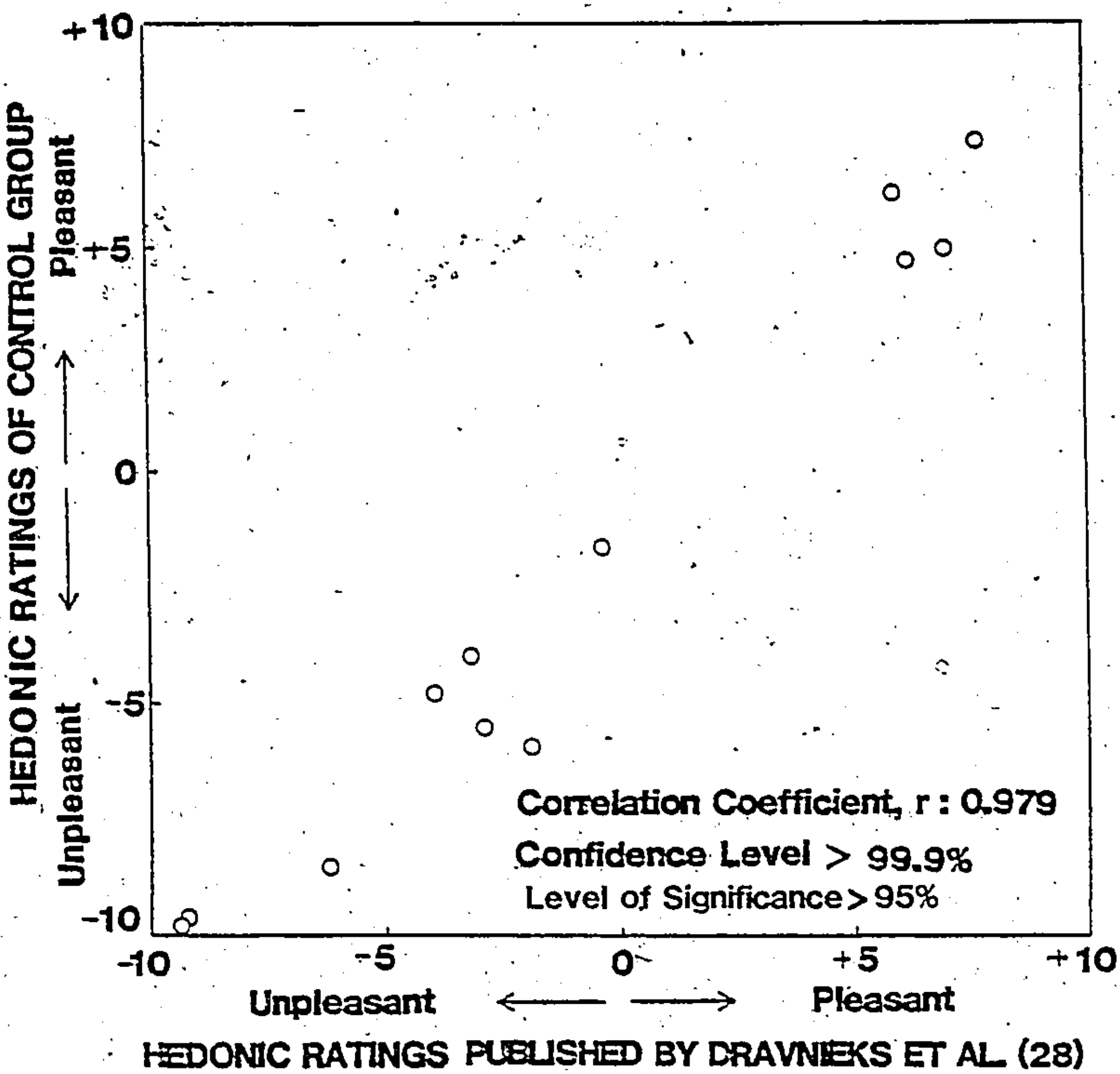

FIGURE 3.7: Correlation Between Hedonic Ratings of Odors Expressed by the Control Group and Those Published by Dravnieks et al. (18)

TABLE 3.3: Comparison of Computed and Tabulated Values of t for Various Levels of Significance

Control Group v_s	Calculated t	Tabulated Values of t			
		α* = 0.001	α = 0.01	α = 0.05	α = 0.1
Fast Food	2.541	3.792	2.819	2.074	1.717
Landfill	2.878	3.745	2.797	2.064	1.711
Sewage	3.591	3.745	2.797	2.064	1.711
Foundry	1.562	3.745	2.797	2.064	1.711
Dravnieks	2.750	4.437	3.106	2.201	1.796
Paint Auto Upwind	1.460	3.745	2.797	2.064	1.711
Paint Auto Downwind	3.778	3.745	2.797	2.064	1.711

*Level of Significance

the age of respondents can affect their hedonic ratings of odors. Table 3.4 correlates the hedonic values of odors for the different age groups, along with the weighted averages and the standard deviations from the average values.

A comparison of these data shows that teenagers do not like the smell of

- cut grass (-0.7)
- coffee (-2.0)

whereas other age group ratings varied from

- +2.0 to +4.6 for cut grass
- +3.1 to +8.0 for coffee.

On the other hand teenagers do like the smells associated with

- fried chicken outlets (+1.7)
- hamburger establishments (+1.3)
- Chinese restaurants (+1.0)
- leather jackets (+0.7).

Other age groups rated these odors to be neutral to negative with values ranging from

- -0.2 to -2.8 for fried chicken outlets,
- -1.3 to -5.0 for hamburger establishments
- -0.5 to -4.2 for Chinese restaurants
- -0.3 to -5.0 for leather jackets.

An analysis of the standard deviations of hedonic ratings from the average values shows that people in the 20 to 49 age group

TABLE 3.4: Hedonic Ratings of Odors, Expressed by the Residents in the Neighborhood of the Landfill Site According to Their Age Groups, Along with the Weighted Average for All and the Standard Deviations from the Average Values for the Various Odors.

Odor Description	10-19	20-29	30-39	40-49	50-59	60-69	70-up	Average	10-19 ± SD	20-29 ± SD	30-39 ± SD	40-49 ± SD	50-59 ± SD	60-69 ± SD	70-up ± SD
cut grass	- 0.7	+ 2.1	+ 3.1	+ 4.1	+ 4.6	+ 2.9	+ 2.0	+ 2.5	3.2	0.4	0.6	1.6	2.1	0.4	0.5
car/truck fumes	-10.0	- 9.1	- 9.0	- 9.4	- 9.4	- 9.3	-10.0	- 9.3	0.7	0.2	0.3	0.1	0.1	0.0	0.7
fried chicken outlets	+ 1.7	- 0.2	- 0.2	- 2.8	- 1.9	- 1.7	- 2.0	- 0.8	2.5	0.6	0.6	2.0	1.1	0.9	1.2
sewers.	- 9.3	-10.0	-10.0	- 9.7	-10.0	- 9.9	-10.0	- 9.9	0.6	0.1	0.1	0.2	0.1	0.0	0.1
vinegar	- 6.3	- 6.5	- 6.1	- 5.9	- 3.7	- 2.1	- 2.0	- 5.3	1.0	1.2	0.8	0.6	1.6	3.2	3.3
garbage	-10.0	-10.0	- 9.9	-10.0	-10.0	- 9.9	- 9.0	- 9.9	0.1	0.1	0.0	0.1	0.1	0.0	0.9
hospital	- 6.7	- 5.8	- 5.6	- 6.3	- 5.4	- 3.5	- 3.0	- 5.4	1.3	0.4	0.4	0.9	0.0	1.9	2.4
fruit market	+ 5.0	+ 0.6	0.0	- 0.6	- 1.2	+ 0.9	+ 1.5	+ 0.5	4.5	0.1	0.1	1.1	1.7	0.4	1.0
gasoline	- 5.0	- 5.8	- 5.4	- 5.0	- 4.6	- 6.0	- 7.0	- 5.6	0.6	0.2	0.2	0.6	1.0	0.4	1.4
hamburger restaurants	+ 1.3	+ 0.7	- 1.3	- 2.5	- 4.2	- 2.9	- 5.0	- 1.8	3.1	2.5	0.5	0.7	2.4	1.1	3.2
fresh popcorn	+ 5.7	+ 5.5	+ 5.6	+ 4.7	+ 4.4	4.7	+ 5.5	+ 5.2	0.5	0.3	0.4	0.5	0.8	0.5	0.3
ammonia	- 9.0	- 8.8	- 9.7	- 8.8	- 6.3	- 7.9	- 7.0	- 8.6	0.4	0.2	1.1	0.2	2.3	0.7	1.6
paint	- 4.3	- 5.0	- 5.4	- 6.3	- 5.6	- 4.5	- 4.5	- 5.1	0.8	0.1	0.3	1.2	0.5	0.6	0.6
roses	+ 6.0	+ 7.3	+ 6.8	+10.0	+ 7.7	7.3	+ 6.0	+ 7.3	1.3	0.0	0.5	2.7	0.4	0.0	1.3
beer	0.0	- 1.6	- 3.9	- 3.4	- 5.6	- 3.9	- 1.5	- 2.9	2.9	1.3	1.0	0.5	2.7	1.0	1.4
outside a chinese restaurant	+ 1.0	+ 0.5	- 1.5	- 3.1	- 4.2	- 4.0	- 4.0	- 1.8	0.8	1.3	0.3	1.3	2.4	2.2	1.4
locker/dressing room	- 8.7	- 8.4	- 9.1	- 8.4	- 9.0	- 6.5	- 5.6	- 8.2	0.5	0.2	0.9	0.2	0.8	1.7	2.6
baking bread	+ 6.0	+ 7.5	+ 7.4	+ 9.1	+ 8.3	+ 9.0	+ 5.0	+ 7.7	1.7	0.2	0.3	1.4	0.6	1.3	2.7
wood fire	+ 3.0	+ 5.0	+ 4.5	+ 5.9	+ 6.7	+ 5.9	+ 1.5	+ 4.9	1.9	0.0	0.4	0.9	1.7	0.9	3.4
chocolate	+ 3.0	+ 3.5	+ 3.8	+ 5.0	+ 5.0	+ 3.5	+ 5.5	+ 3.8	0.8	0.3	0.0	1.2	1.2	0.3	1.7
cigarettes	- 7.7	- 6.1	- 7.0	- 5.0	- 4.6	- 6.6	- 6.5	- 6.3	1.4	0.2	0.7	1.3	1.7	0.3	0.2
carnival	- 2.3	- 3.1	- 2.6	- 2.5	- 3.4	- 2.8	- 3.3	- 3.0	0.7	0.1	0.4	0.5	0.4	0.2	0.3
peanuts	0.0	+ 2.4	+ 2.4	+ 3.1	+ 3.8	+ 5.8	+ 3.0	+ 2.9	2.9	0.5	0.5	0.2	0.9	2.9	0.1
barbeque	+ 5.7	+ 6.9	+ 6.1	+ 6.6	+ 3.3	+ 4.3	+ 3.5	+ 5.7	0.0	1.2	0.4	0.9	2.4	1.4	2.2
leather jacket	+ 1.3	+ 0.7	- 1.9	- 0.3	- 1.3	- 1.5	- 5.0	- 0.7	2.0	1.4	1.2	0.4	0.6	0.8	4.3
coffee	- 2.0	+ 3.1	+ 4.3	+ 5.9	+ 7.3	+ 5.6	+ 8.0	+ 4.2	6.2	1.1	0.1	1.7	3.1	1.4	3.8

are more representative of the community than teenagers or citizens in the over 50 age bracket.

Using standard deviations of ±1.5 as an arbitrary basis, odors can be grouped into two categories. In Table 3.5 category I represents those odors about whose hedonic ratings there was close agreement among all age classifications. Category II includes those odors for which there were significant differences in hedonic ratings from the different age groups.

TABLE 3.5: Two Categories of Odors Based on Agreement Among the Various Age Groups

Category I (All Age groups Agree)	Category II (Disagreement Among Age Groups)
car/truck fumes	cut grass
sewers	fried chicken outlets
garbage	vinegar
gasoline	hospital
fresh popcorn	fruit market
paint	ammonia
carnival	roses
	beer
	outside Chinese restaurant
	locker dressing room
	baking bread
	woodfire
	chocolate
	cigarettes
	peanuts
	barbeque
	leather jacket
	coffee

From Table 3.5, it is evident that people of all age groups agree closely on the hedonic ratings of most of the offensive odors. However there is considerable difference of opinion about the hedonic ratings of most of the neutral and pleasant odors.

2. Identification of Odor Sources in a Community

The answers to Question 32 help to confirm the validity of spontaneous complaints which are generally generated by less than 15% of residential sites.

Table 3.6 provides the responses to Question 32, "What odors in the air seriously bother you?". The descriptions and frequencies of identification of odors encountered in the various locations provide a means of defining the odorous source or sources creating the alleged odor problems in the different communities.

From Table 3.6, it is apparent that people in the control group, who represent a highly heterogenous community, are bothered seriously by the smells associated with

- cigarette smoke
- auto and truck emissions
- factory pollution
- gasoline
- garbage
- sewers
- skunks.

TABLE 3.6: Description and Frequency of Identification of Odors Encountered by Residents in the Six Communities and the Control Group

Description of Odor	Percent People Seriously Bothered						
	Control Group	Fastfood Restaurant	Sewage Treatment Plant	Paint-Auto Plant Upwind	Paint-Auto Plant Downwind	Landfill Site	Foundry
Cigarette Smoke	28	7	6	20	4	8.5	17
Auto Emissions	22	23	9	24	15	17.0	18
Pollution	22	9	4	13	4	1.8	8
Bus & Truck Fumes	21	28	26	11	12	12.6	15
Gasoline	13	8	4	4	12	5.9	-
Garbage	11	21	6	17	10	76.0	10
Sewers	9	-	11	4	17	8.0	7
Sulphur	9	9	9	6	-	1.0	-
Skunk	5	-	17	11	4	4.3	-
Strong Perfumes	4	-	-	-	-	2.0	-
Foundry	3	-	-	-	-	-	48
Ammonia (bleach)	2	2	2	2	-	0.4	-
Tar Roofing (hot asphalt)	2	2	13	2	2	1.0	-
Burning Rubber	2	-	-	-	2	0.4	3
Methane	2	-	-	2	-	-	-
Sewage Treatment Plant	2	-	34	-	-	-	-
Melting Metal Fumes	3	-	-	2	-	-	-
Brewery	2	-	6	2	2	-	5
Burning Leaves	2	-	-	-	-	2	-
Factory Smoke	-	26	26	30	4	13.5	-
Burning Garbage	-	2	-	-	-	-	-
Paint Fumes	1	4	-	15	79	2	-
Fertilizer	-	4	2	4	-	2	-
Smells from Factories in Detroit	1	9	2	-	-	-	-
Smells from Garbage Plant	-	2	-	-	-	-	-
Ammonium Hydroxide	-	2	-	-	-	-	-
Smells from Zug Island	1	2	6	-	2	-	-
Dust	-	2	-	-	2	-	-
Insecticide	-	2	-	2	-	-	-
Fastfood Restaurant	1	2	-	-	-	-	-

In addition to these odors, residents living in any neighborhood might also be bothered by the odors associated with certain industrial or commercial operations existing in their locality.

For example, in the case of the community in the neighborhood of the fast food restaurant, only 2% of the people were bothered by the fast food odors. This community response is consistent with the total absence of complaints about fast food odors to the local air pollution control agency office. The location of the facility is in a very high traffic density region (51% annoyance by autos, buses and trucks) which is subjected to industrial emissions from the U.S. side of the Detroit River causing annoyance among 37% of the respondents. In addition 23% of the residents were disturbed as a result of being on the direct route of garbage trucks moving to and from a private waste hauling parking area.

In the neighborhood of the sewage treatment plant, 34% of the residents surveyed were bothered by this operation. This significant adverse response validates the spontaneous complaints recorded by the local regulatory agency. The annoyances registered against bus and truck fumes (26%) reflects the community's proximity to a major highway. Fallout of particulate matter and odors from industrial operations across the Detroit River are responsible for the 32% adverse reactions to factory smoke and smells from Zug Island.

Residents living upwind from the automotive paint application facility were bothered more by automobile emissions (24%) and general factory smoke (30%) than by paint fumes (15%). It must be appreciated that the 15% annoyance level is sufficient to generate more than 12 complaints in six months and encourage the citizens to join a community action group. Seventy-nine percent of those surveyed in the downwind community identified the upwind paint application facility as the source of community odor problems. A well organised community action group is led by people from this area. They have enlisted the aid of municipal and provincial politicians to help solve their problem.

The 76% of the residents surveyed in the neighborhood of the landfill site who identified garbage odor as a community problem represents more individuals than the total number of complainers documentated over a two year period. In other communities, including the control area, garbage odors were listed as problems by less than 25% of the respondents. With 76% of those surveyed in the landfill community identifying garbage odors as a serious problem, there is no doubt that the landfill site is creating a detrimental effect on the air quality in that locality. The activites of the citizen action group that forced an environmental hearing emphasized the seriousness of the odor pollution problem.

In the neighborhood of the foundry, a citizen action group has enlisted the support of municipal and provincial politicians who encourage regular public and private meetings between the community, foundry operators and regulatory agency members. The spontaneous complaint level leading to the formation of the action group is confirmed by the 48% of those surveyed who identified foundry odors as bothersome.

3. Reaction to Changes in Odor Character

Question 33 was formulated specifically to assess citizen reactions to changes in the character of the odor in the community as a result of treatment of fast food restaurant odors with hypochlorite scrubbing solutions.

Table 3.7 shows the average ratings of five specific odors by the respondents in various localities, on a scale of 1 to 5, where

- 1 = the best
- 5 = the least.

It is evident that the smells associated with hay, a hamburger restaurant and a swimming pool are ranked at the same level, whereas barbeques and garbage are at the extreme of the scale for the best and the least preferred odors, respectively.

The data in Table 3.7 suggest that installation of expensive scrubbing devices using hypochlorite solution can be as objectionable or worse than the original fast food odors if excess chlorine odors are omitted to the neighborhood.

4. Validation of Spontaneous Complaints

On the basis of public attitude surveys carried out in 7 different complaint boudaries, it is evident that idenfication of a specific source by 15% or more of the people surveyed in a locality is indicative of a community odor problem. Regulatory agencies should consider spontaneous complaints from such areas to be real

TABLE 3.7: Comparison of Average Ratings of Five Specific Odors Expressed by the Residents in Six Communities And the Control Group

Odor Description	Control Group	Fast Food Restaurant	Sewage Plant	Paint Auto - Upwind	Plant Downwind	Landfill Site	Foundry
Barbeque	1.6	1.4	1.4	1.6	1.7	1.4	1.8
Hay	2.5	3.1	2.7	2.7	2.6	2.6	2.3
Hamburger Restaurant	2.9	2.8	2.8	3.2	3.4	2.8	3.1
Swimming Pool	3.0	3.0	2.9	2.7	2.6	2.9	2.8
Garbage	5.0	—	5.0	5.0	5.0	4.9	4.9

of poor ambient air quality.

In order to establish the validity of the complaints for legal purposes, it is recommended that regulatory agencies

- survey a representative number of residents of the community in the neighborhood of the suspected odor source
- survey an equally representative number of people in a community which is not directly under the influence of the emissions from the suspected source
- analyze the data from the two locations separately
- compare the hedonic ratings of the respondents from both locations to check if there are any differences in the reactions of people towards commonly encountered odors
- evaluate the percentage of people who are bothered by specific odors in their locality in terms of their responses to Question 32.
- investigate a source or sources if the percentage of people identifying a suspected odor source is 15% or higher.

The results of this exercise by the regulatory agency will provide the answer to the question "Is there a recognizable odor problem in the community?

If it is established that there is a genuine odor problem in a community, it then becomes important to determine

- "how bad" is the odor?
- "how much" odor is there?

IV. QUANTIFICATION OF COMMUNITY ANNOYANCE

At the present time, there are no documented procedures for assessing the magnitude of a community annoyance due to odors. The current methods of data analysis provide only detection thresholds. The ASTM E679 and ranking-plotting methods are described in detail in Appendix I. In order to account for the effects of successful guessing by panelists on the magnitudes of detection thresholds, the maximum likelihood estimator (MLE) model was developed as described in Appendix II.

None of the currently available models provide an overall picture of the impact of an odor pollution problem on a community since they are not designed to quantify the magnitude of the nuisance caused by the odor. Although the maximum likelihood estimator model can, in principle, provide discrimination thresholds (that is, thresholds at which panelists are sure that they can establish the presence of an odorant), it fails to develop any information related to the impact of an odorous stimulus on a neighborhood or a panel of judges in terms of complaint levels or degrees of annoyance which are the most important dimensions for defining an odor nuisance in a locality.

For legal purposes it is necessary to establish some quantification of the offensiveness of an odor at its source and in the downwind community by assigning magnitudes to the odor character at each location.

In order to account for and evaluate the pertinent odor dimensions, a fast, simple and acceptably accurate method of presenting an overall view of an odor impact on a community was developed and applied during this program. This new approach provides a practical procedure for routinely evaluating all the essential odor dimensions including needed probabilities of

- detection
- complaint

as well as predicted degree of annoyance profiles in terms of the Odor Impact Model (OIM) described in detail in Appendix IV.

An existing or potential neighborhood odor impact can now be assessed in the laboratory by a panel of judges representing a community where an odor source is or will be located. The proposed model has been successfully applied to a variety of odorous sources during this program. The detection threshold results agree well with those obtained from ranking-plotting and ASTM methods which provide only detection thresholds.

A. Odor Impact Model

The Odor Impact Model is basically an extension of the detection threshold determination with a five or six level dynamic dilution olfactometer. In addition to identifying the ports that are perceived to be emitting odorous material, panelists are also required to specify the ports at which they are positive about the presence of the odor. This exercise produces the panel discrimination profile. Furthermore, panel members are provided with a preprinted form on which they are asked to indicate at which dilutions they would complain if they were exposed to similar odorous stimuli for an average period of 8 hours.

In addition they must rate their perceived magnitude or intensity of annoyance at each dilution on a scale ranging from 0 to 10 using

- 0 as no annoyance
- 10 as maximum measure of annoyance.

For quantification purposes this scale has been subdivided into 5 categories in order to relate qualitative perceptions of odors to numerical ranges that provide the

- 0 to 2 ≃ tolerable
- 2 to 4 ≃ unpleasant
- 4 to 6 ≃ very unpleasant
- 6 to 8 ≃ terrible
- 8 to 10 ≃ unbearable

zones.

Using this approach an odor panel can provide complete profiles of

- percent probabilities of detection, (PPD)
- percent probabilities of discrimination, (PPDisc)
- percent probabilities of complaint, (PPC)
- predicted degrees of annoyance, (PDA)

for any odor sample. Figure 4.1 illustrates idealized Odor Impact Model profiles.

B. "How Bad" is the Odor?

Laboratory data always indicate that panelists will not complain about an odor until the number of dilutions is reduced well below the detection threshold value.

In order to quantify "how bad" an odor is, it is necessary to determine the dilutions at which some specified fraction or all panel members would complain. Furthermore it is essential to establish their intensity of annoyance at the dilutions corresponding to their complaint thresholds.

In the past, the dilution level at which 50% of a panel could detect the presence of an odor (ED_{50} or D/T) was used to describe the concentration of that odor. Many regulatory agencies specify the ED_{50} (D/T) value in terms of odor units or the number of dilutions to threshold as a level not to be exceeded at the source or in the ambient atmosphere as illustrated in Table 2.1. In effect, this magnitude is a crude measure of "how bad" an odor is.

Intensity has been regarded as a sensory counterpart of odorant concentration [30]. It has been used to express "how weak" or "how strong" an odor might be using, for example, a category scale where

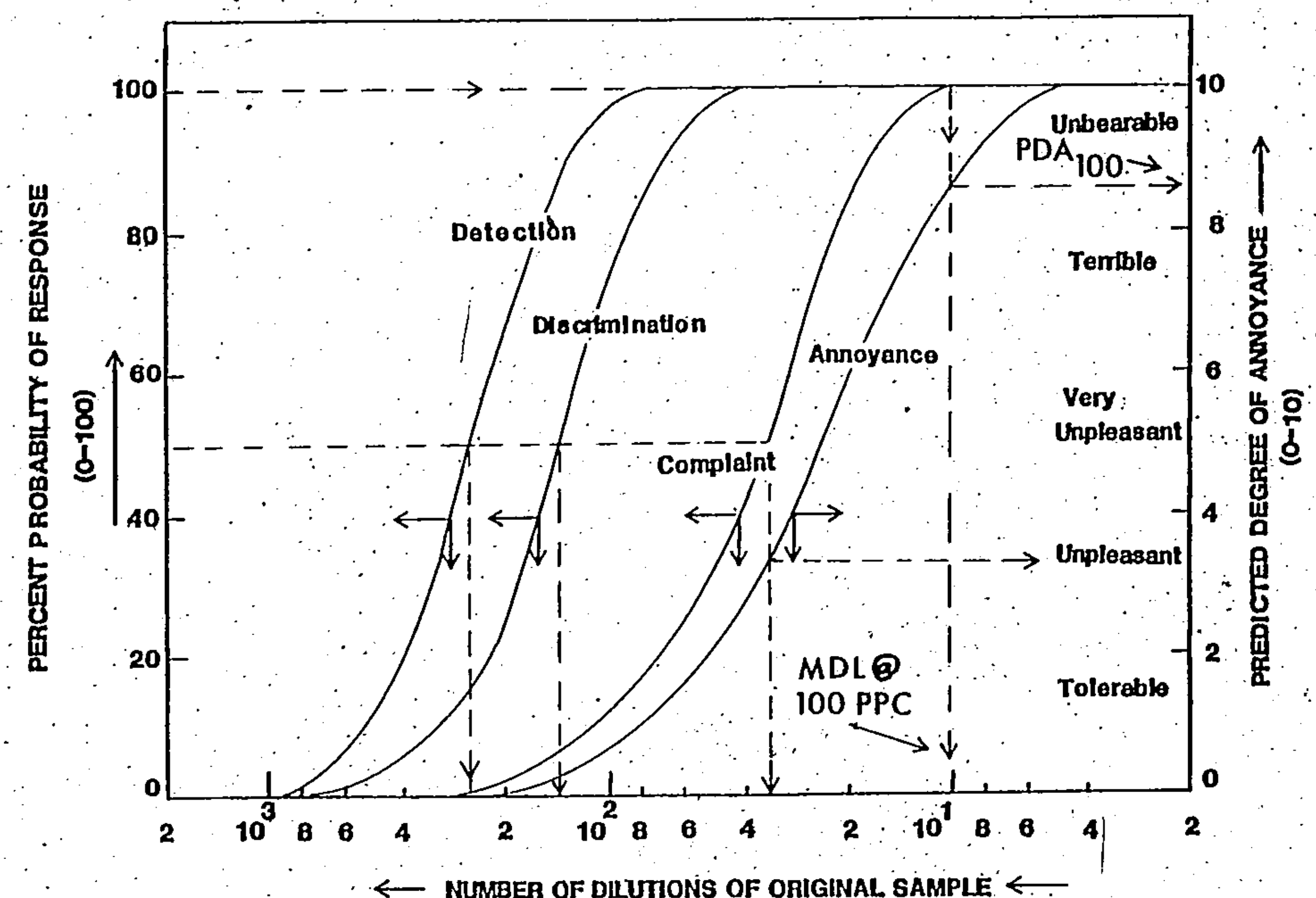

FIGURE 4.1: Idealized Odor Impact Model Profiles

- 1 = very weak
- 2 = weak
- 4 = strong
- 5 = very strong.

However it does not quantify "how bad" an odor really is. Consequently, intensity has not been used by regulatory agencies for control purposes.

The use of ED_{50} (D/T) or intensity magnitudes is of limited value since

- people do not normally complain about an odor at the detection level
- neither accounts for the hedonics of the odor.

Using the Odor Impact Model as the basis, it is possible to describe "how bad" an odor is, in terms of components that quantify

- intensity
- hedonics.

1. <u>Measure of Intensity</u>

The intensity of an odor can be appreciated in terms of an experimentally determined dilution level at which all panel members complain. Such a dilution level is shown in Figure 4.1 as the maximum dilution level at which 100% of the panel members would still complain about the odor under consideration (designated as MDL @ 100 PPC).

2. Measure of Hedonics

The magnitude of annoyance at any dilution level accounts for the hedonics of the odor. In Figure 4.1, the measure of hedonics is provided by the predicted degree of annoyance at 100% probability of complaint, designated as PDA_{100}.

3. Measure of Odor Offensiveness

The offensiveness of an odor is determined by its

- intensity (MDL @ 100 PPC)
- hedonics (PDA_{100}).

On this basis it is possible to quantify "how bad" an odor is in terms of what can be considered as the degree of offensiveness (DO) defined by

$$DO = (MDL @ 100 PPC) \ (PDA_{100}) \quad (1)$$

where

MDL @ 100 PPC = maximum number of dilutions of original sample to 100% complaint threshold, odor units/ft^3 or ft^3/ft^3

PDA_{100} = predicted degree of annoyance at the 100% complaint threshold on a scale of 0 to 10.

The MDL @ 100 PPC is taken as a significant quantity since it is normally an experimentally determined dilution level at which all members of a panel have complained and expressed their personal degree of annoyance on a scale of 0 to 10.

It must be emphasized that the degree of offensiveness (DO) is only a measure of "how bad" an odor is at the source. It does not say anything about the impact on a downwind receptor.

In situations where there are several odor sources at a single facility or several different odor sources in the community, each with different odor hedonics, the DO becomes particularly important as a means of ranking the sources in order of their offensiveness. This ranking becomes indispensable for preliminary prioritization of budget allocations for control equipment for the various sources.

In spite of its importance, it should be apparent that the degree of offensiveness (DO) is not a true measure of the odor impact of any particular odor source on a community without consideration of the amounts of odors emitted per unit time. A low emission rate of an odor with a high DO can be less serious than a high volumetric flow rate of an odor with a relatively lower DO in terms of impact on a downwind community or degree of control required at the source.

C. "How Much" Odor is There?

Traditionally the dilution level at which 50% of a panel cannot detect the presence of an odor (Ed_{50} or D/T) is muliplied by the source volumetric flow rate, Vo, to provide the odor emission rate according to

$$Q = (ED_{50} \text{ or } D/T)\ (V_o) \tag{2}$$

where

Q = odor emission rate, odor units/min or ft^3/min

ED_{50} or D/T = dilution level at 50 percent probability of detection, odor units/ft^3 or ft^3/ft^3 (suggested terminology, DL @ 50 PPD)

V_o = source volumetric flow rate, ft^3/min

This classical odor emission rate does not provide a realistic measure of how much odor there is to deal with because it fails to recognize

- the hedonics of the odor
- that complaints are not generated at the detection threshold level.

A more realistic approach would incorporate the volumetric flow rate with the DO to provide a potential level of source annoyance (PLSA) according to

$$\begin{aligned} PLSA &= (MDL\ @\ 100\ PPC)\ (PDA_{100})\ (V_o) \\ &= (DO)\ (V_o) \end{aligned} \tag{3}$$

The PLSA provides ratings of different odorous sources at a specific facility in terms of their hedonic and volumetric flow parameters. Figure 4.2 illustrates how a number of sources can be ranked in terms of DO and PLSA magnitudes. Although Source #1 is emitting a very obnoxious odor with the highest degree of offensiveness such that

$$DO_1 > DO_2 > DO_3,$$

its impact on the community is less significant than of Sources #2 and #3 which have considerably higher volumetric flow rates since

$$PLSA_1 < PLSA_2 < PLSA_3$$

Successful evaluation of DO and PLSA values will provide answers to the questions

- how bad is the odor?
- how much odor is there?

However, to quantify the impact of a particular source on its surrounding community, it is necessary to assess the ambient odor levels in the neighborhood as a result of atmospheric transport over different distances with due consideration of meteorological and topographical characteristics of the region.

D. Quantification of Odor Impact

Quantification of odor impact on a community can be achieved through appropriate dispersion modelling in conjunction with the Odor Impact Model. Estimates of the number of dilutions of the source emissions at different downwind distances provide measures of PPC and corresponding PDA values from the Odor Impact Model profiles.

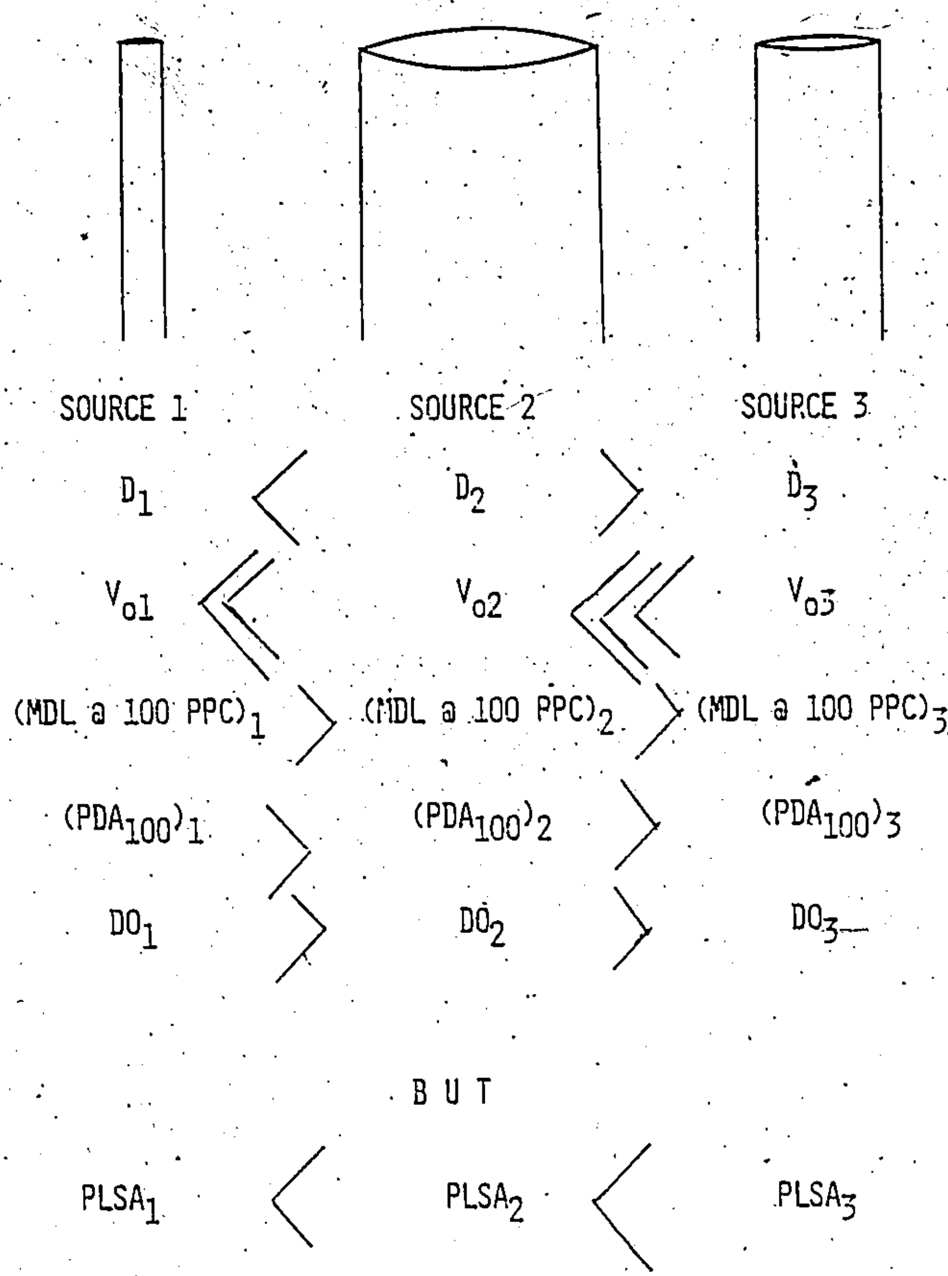

FIGURE 4.2: Sources Ranked in Terms of DO and PLSA Magnitudes

The Potential Odor Impact (POI) in the community at various distances and elevations for a range of meteorological conditions can be expressed as

$$POI = (PPC)(PDA) \tag{4}$$

where

POI = potential odor impact at any location for specified conditions on a scale of 0 to 1000

PPC = percent probability of complaint at any location for specified conditions, on a scale of 0 to 100

PDA = predicted degree of annoyance corresponding to PPC at any location for specified conditions, on a scale of 0 to 10

V. DEVELOPMENT OF EXPERIMENTAL PROCEDURES

A. Description of Equipment for Odor Threshold Determinations

A six level dynamic dilution olfactometer designed by Illinois Institute of Technology Research Institute (IITRI), Chicago, Illinois [5] was used in this program for highly odorous samples. This instrument provides six dilution levels each equipped with a set of three glass sniffing ports. Two of the ports emit deodorized room air (blanks) while the third discharges the odorous gas diluted with deodorized air.

The odorous samples were delivered to the olfactometer from Tedlar bags at a rate of 100 cm^3/min by means of a peristaltic pump. The deodorized dilution air was supplied at a total rate of 9000 cm^3/min. Two manifolds were provided for dividing the odor and air samples into specific ratios. Capillary tubes of different lengths regulated the amounts of samples required to make up the specified dilution levels. Each port delivered approximately 500 cm^3/min of air or odorous sample. The concentrations of odors at each dilution level increased from left to right according to the approximate dilution factors of 1440, 490, 162, 56, 20 and 7.

The instrument could also be extended to provide higher dilutions by the use of attenuators.

A signal box with six triple sets of lights provided panelists inside an odor free room with means of communicating their responses to the panel coordinator. A schematic diagram of the olfactometer is shown in Figure 5.1.

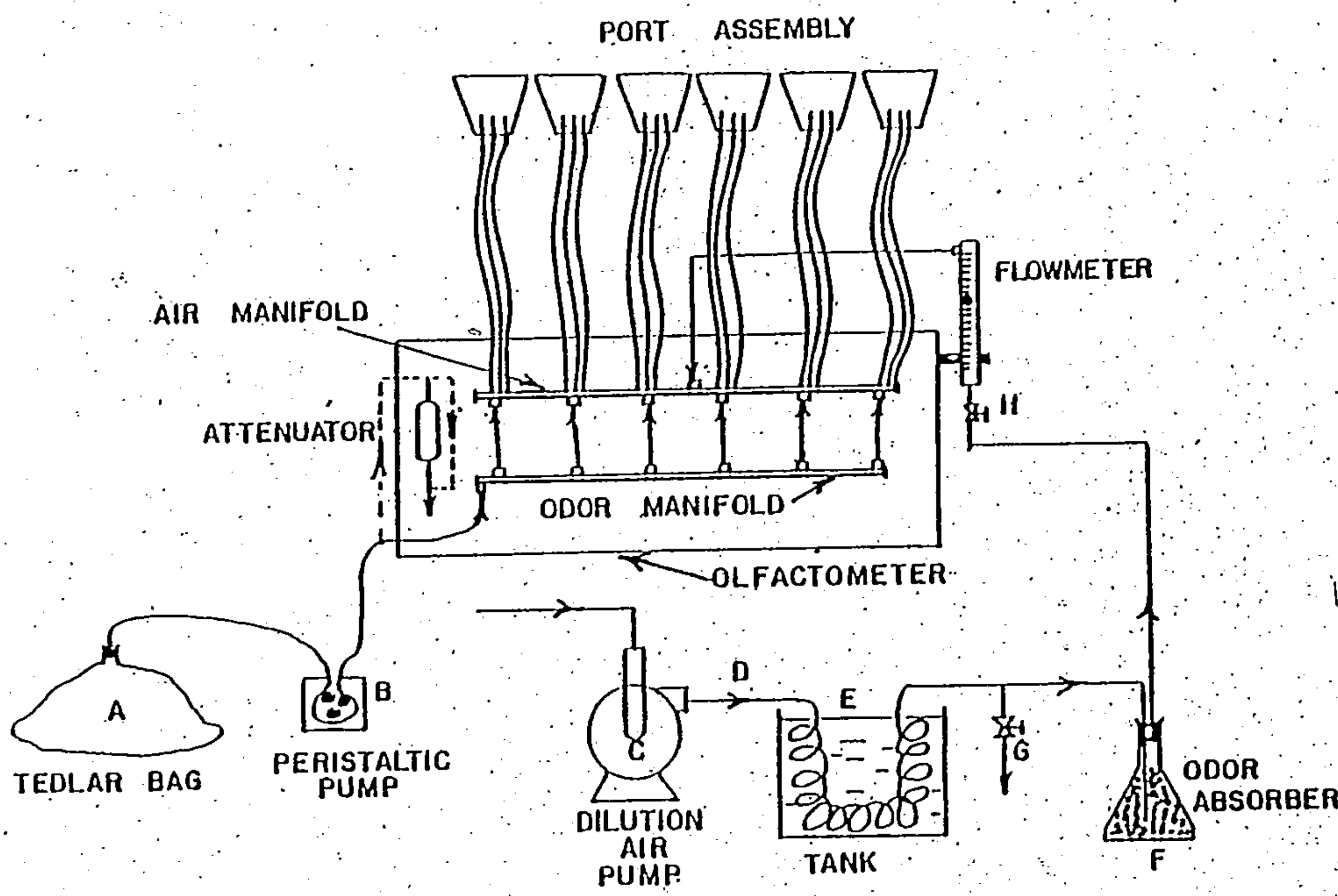

FIGURE 5.1: Flow Diagram for Odor Measurement System

In order to evaluate more dilute samples, a five dilution level olfactometer was designed to provide dilution factors of 17, 8, 6, 3 and 1.

B. Odor Test Room

All odor stimuli determinations were carried out in an odor-free environment maintained inside a previously designed odor test room [31]. This 4 ft. x 4 ft. x 8 ft. high facility is a double walled chamber equipped with a door, a glass window, an interior light, an electric air cleaner and an exhaust fan for ventilating odors. The inside walls and ceiling of the room are constructed of washable arborite. A remote control signal box is mounted on one exterior wall for communication of panel responses to the panel coordinator.

The air cleaner is capable of delivering odor free background air into the test room at low and high flows of 100 ft^3/min and 150 ft^3/min respectively. It consists of a two stage electrostatic precipitator rated for particulate removal down to 0.03 microns [32], a replaceable activated charcoal filter for smoke and odor elimination and an outside lint screen for trapping larger dust particles.

C. Selection of Panel Members

The objective of any odor evaluation program determines the rationale for panelist selection. For example, if the goal is to measure odor sensitivity distribution and the mean odor detection threshold of the population at large, no selection of panelists is necessary and as many panelists as possible should be used [33].

For some odors, people can be found who are significantly less sensitive than the average population [33,34]. However, lower sensitivity of any individual to a specified odor does not automatically imply lower sensitivity to all odors [35].

Some researchers recommend using the more sensitive fraction of panelists in order to provide a safety factor in the results [36]. Others would use a more homogeneous group whose sensitivity is average to produce a higher degree of reproducibility.

In the present program, panelists were selected from a larger group of panel members after eliminating extremely sensitive or insensitive individuals based on previous experiences with them and their availability. They were chosen from different age groups representing both sexes.

D. Experimental Procedure

Inside the odor booth each panelist was provided with a preprinted form for recording the individually perceived complaint intensity at each dilution level. Figure 5.2 illustrates the design of the complaint rating form. Participants were asked to:

- proceed individually by starting from the most dilute level (left) and proceed towards higher concentrations of the sample
- sniff fresh air from the air cleaner provided in the odor booth to sharpen their senses of smell between dilution levels and ports within a dilution level.

NAME: ____________________

At any port where you are certain, beyond a doubt, about the presence of the odor under investigation, circle a value which expresses your degree of annoyance or potential complaint level if you were exposed to a similar odor emitted intermittently over an 8 hour period every day during the warm May to September months of every year, using a scale from 0 to 10.

Sampling Station	1	2	3	4	5	6
NO ANNOYANCE	0	0	0	0	0	0
	1	1	1	1	1	1
	2	2	2	2	2	2
	3	3	3	3	3	3
	4	4	4	4	4	4
	5	5	5	5	5	5
	6	6	6	6	6	6
	7	7	7	7	7	7
	8	8	8	8	8	8
	9	9	9	9	9	9
MAXIMUM ANNOYANCE	10	10	10	10	10	10

1. At what levels are you sure that you can describe the odor?

____

2. Please describe the odor in one or two words by comparing to your previous experiences. ____________________

FIGURE 5.2: A Complaint Rating Form

- press the switch corresponding to the port at which they could detect the odor.

- identify the dilution level at which they were sure, beyond any doubt, about the presence of the odor.

- express, using the preprinted form, the dilutions at which they would complain if they were exposed to similar odorous stimuli for an average period of eight hours and rate their degree of annoyance at each level on a scale of 0 to 10 using 0 as no annoyance and 10 as the maximum measure of annoyance.

The panel responses through the signal box were also recorded by the panel leader located outside the odor test room for subsequent evaluation of percent probabilities of detection and complaint as well as the predicted degrees of annoyance in terms of the odor impact modelling technique.

VI. RESULTS AND DISCUSSIONS

The results of this study are discussed in terms of typical odorous emissions from

- a wastewater treatment facility
- a paint manufacturing plant
- several fast food restaurants
- a municipal solid waste landfill site
- an automotive foundry.

At each site, data acquistion was limited by the extent of the problem that had to be resolved. At times, some of the sampling and analysis programs were governed by the political situations that developed as a result of involvement by citizen action groups and elected politicians. As a result, access to some facilities was terminated once political pressure was reduced on plant operators. Studies involving industrial operations can be carried out only with the full cooperation of the plant management. Consequently it was not always possible to complete comprehensive scientific investigations within the time periods allotted.

The results are presented in chronological order to emphasize the successive improvements in assessing the impact of odorous sources on the surrounding communities.

The automotive foundry provided the best opportunity for implementing the capabilities of the Odor Impact Model.

A. Wastewater Treatment Facility

The wastewater treatment facility provided an ideal location for initiations of field studies because hydrogen sulphide, total reduced sulphurs and sulphur dioxide could be identified and collected at various loctions as major odorous components. The steady state operations of the plant ensured a constant emission rate that could be handled by conventional dispersion equations. Because of the quality and hedonics of the odorous components, there were documented citizen complaints defining a complaint area. In addition, the operational scrubber provided an opportunity for assessing odor removal efficiencies in terms of

- overall odor on the basis of ED50 (D/T) values
- hydrogen sulphide
- total reduced sulphur
- overall odor on the basis of degree of offensiveness (DO).

Figure 6.1 illustrates the relative locations of odor sources at the wastewater treatment plant. The Odor Impact Model Profiles for the odorous emissions from the various sources are

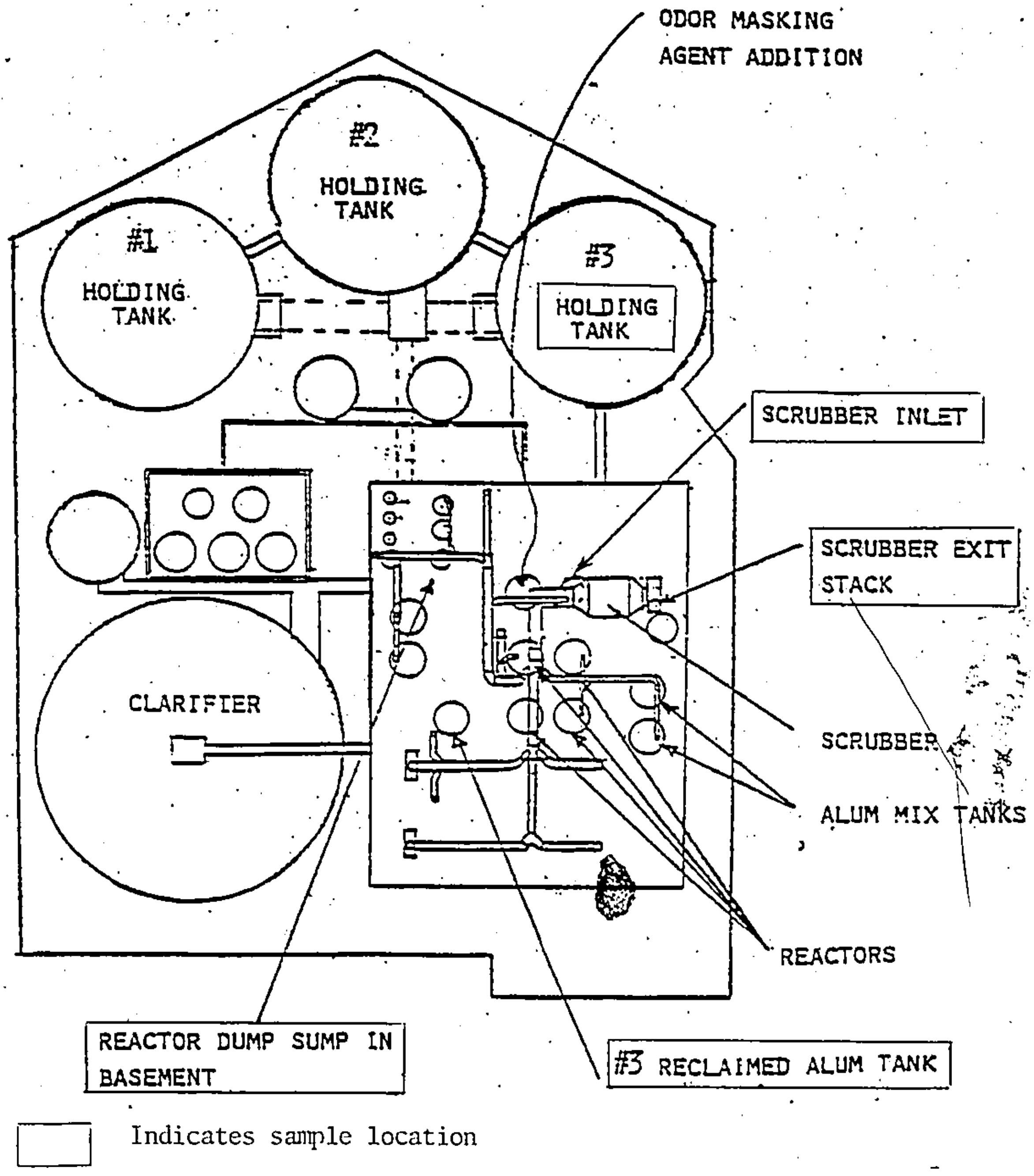

FIGURE 6.1: Relative Locations of Odor Sources at The Wastewater Treatment Facility

provided in Figures 6.2 to 6.6.

Table 6.1 illustrates the profile data in terms of 100, 50 and zero percent probabilities of detection (PPD) and complaint (PPC) as well as predicted degrees of annoyance (PDA) and degrees of offensiveness (DO) of the odors.

Although the levels of offensiveness of the head space reactor dump (DO=150) and the alum tanks (DO=88) are relatively high, these emissions are diluted with high volumes of ambient air before they enter the scrubber (DO=48). Since the alum tanks are totally enclosed, they need not be considered as direct odor sources into the atmosphere. In principle, the reactor dump is partially enclosed and its contributions to the odor problem could be considered in terms of fugitive odor emissions through open plant doors and windows.

Generally, holding tanks (DO=50) become significant odor emitters when they are being filled. However, even under holding conditions they can be recognized as sources of odors on hot, windy days. The clarifier is not generally offensive except if there are unpredictable upsets in plant operations. The scrubber exit stack (DO=34) represents the main point of direct odor release to the environment.

Table 6.2 summarizes the data collected at various locations of the wastewater treatment facility in terms of ED_{50} values as well as hydrogen sulphide, total reduced sulphur and sulphur dioxide concentrations.

Since the odors from the exhaust stack gases consisted of

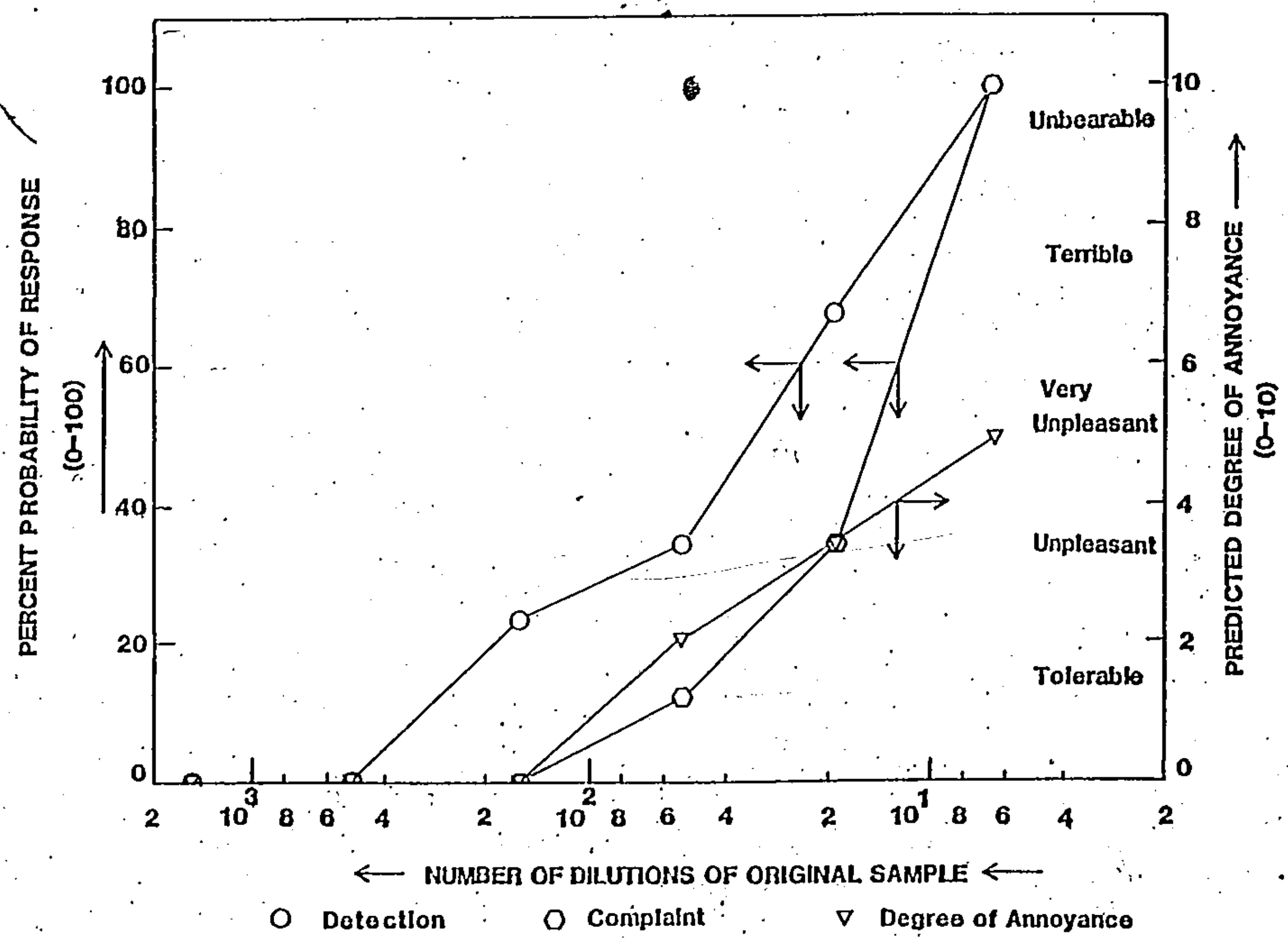

FIGURE 6.2: Odor Impact Model Profiles For Typical Odorous Emissions From The Scrubber Exhaust Stack

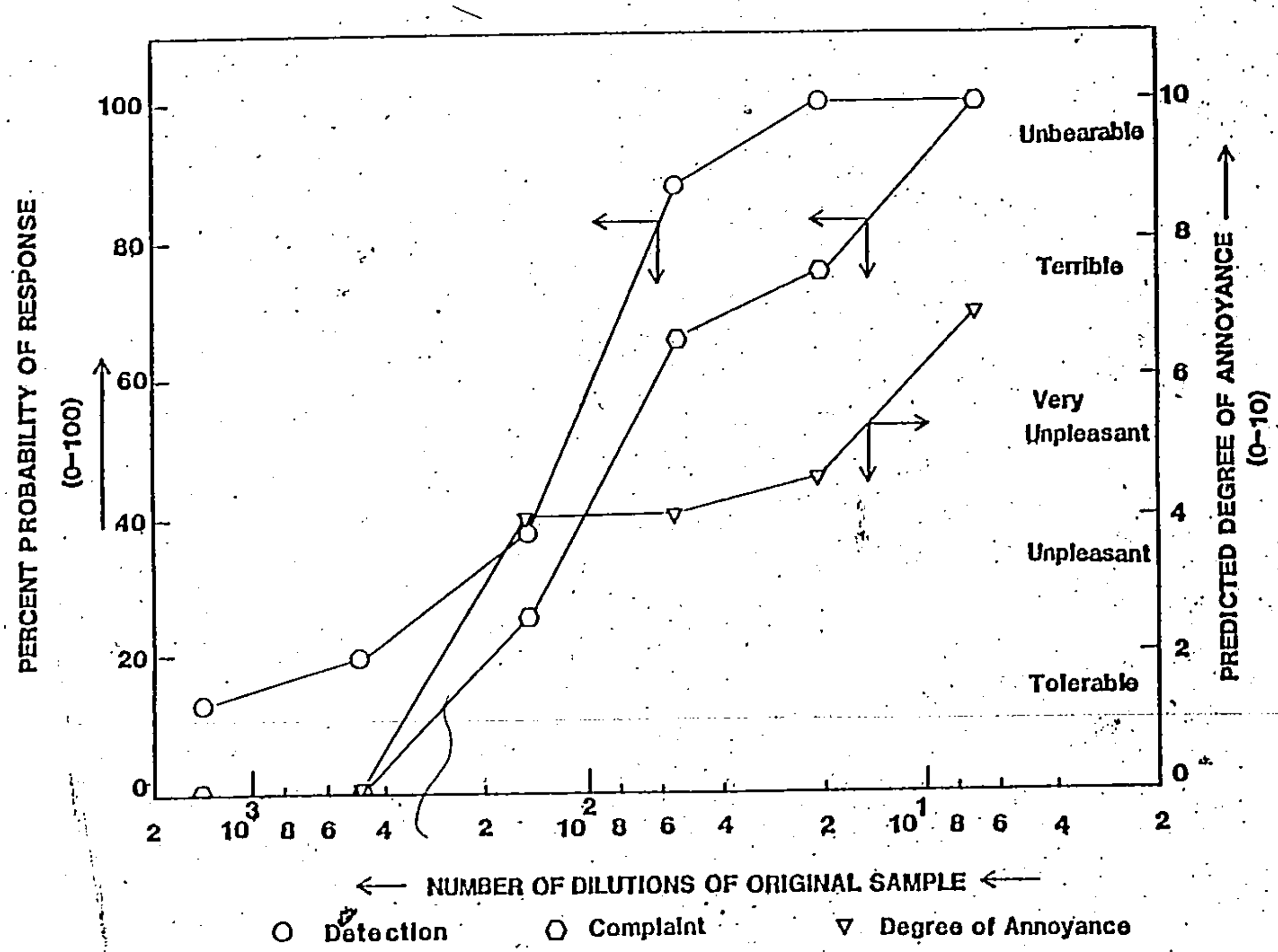

FIGURE 6.3: Odor Impact Model Profiles For Typical Odorous Emissions Into The Scrubber

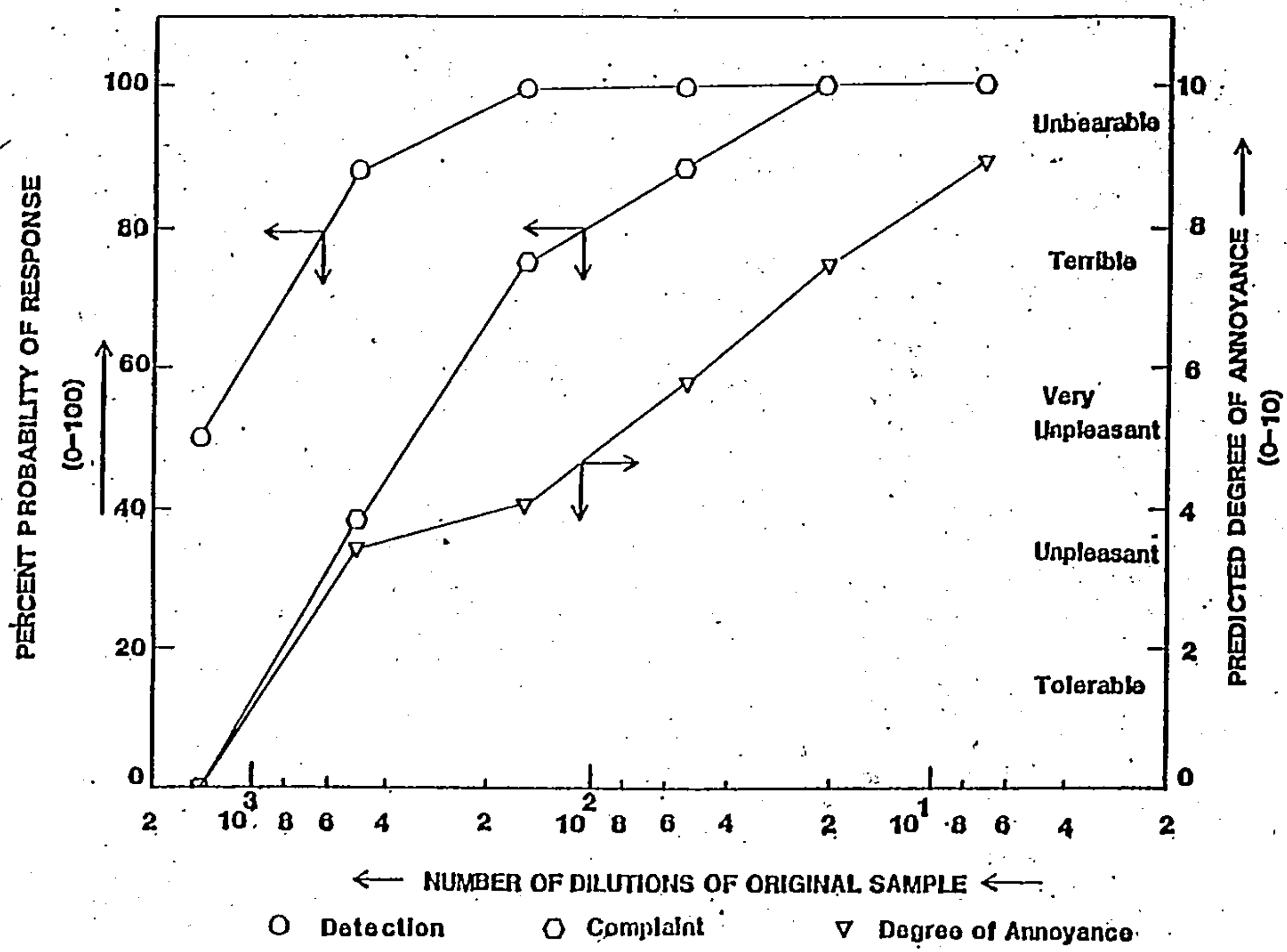

FIGURE 6.4: Odor Impact Model Profiles For Typical Odorous Emissions From The Reactor Dump

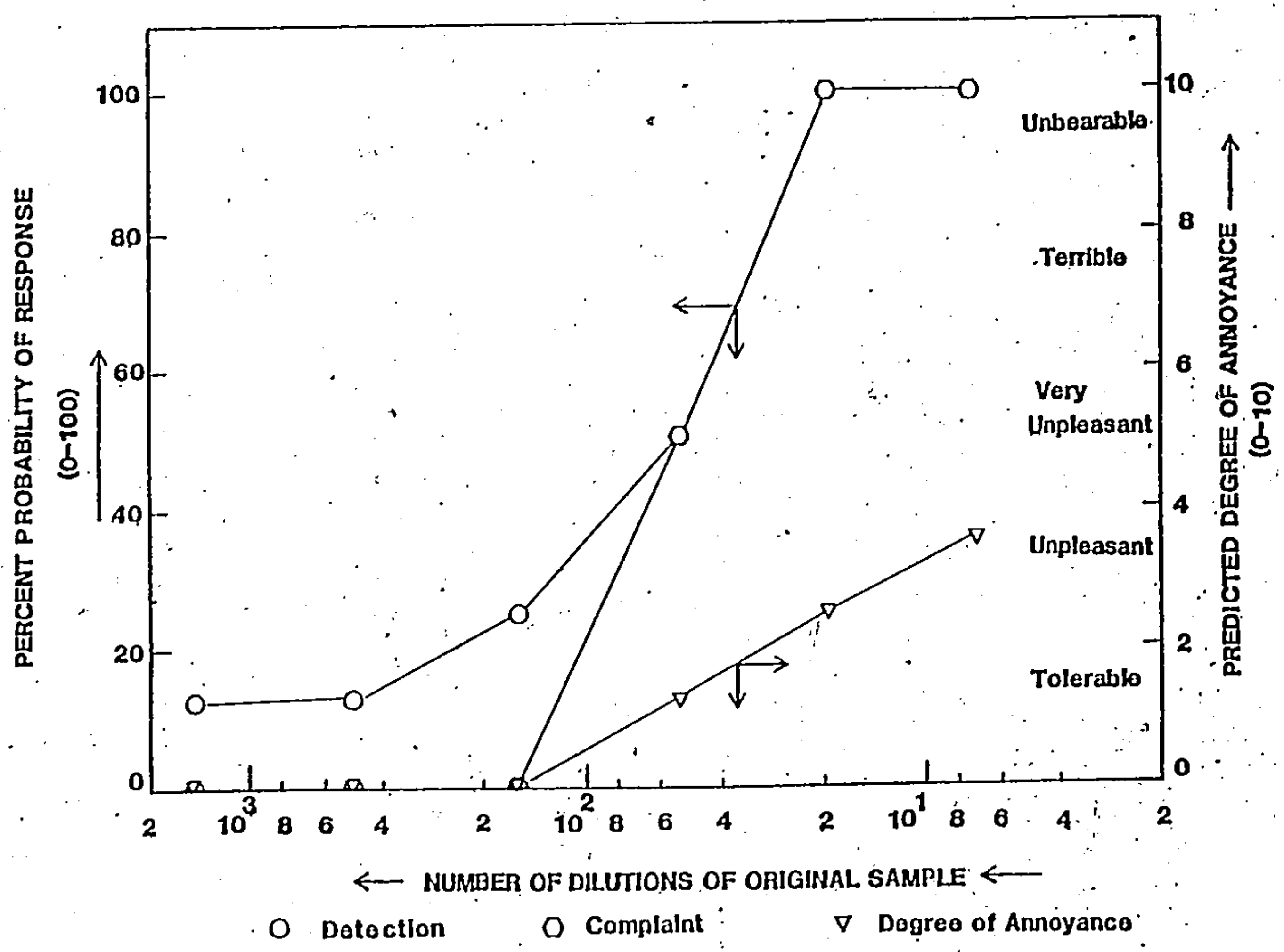

FIGURE 6.5: Odor Impact Model Profiles For Typical Odorous Emissions From Holding Tank #3

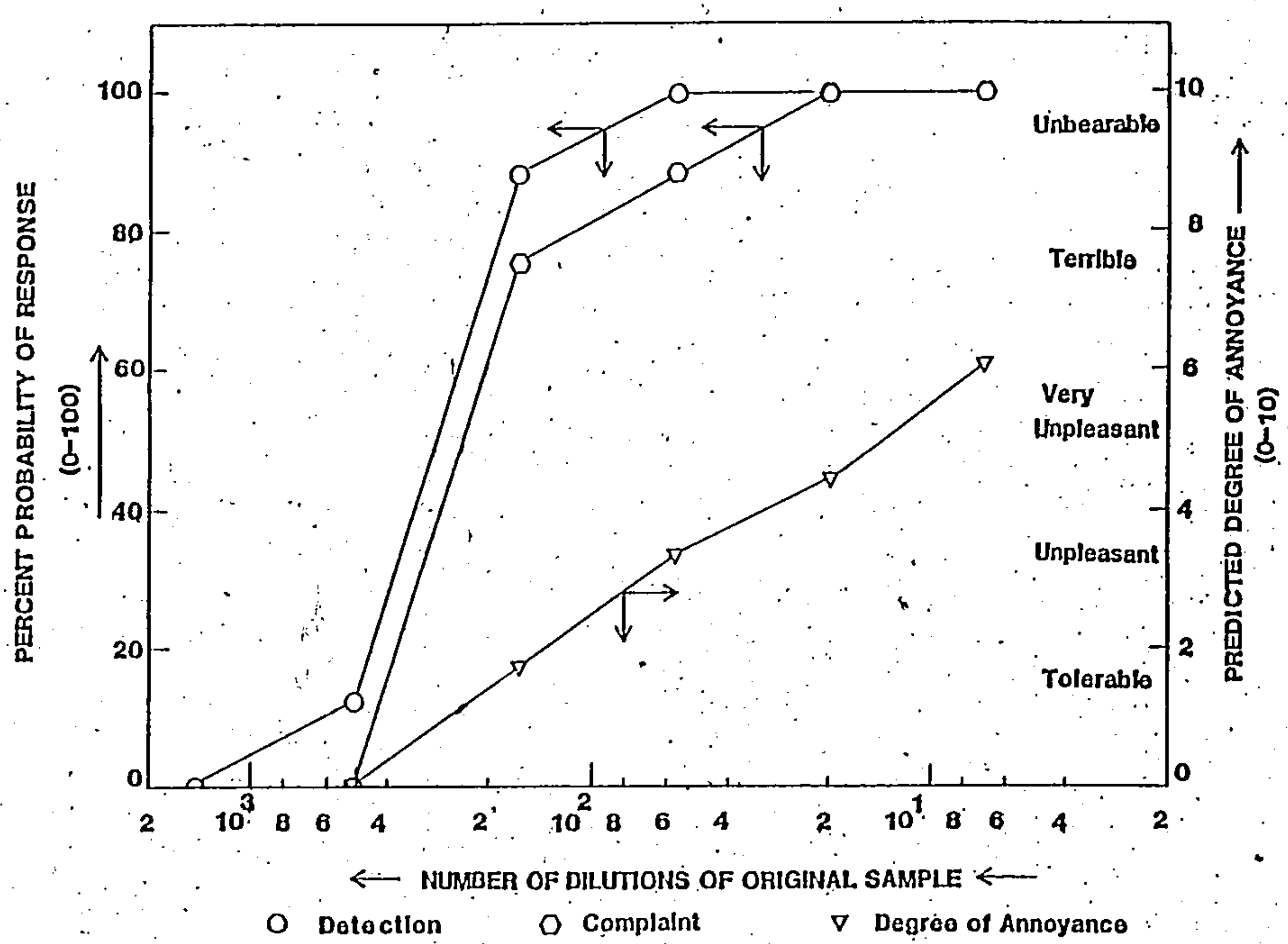

FIGURE 6.6: Odor Impact Model Profiles of Typical Odorous Emissions From The Alum Tank

TABLE 6.1: Sensory Characteristics of Odors From Five Different Locations of the Wastewater Treatment Plant

Sample	ED_{50} Ranking Plotting	DL @ 50 PPD	MDL @ 100 PPC	PDA_{100} (0-10)	DL @ 50 PPC	PDA_{50} (0-10)	DL @ 0 PPD	DL @ 0 PPC	Degree of Offensiveness (DO)
Scrubber Stack Exhaust	34	32	7	4.9	19	3.4	500	160	34.3
Scrubber Inlet	135	130	7	6.9	80	4.0	2600	500	48.3
Head Space Reactor Dump	1330	1450	20	7.5	350	3.6	6000	1450	150
Top of Holding Tank #3	71	56	20	2.5	56	1.2	2600	160	50
Exhaust From Alum Tank #3	282	285	20	4.4	235	1.1	1450	500	88

TABLE 6.2: Summary of Odorous Emission Levels at Wastewater Treatment Facility

Sample		ED_{50} Ranking-Plotting	Hydrogen Sulphide (ppm)	Total Reduced Sulphur (ppm)	Sulphur Dioxide (ppm)
Scrubber Exhaust Stack					
Test #1	Inlet	135	3.20	Not Done	Not Done
	Outlet	34	1.24		
Test #2	Inlet	282	Not Done	3.4	2.8
	Outlet	96	0.03	2.2	4.2
Test #3	Inlet	141	Not Done	Not Done	Not Done
	Outlet	159			
(odor masking)					
Holding Tank #3		71	None Detected	Not Done	Not Done
Reclaim Alum Tank		282	None Detected	Not Done	Not Done
Reactor Dump Sump		1330	1.90	Not Done	Not Done

hydrogen sulphide, total reduced sulphur, sulphur dioxide and often odor masking agents that were themselves odorous, it was difficult to relate degree of offensiveness (DO) values to gas compositions. Consequently the impact of the wastewater treatment plant on the surrounding community was assessed only in terms of hydrogen sulphide impingement levels in the neighborhood from concentrations that could be determined in the stack gases. The atmospheric dispersion [26] of the steady state emissions of hydrogen sulphide showed that the impingement concentrations could create adverse community reactions at distances of 875 feet and 1560 feet from the exhaust stacks for C and D stabilities, respectively, since levels exceeded published detection threshold values. According to the information provided by the operators of the wastewater treatment plant, the majority of the documented citizen complaints originated from homes located 900 feet to 1800 feet from the wastewater treatment plant.

Although this preliminary study showed that it would be possible to rank various odorous sources at a single facility in terms of their DO values, it emphasized the limitations of focussing attention on major odorous components.

There are still no established procedures for evaluating performance characteristics of odor control equipment handling multicomponent gas streams. Table 6.3 illustrates the variability in calculated removal efficiencies for a wet scrubber when different

TABLE 6.3: Performance Characteristics of The Scrubber

Component	Removal Efficiency %	
Total Odors (based on ED_{50})	75	Test 1
	66	Test 2
Hydrogen Sulphide	61	Test 2
Total Reduced Sulphur	55	Test 2
Degree of Offensiveness	29	Test 1

components are used as a basis of evaluation. Since the removal of hydrogen sulphide and total reduced sulphur compounds produce sulphur dioxide, which is odorous, removal efficiencies based on removal of single components will not provide a true picture of the reduction of odor impact on the surrounding community. Evaluation of removal efficiency using DO as a basis is more realistic than the ED_{50} approach since the DO provides measures of intensity and hedonics of the odors before and after the scrubber.

B. Paint Manufacturing Plant

The odor related conflicts in the community surrounding the paint manufacturing facility, made it difficult for this investigation to be accepted as an objective attempt to establish odor impacts from the plant.

The existence of multiple odor sources at neighboring industrial establishments in the area under investigation created additional technical problems.

Identification of over 20 potential odorants as raw materials or finished products being emitted by various plants in the area illustrated the difficulties that citizens and regulatory agency personnel would have in relating odorous episodes to emissions from any specific industry in the locality. Although the complaint area appeared to be well defined, the citizen complaints were not specific to individual odor emitters.

The potential for a fundamental study existed but the adversarial atmosphere created by an impending legal action limited the extent of sample collection.

There was no doubt that the emissions from stacks created odor problems in the downwind community, however, complaints from upwind areas could not be explained until personal inspections of the neighborhood were carried out. A tour of the neighborhoods indicated that significant odor problems were recognizable along the streets at manholes and catch basins. Apparently discharge of scrubber liquors and perhaps even products into the sewer system created unpleasant conditions in areas that were not necessarily downwind from suspected sources.

The paint manufacturing plant provided an opportunity for odor collection from 13 stacks. Figure 6.7 shows the relative locations of the exhaust stacks on the Resin and Paint Manufacturing buildings of the facility. To meet immediate political and regulatory requirements data analysis was limited to traditional ED_{50} (D/T) evaluations. Consequently, odor levels levels from the Resin and Paint Manufacturing exhaust stacks are summarized in Tables 6.4 and 6.5 in terms of ED_{50} magnitudes. The odor thresholds were determined using the Ranking-Plotting method. The plots are provided in Appendix V.

Unfortunately, the relation of source odor levels to citizen reactions and locations of spontaneous complaint areas were not well documented by the regulatory agency. Consequently, an

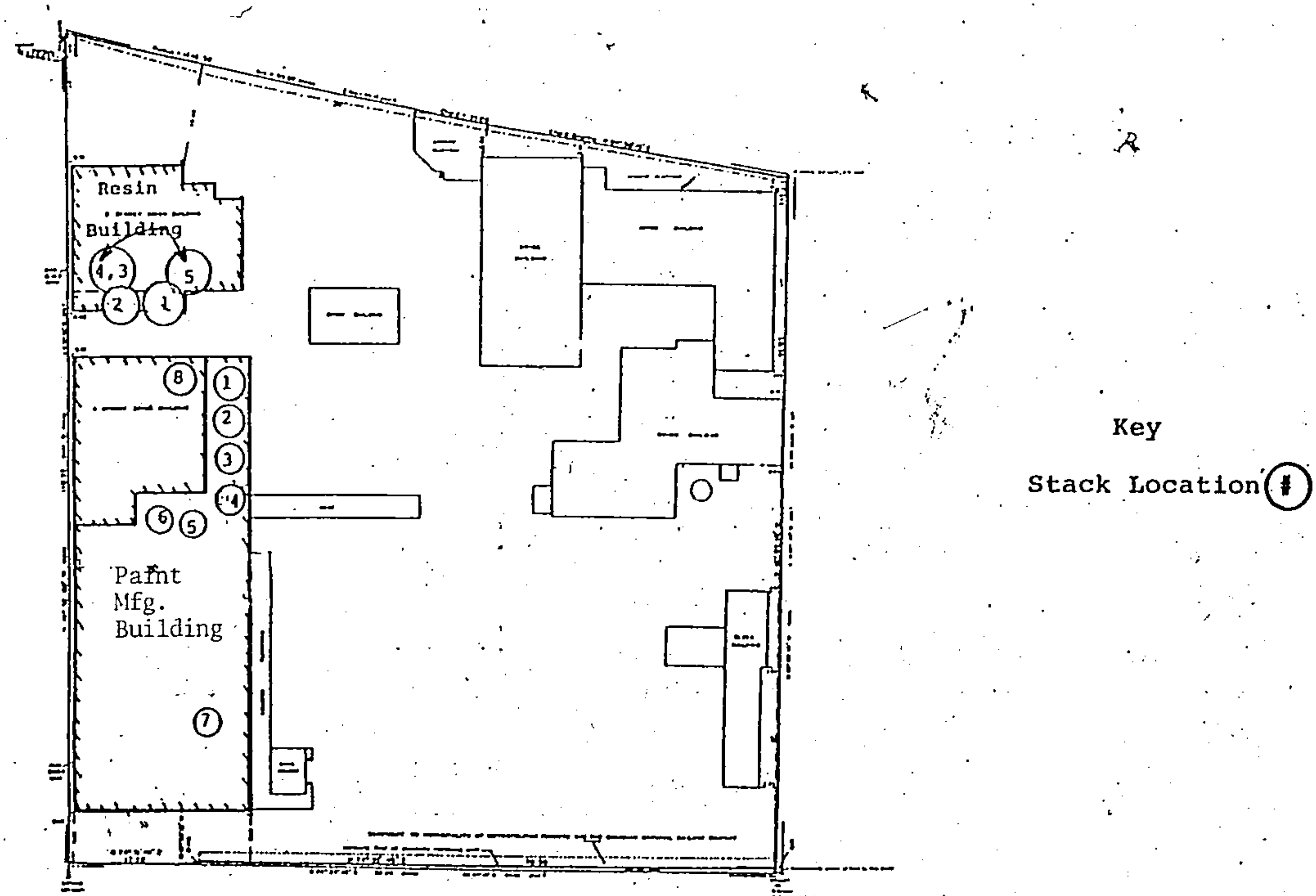

FIGURE 6.7: Relative Locations of Exhaust Stacks on Resin Plant and Paint Manufacturing Buildings

TABLE 6.4: Summary of Resin Plant Exhaust Odor Levels

Date 1982	Stack	Volumetic Flow Rate Acfm	Odor Level, ED50 Odor Units	Notes
Dec. 9	R3	73	640	Normal operation
	R3	73	650	Venturi only
	R3	73	720	All water off
	R3	73	1000	Spray only
Dec. 10	R3	N.M.	280	Normal operation
Dec. 14	R3	96	630	Normal operation
Dec. 9	R4	2	140	Normal operation
Dec. 10	R4	2	110	Normal operation
Dec. 13	R5	2.2	1500	Normal operation
Dec. 9	R1	22,300	60	Normal operation
Dec. 10	R1	N.M.	135	Normal operation
Dec. 13	R1	20,600	75	Normal operation
Dec. 14	R1	N.M.	55	Normal operation
Dec. 9	R2	3,700	50	Normal operation
Dec. 10	R2	N.M.	80	Normal operation
Dec. 13	R2	3,000	280	Normal operation
Dec. 14	R2	N.M.	25	Normal operation

N.M. = Not Measured

TABLE 6.5: Summary of Paint Manufacturing Building Exhaust Odor Levels

Date 1982	Stack	Volumetic Flow Rate Acfm	Odor Level, ED50 Odor Units
Dec. 8(PM)	M1	NM	70
Dec. 9(PM)	M1	1,100	NM
Dec. 14(AM)	M1	1,300	164
Dec. 8(PM)	M2	9,000	50
Dec. 14(AM)	M2	11,200	70
Dec. 8(PM)	M3	3,900	180
Dec. 14(AM)	M3	3,100	150
Dec. 8(PM)	M4	6,000	40
Dec. 14(AM)	M4	5,800	96
Dec. 8(PM)	M5	800	15
Dec. 13(AM)	M5	800	12
Dec. 8(PM)	M6	4,800	20
Dec. 13(AM)	M6	5,300	130
Dec. 8(PM)	M7	8,500	7
Dec. 13(AM)	M7	8,900	100
Dec. 8(PM)	M8	1,900	40
Dec. 8(AM)	M8	1,900	160

NM = Not Measured

arbitrary decision was made to define a "probable complaint area" in terms of ambient odor levels exceeding 1.0 odor units being sufficient evidence for "probable" complaint generation. Odor levels ranging between 0.5 and 1.0 odor units were assigned a rating of "possible odor impact". Predicted ambient odor levels below 0.5 odor units were projected to have minimal or zero effect on tbe surrounding community. Ambient impingement odor levels were calculated using appropriate modifications (in terms of source and ambient dilution ratios) of pertinent dispersion equations provided in Regulation 308 under the Environmental Protection Act [26].

Tables 6.6 and 6.7 illustrate the definition of areas of "probable" and "possible" odor complaints as determined by odor levels exceeding 1.0 odor units and ranging between 0.5 to 1.0 odor units, respectively considering the combined maximum odor emissions from all 13 stacks of the facility. The 8 meter elevation odor levels are relevant for assessing the impact on neighboring 2-storey residences. It must be emphasized that the criteria used to define "probable" and "possible" complaint areas are considerably more restrictive than those adopted by various jurisidictions for odor control purposes. Normally, residential zone odor levels are expected to be maintained below 2.0 odor units through regulations or criteria objective standards [3,25,27] as shown in Table 2.1.

The sample collection needed to extend the program in the neighborhood of the paint manufacturing facility was discontinued when a major health study was announced.

TABLE 6.6: Odor Impingement Levels at an Eight Meter Height Resulting From All Sources

DISTANCE ABOVE GROUND 8.0000000 METERS

CONCENTRATION IN ODOR UNITS

DISTANCE IN THE Y DIRECTION.

DIST. FROM STACK	0	10	20	30	40	50	60	70	80	90	100
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40.0	-0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60.0	0.000	0.000	0.000	0.927	0.012	0.000	0.000	0.000	0.000	0.000	0.000
70.0	0.002	2.673	1.836	1.190	0.044	0.002	0.000	0.000	0.000	0.000	0.000
80.0	1.054	2.190	1.662	1.157	0.077	0.007	0.001	0.003	0.000	0.000	0.000
90.0	0.991	1.858	1.627	1.132	0.140	0.016	0.004	0.009	0.001	0.000	0.000
100.0	0.913	1.630	1.553	1.084	0.220	0.028	0.012	0.020	0.003	0.000	0.000
110.0	0.837	1.442	1.462	1.028	0.270	0.043	0.023	0.033	0.008	0.000	0.000
120.0	0.771	1.304	1.366	0.972	0.310	0.061	0.036	0.046	0.014	0.001	0.000
130.0	0.716	1.193	1.274	0.910	0.338	0.081	0.050	0.058	0.021	0.002	0.000
140.0	0.671	1.100	1.188	0.859	0.359	0.101	0.064	0.068	0.029	0.004	0.000
150.0	0.634	1.023	1.110	0.825	0.373	0.121	0.077	0.076	0.036	0.007	0.000
160.0	0.604	0.957	1.040	0.786	0.383	0.141	0.089	0.083	0.043	0.010	0.000
170.0	0.580	0.900	0.978	0.751	0.390	0.159	0.100	0.088	0.048	0.013	0.000
180.0	0.559	0.851	0.923	0.720	0.395	0.175	0.107	0.092	0.053	0.016	0.000
190.0	0.542	0.807	0.873	0.692	0.398	0.190	0.118	0.095	0.056	0.020	0.000
200.0	0.526	0.768	0.829	0.667	0.401	0.204	0.126	0.097	0.060	0.023	0.000
210.0	0.512	0.733	0.790	0.644	0.403	0.216	0.134	0.099	0.062	0.026	0.000
220.0	0.499	0.701	0.754	0.623	0.404	0.227	0.141	0.102	0.064	0.029	0.000
230.0	0.487	0.673	0.721	0.604	0.404	0.236	0.147	0.104	0.066	0.031	0.000
240.0	0.475	0.646	0.691	0.587	0.404	0.245	0.154	0.106	0.068	0.034	0.000
250.0	0.464	0.621	0.664	0.570	0.403	0.252	0.159	0.108	0.069	0.036	0.000
260.0	0.453	0.599	0.639	0.555	0.402	0.258	0.165	0.111	0.071	0.038	0.000
270.0	0.443	0.577	0.615	0.540	0.400	0.264	0.170	0.114	0.073	0.040	0.000
280.0	0.433	0.557	0.593	0.526	0.397	0.268	0.175	0.116	0.074	0.042	0.000
290.0	0.423	0.539	0.572	0.512	0.394	0.272	0.180	0.119	0.076	0.044	0.000
300.0	0.414	0.521	0.553	0.499	0.390	0.275	0.184	0.122	0.078	0.045	0.000
310.0	0.405	0.504	0.535	0.487	0.387	0.277	0.188	0.125	0.080	0.047	0.000
320.0	0.395	0.488	0.517	0.474	0.382	0.279	0.192	0.128	0.083	0.049	0.000
330.0	0.387	0.473	0.501	0.463	0.378	0.280	0.195	0.131	0.084	0.051	0.000
340.0	0.378	0.459	0.486	0.451	0.373	0.280	0.197	0.133	0.087	0.052	0.000
350.0	0.369	0.445	0.471	0.440	0.368	0.280	0.200	0.135	0.089	0.054	0.000
360.0	0.361	0.432	0.457	0.429	0.362	0.280	0.202	0.139	0.091	0.056	0.000
370.0	0.353	0.420	0.443	0.419	0.357	0.279	0.203	0.141	0.093	0.058	0.000
380.0	0.345	0.408	0.431	0.406	0.351	0.277	0.205	0.143	0.095	0.060	0.000
390.0	0.337	0.397	0.418	0.398	0.345	0.276	0.206	0.145	0.097	0.062	0.000
400.0	0.330	0.386	0.407	0.389	0.339	0.274	0.205	0.147	0.099	0.064	0.000

Region of Probable Odor Complaints

Possible Odor Complaints

TABLE 6.7: Ground Level Odor Impingement Resulting from all Sources

DISTANCE ABOVE GROUND 0.0000000 METERS

CONCENTRATION IN ODOR UNITS

DISTANCE IN THE Y DIRECTION

DIST. FROM STACK	0	10	20	30	40	50	60	70	80	90	100
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70.0	0.000	0.165	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80.0	0.144	0.204	0.035	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90.0	0.230	0.374	0.084	0.016	0.001	0.000	0.000	0.000	0.000	0.000	0.000
100.0	0.310	0.403	0.162	0.044	0.006	0.000	0.000	0.000	0.000	0.000	0.000
110.0	0.375	0.554	0.253	0.080	0.016	0.001	0.000	0.000	0.000	0.000	0.000
120.0	0.424	0.607	0.347	0.143	0.033	0.004	0.000	0.000	0.000	0.000	0.000
130.0	0.450	0.646	0.434	0.205	0.056	0.008	0.002	0.001	0.000	0.000	0.000
140.0	0.481	0.674	0.509	0.266	0.085	0.016	0.004	0.003	0.001	0.000	0.000
150.0	0.496	0.693	0.569	0.324	0.117	0.026	0.007	0.005	0.002	0.000	0.000
160.0	0.506	0.704	0.613	0.375	0.150	0.040	0.012	0.008	0.004	0.001	0.000
170.0	0.511	0.709	0.649	0.418	0.183	0.056	0.019	0.012	0.006	0.002	0.000
180.0	0.514	0.710	0.671	0.453	0.215	0.074	0.028	0.017	0.009	0.003	0.000
190.0	0.514	0.705	0.684	0.483	0.244	0.093	0.038	0.023	0.013	0.004	0.000
200.0	0.512	0.698	0.689	0.503	0.270	0.113	0.049	0.029	0.017	0.006	0.000
210.0	0.509	0.688	0.689	0.518	0.294	0.133	0.061	0.036	0.021	0.009	0.000
220.0	0.504	0.676	0.684	0.529	0.314	0.152	0.073	0.043	0.025	0.011	0.000
230.0	0.499	0.662	0.675	0.535	0.331	0.170	0.086	0.050	0.030	0.014	0.000
240.0	0.493	0.647	0.664	0.537	0.346	0.187	0.098	0.058	0.034	0.016	0.000
250.0	0.486	0.631	0.651	0.537	0.358	0.203	0.111	0.065	0.038	0.019	0.000
260.0	0.478	0.615	0.637	0.534	0.367	0.217	0.122	0.072	0.043	0.022	0.000
270.0	0.470	0.597	0.622	0.530	0.375	0.230	0.134	0.080	0.047	0.025	0.000
280.0	0.461	0.583	0.607	0.523	0.380	0.241	0.144	0.087	0.052	0.028	0.000
290.0	0.453	0.567	0.591	0.516	0.384	0.251	0.154	0.094	0.056	0.031	0.000
300.0	0.444	0.551	0.575	0.508	0.385	0.259	0.163	0.100	0.061	0.034	0.000
310.0	0.434	0.535	0.559	0.499	0.386	0.266	0.171	0.107	0.065	0.037	0.000
320.0	0.425	0.520	0.544	0.490	0.386	0.272	0.178	0.113	0.069	0.040	0.000
330.0	0.416	0.505	0.528	0.481	0.384	0.276	0.184	0.118	0.073	0.043	0.000
340.0	0.407	0.490	0.513	0.471	0.382	0.280	0.190	0.123	0.077	0.045	0.000
350.0	0.398	0.476	0.499	0.461	0.379	0.282	0.195	0.128	0.081	0.048	0.000
360.0	0.389	0.462	0.485	0.451	0.375	0.284	0.199	0.133	0.085	0.051	0.000
370.0	0.380	0.449	0.471	0.440	0.371	0.284	0.203	0.137	0.088	0.054	0.000
380.0	0.371	0.437	0.458	0.430	0.366	0.284	0.206	0.141	0.091	0.056	0.000
390.0	0.363	0.424	0.445	0.421	0.361	0.284	0.208	0.144	0.095	0.059	0.000
400.0	0.355	0.413	0.433	0.411	0.355	0.283	0.210	0.147	0.098	0.062	0.000

☐ Region of Possible Odor Complaints

C. Fast Food Restaurants

To date, there have not been any complaints regarding odors emitted from fast food restaurants in the Windsor area. However, a few have been registered in downtown Toronto, Ontario and Chatham, Ontario [37]. In certain American states, Louisiana specifically, restaurants and other establishments preparing food for human consumption [38], are exempted from ambient odor regulations.

A fast food facility provided an opportunity for odor sample collection and the surrounding community for running the odor survey. This exercise was a sensitive undertaking because the regulator agency did not want the survey team to arouse any awareness that may have never surfaced without this activity.

Table 6.8 provides the hedonic ratings of odors expressed by the residents in the vicinity of the fast food outlet and those by the control group. Figure 3.1 illustrated the good agreement between the values from the two groups. This agreement shows that people's reactions to odors in the neighborhood of the fast food restaurant were no different from those in the control area.

Table 6.9 provides the descriptions of odors and percentages of people bothered by them in the neighborhood of the outlet and the control group. It is evident that the residents in the vicinity of the restaurant are not significantly bothered by the odors emitted from the outlet and, as a result, there have not been any spontaneous complaints to the local air pollution control agency.

Table 6.10 provides a comparison of average ratings of five specific odors by the residents in the neighborhood of the fast food

TABLE 6.8: Comparison of Hedonic Ratings of Odors Expressed By People In The Neighborhood Of The Fast Food Restaurant And The Control Group.

Odor Description	Fast Food Restaurant	Control Group
cut grass	+0.7	+2.6
car/truck fumes	-9.1	-8.9
Fried chicken outlets	-1.3	-0.7
Vinegar	-5.3	-3.9
garbage	-9.6	-9.8
hospital	-5.2	-4.7
gasoline	-3.8	-5.5
hamburger restaurants	-2.2	-0.9
fresh popcorn	+2.2	+4.7
ammonia	-8.2	-8.5
paint	-5.8	-5.9
roses	+6.0	+7.4
beer	-0.7	-1.6
outside chinese restaurant	-0.7	-0.7
locker/dressing room	-7.4	-8.4
baking bread	+6.0	+7.9
wood fire	+1.8	+6.0
chocolate	+3.2	+5.0
cigarettes	-6.5	-7.8
carnival	-2.4	-1.5
peanuts	+0.5	+2.8
barbeque	+6.0	+6.2
leather jacket	+0.1	+1.3

t test paired data level of significance > 95%.

TABLE 6.9: Comparison of Descriptions of Odors and Percentages of People Bothered by Them in the Neighborhood of the Fast Food Restaurant and the Control Area

Description of Odor	Percent People* Seriously Bothered	
	Control Group	Fastfood Restaurant
Cigarette Smoke	28	7
Auto Emissions	22	23
Pollution	22	9
Bus & Truck Fumes	21	28
Gasoline	13	8
Garbage	11	21
Sewers	9	-
Sulphur	9	9
Skunk	5	-
Strong Perfumes	4	-
Foundry	3	-
Ammonia (bleach)	2	2
Tar Roofing (hot asphalt)	2	2
Burning Rubber	2	-
Methane	2	-
Sewage Treatment Plant	2	-
Melting Metal Fumes	3	-
Brewery	2	-
Burning Leaves	2	-
Factory Smoke	-	26
Burning Garbage	-	2
Paint Fumes	1	4
Fertilizer	-	4
Smells from Factories in Detroit	1	9
Smells from Garbage Plant	-	2
Ammonium Hydroxide	-	2
Smells from Zug Island	1	2
Dust	-	2
Insecticide	-	2
Fastfood Restaurant	1	2

*Multiple complaints from respondents allow the sum of percentage responses to exceed 100

TABLE 6.10: Comparison of Average Ratings of Five Specific Odors by the Residents in the Neighborhood of the Fast Food Restaurant and the Control Group

Source of Odor	Average Response (1-5) (1 = Best & 5 = Least) Fast Food Restaurant	Control Area
Barbeque	1.4	1.6
Hay	3.1	2.5
Hamburger Restaurant	2.8	2.9
Swimming Pool	3.0	3.0
Garbage	–	5.0

restaurant and the control area. The responses were particularly important in the case of potential control of fast food restaurant odors with hypochlorite scrubbing solutions. From Table 6.10 it is apparent that the chlorine odor is just as unacceptable as the odors associated with hamburger restaurants. There would be no improvement in the community odor problems if the original fast food odors are replaced with the smell of chlorine.

A portable Miran infrared (IR) gas analyzer was used to determine if the restaurant emissions could be discussed in terms of a major component. Figures 6.8 and 6.9 illustrate IR scans of clean air and the emissions from the fast food facility, respectively. A comparison of these two figures suggests that fast food emissions could be discussed in terms of oleic acid (measured at 3.36 μ m wavelength) which is a major component of emissions from hamburger restaurants.

The operation of a fast food restaurant was simulated in the laboratory using the raw materials supplied by the management for development of the Odor Impact Model profiles. The emissions generated in the laboratory were fed directly into the olfactometer and presented to the odor panel members in the odor test room. Figure 6.10 illustrates the Odor Impact Model profiles for the emissions from the simulated process. Figures 6.11 and 6.12 depict the Odor Impact Model profiles for two typical emissions from the fast food facility.

The data from the profiles are provided in Table 6.11 in terms of oleic acid equivalent (ppm) and numbers of dilutions of the

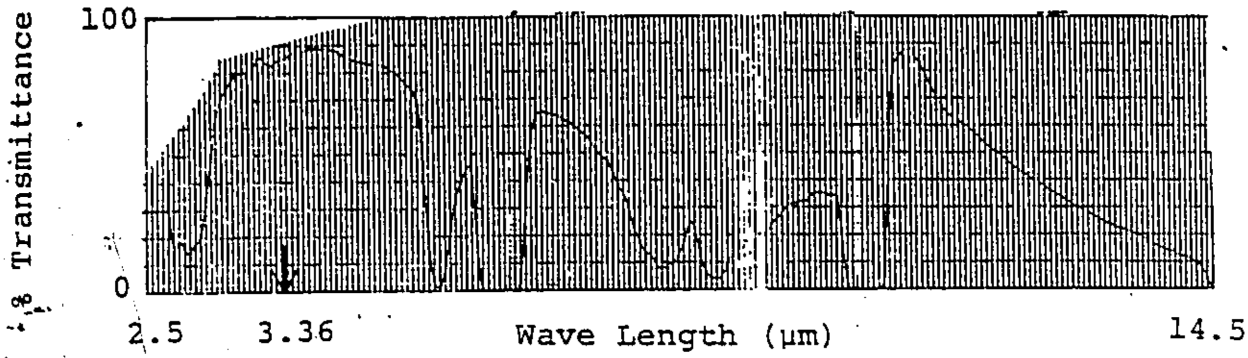

FIGURE 6.8: The Infrared Gas Analyzer Scan for Carbon Filtered Air

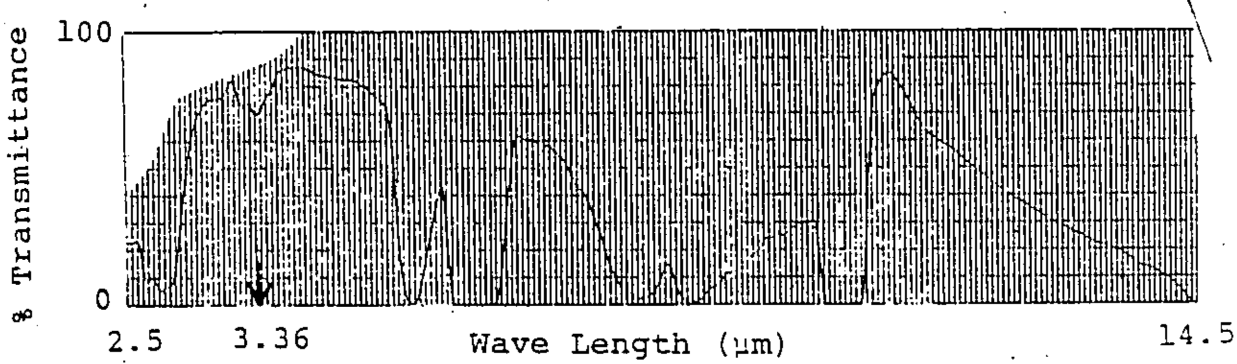

FIGURE 6.9: The Infrared Gas Analyzer Scan For Typical Odorous Emissions From The Fast Food Facility

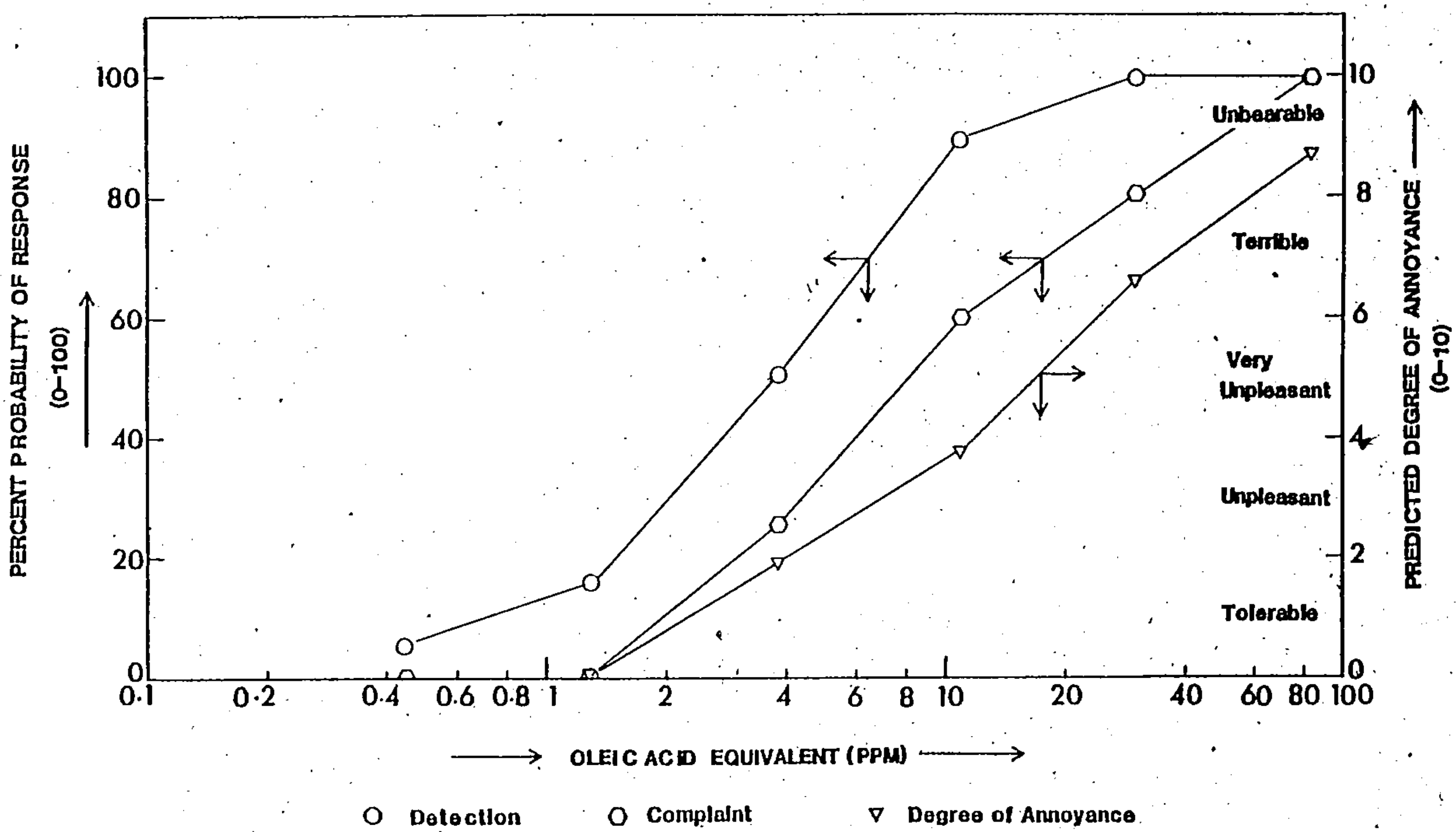

FIGURE 6.10: Odor Impact Model Profiles for Typical Laboratory Simulated Odorous Emissions of the Fast Food Restaurant

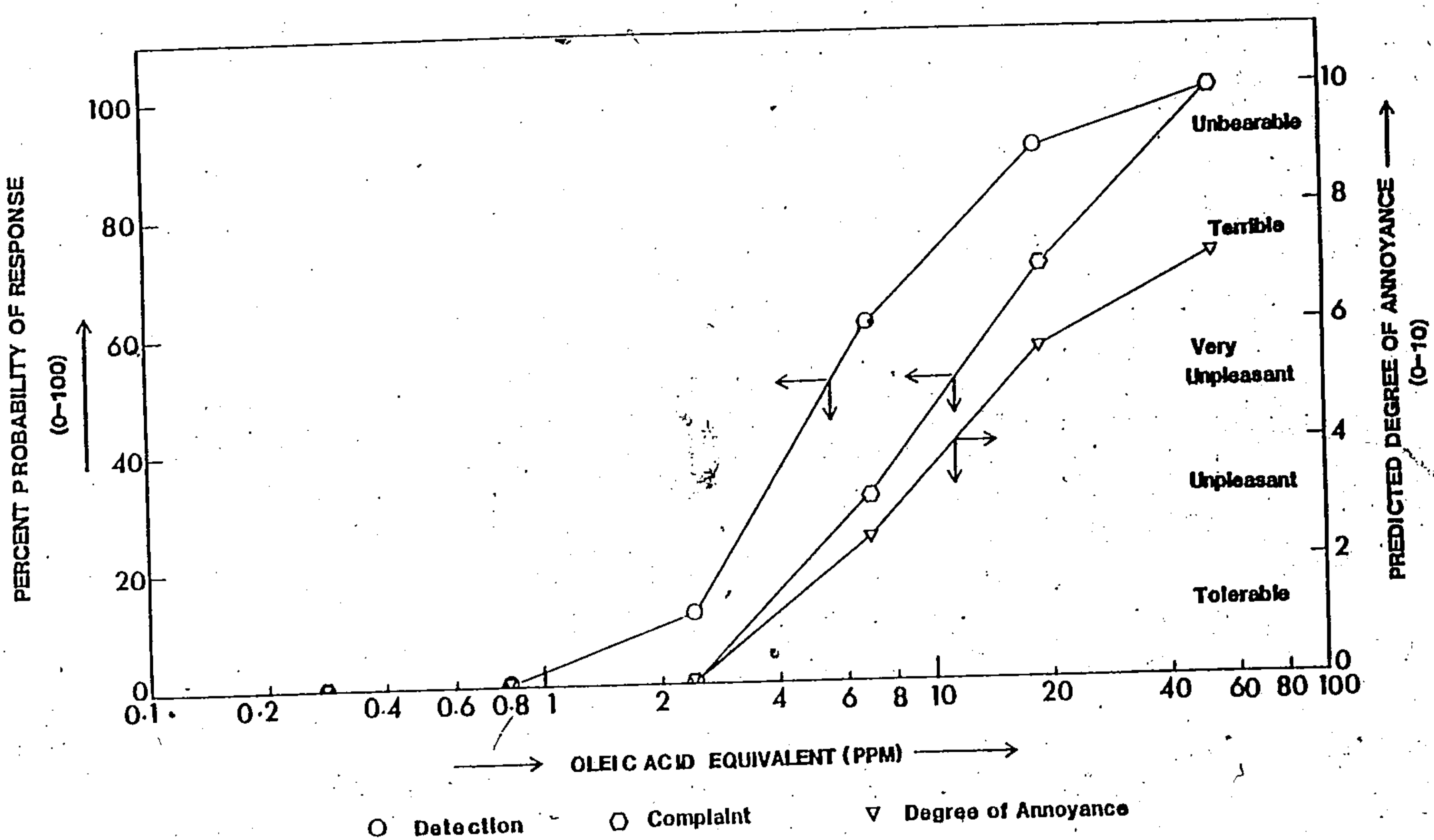

FIGURE 6.11: Odor Impact Model Profiles for Typical Odorous Emissions of the Fast Food Restaurant

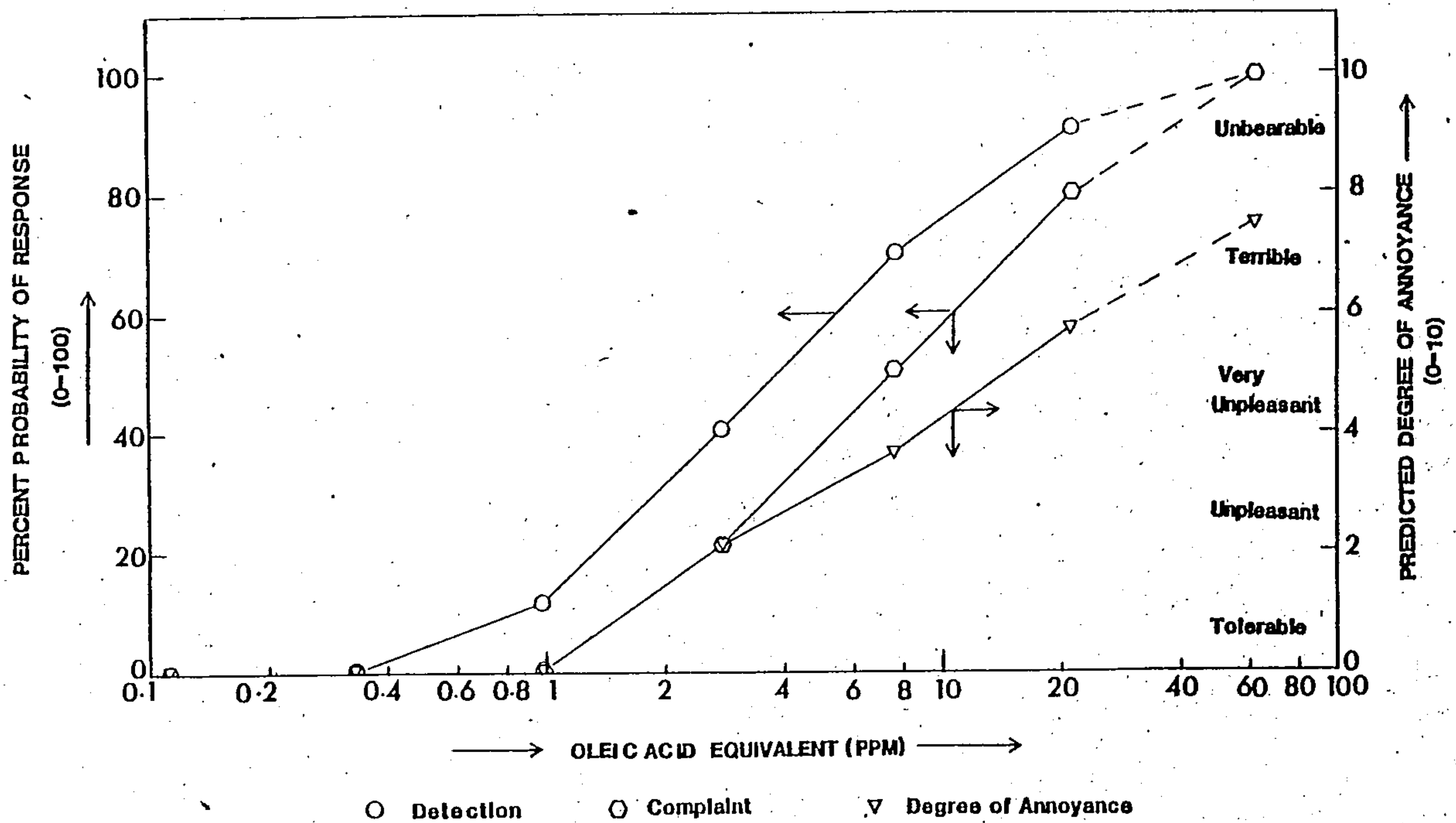

FIGURE 6.12: Odor Impact Model Profiles for Typical Diluted Odorous Emissions of the Fast Food Restaurant

TABLE 6.11: Odor Impact Model Profiles Characteristics for Emissions From the Fast Food Restaurant and Laboratory Simulation

SAMPLE	Initial Concentration (Oleic acid Equivalent) (PPM)	Panel Size	LEVEL @ 50 PPD (PPM)	LEVEL @ 50 PPD (O.U.)	LEVEL @ 100 PPC (PPM)	LEVEL @ 100 PPC (O.U.)	PDA_{100} (0-10)	Degree of offensiveness (DO)	LEVEL @ 50 PPC (PPM)	LEVEL @ 50 PPC (O.U.)	PDA_{50} (0-10)
Laboratory Simulation	625	20	3.86	160	90	7	8.7	61	8.4	74	3.2
Fast Food Restaurant Exhaust	390	10	5.5	71	56	7	7.1	50	11.25	35	3.8
	155	10	3.85	40	66	2.5	7.5	19	7.75	20	3.6

original samples. The relatively good agreement between the laboratory and source generated odors shown in Table 6.11 suggests that the use of oleic acid as a key component for fast food restaurant odors has considerable merit for future studies.

The magnitudes of the degree of offensiveness (DO) in Table 6.11 also provides evidence that continuous emissions of high concentrations of fast food restaurant odors in a congested highrise area can generate spontaneous complaints, as have been shown to occur in downtown Toronto. It must be emphasized that the odor panel members were not informed that the samples were typical fast food restaurant emissions, in order to minimize any bias on their part. Although, the degree of offensiveness, DO, of the fast food odors increase significantly with concentrations of oleic acid equivalent as is evident from Table 6.11, the potential impact of any level of fast food odors on the community will be minimal since the emissions are generally sporadic rather than continuous. In addition, there have not been any odor complaints about the fast food restaurant under investigation because

- the odor source under consideration is involved in preparation of food for human consumption
- the reaction towards fast food odors is neutral based on the hedonic ratings from the survey
- the fast food odors are considered to be harmless
- the neighborhood is not densely populated.

The fast food restaurant proved to be unsuitable for further investigation since

- the odorous emissions were too sporadic for reliable sample collection at downwind locations
- sample collection created smoke problems inside the restaurant due to limitations of the exhaust fan
- there were no registered spontaneous complaints that could be related to public attitude survey results

D. Solid Waste Landfill Site

The unique position of University of Windsor permitted and facilitated participation in a cooperative program with the Air Pollution Control Division of the Michigan Department of Natural Resources, the Environmental Protection Division of the Department of Attorney General, State of Michigan and the Engineering Department of the Charter Township of Avon, Michigan. A 774 unit mobile home park, located less than 500 feet from a domestic solid waste landfill site serving 14 Michigan townships, provided a convenient study area.

The relative locations of the mobile home park and the active landfill site are illustrated in Figure 6.13.

Odor complaints from the mobile homes were most numerous during calm, humid evenings or night time periods. Light winds from the southeast directions also generated 6 to 15 odor complaints per day.

The Avon Township Engineering and/or Fire Departments registered citizen reactions and provided validation of complaints

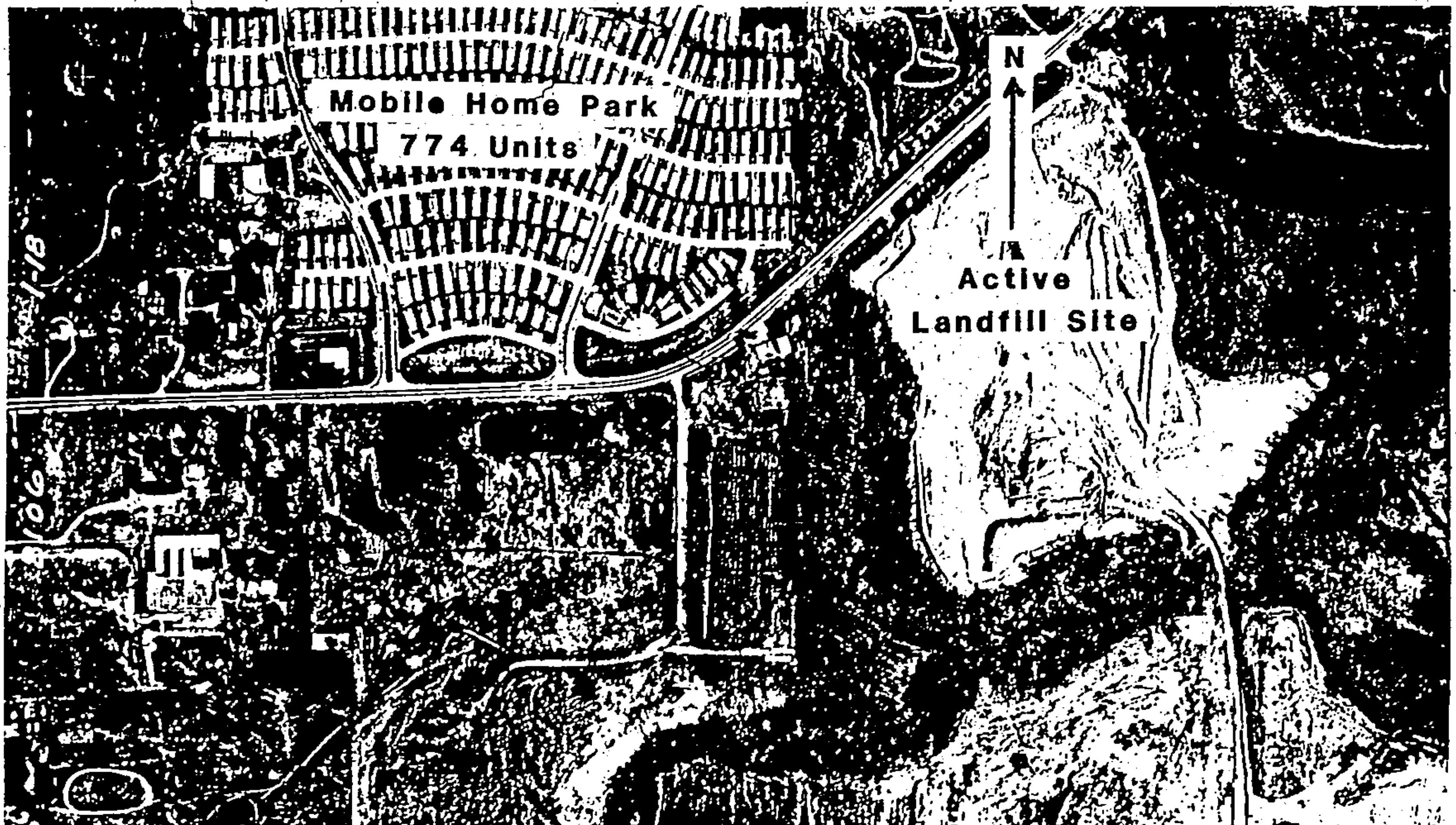

FIGURE 6.13: Relative Locations of Mobile Home Park and Active Landfill Site

whenever personnel were available to visit complainants usually within 15 minutes after telephone calls were completed. Figure 6.14 illustrates the complaint form used by the municipality to record citizen responses to the odors apparently transported from the landfill site.

A review of the daily complaints for the years 1982 and 1983 indicated that the days for which the number of complaints was greater than five should be used for correlation of complaints with meteorological data. Surface weather observations recorded on an hourly basis at Pontiac Airport weather station, which is within 15 miles of the landfill site, were used for the meteorological analysis. Figure 6.15 shows a typical surface weather observation record.

Table 6.12 provides a list of "bad days" when the number of complaints were greater than five. This table also summarizes the time periods when odors were noticed and complaints were made, as well as the wind directions and speeds for those dates and periods. From Table 6.12, it is evident that whenever the wind direction was from the southeast (i.e. from the landfill site towards the trailer park), the number of complaints due to the landfill odors was high.

Figure 6.16 shows typical locations in the trailer park where complaints were registered due to the landfill odors on January 28, 1983.

Figure 6.17 summarizes the major locations and the total number of complaints registered from the mobile home park during 1982 and 1983. According to these data some residents in the southeast

AVON TOWNSHIP CITIZEN COMPLAINT REPORT

COMPLAINANT Philipson SEC# ____

ADDRESS 140 Fontainbleau

DATE 10-18-83 TIME 1825 A/P PHONE 652-3826

REPORT TAKEN BY: 107 DEPT. Fire

NECESSARY TO CHECK: IMMED: ___ WITHIN 24 HRS. ___ A.S.A.P. XXX

COMPLAINT Odor coming from the dump

1852 hrs. 105 advised odor was detected at time of investigation. SEOCIA advised

ROUTING VERIFICATION BY: [signature] - Fire
NAME - DEPARTMENT

REPORT ROUTED TO:

- ___ DEPARTMENT OF PUBLIC SERVICE
- ___ ENGINEERING DEPARTMENT
- ___ BUILDING DEPARTMENT
- ___ HOUSING & ZONING INSPECTOR
- ___ ASSESSING DEPARTMENT
- X SUPERVISOR'S OFFICE
- ___ FIRE DEPARTMENT
- ___ OAKLAND COUNTY ROAD COMMISSION
- ___ OTHER (specify) ________

ATTENTION: E. Borden

+ +

I HAVE ALWAYS HEARD THAT FOR EVERY CALL WE GET OF A COMPLAINT THERE ARE AT LEAST 25 or 50 OTHERS WHO ARE MAKING STATEMENTS LIKE "WHY DON'T THEY DO SOMETHING ABOUT THAT" BUT DON'T BOTHER TO CALL. I LIKE TO FEEL WE'RE HELPING MANY MORE PEOPLE THAN THE COMPLAINANT BY ADDRESSING THE CONCERNS BROUGHT TO OUR ATTENTION. E. Borden

INSTRUCTIONS FOR USE:

1) The person receiving the complaint fills out the top portion -who, what, when, where, and signs it after "Report Taken By".

2) The form (both white and cream parts still intact) is then forwarded to the Department Head of the complaint recorder. The Department Head checks the routing, signs after "Routing Verification By".

3) The white part is then sent to the Supervisor's office and the cream (larger) part sent to the action department.

FIGURE 6.14: Avon Township Complaint Form

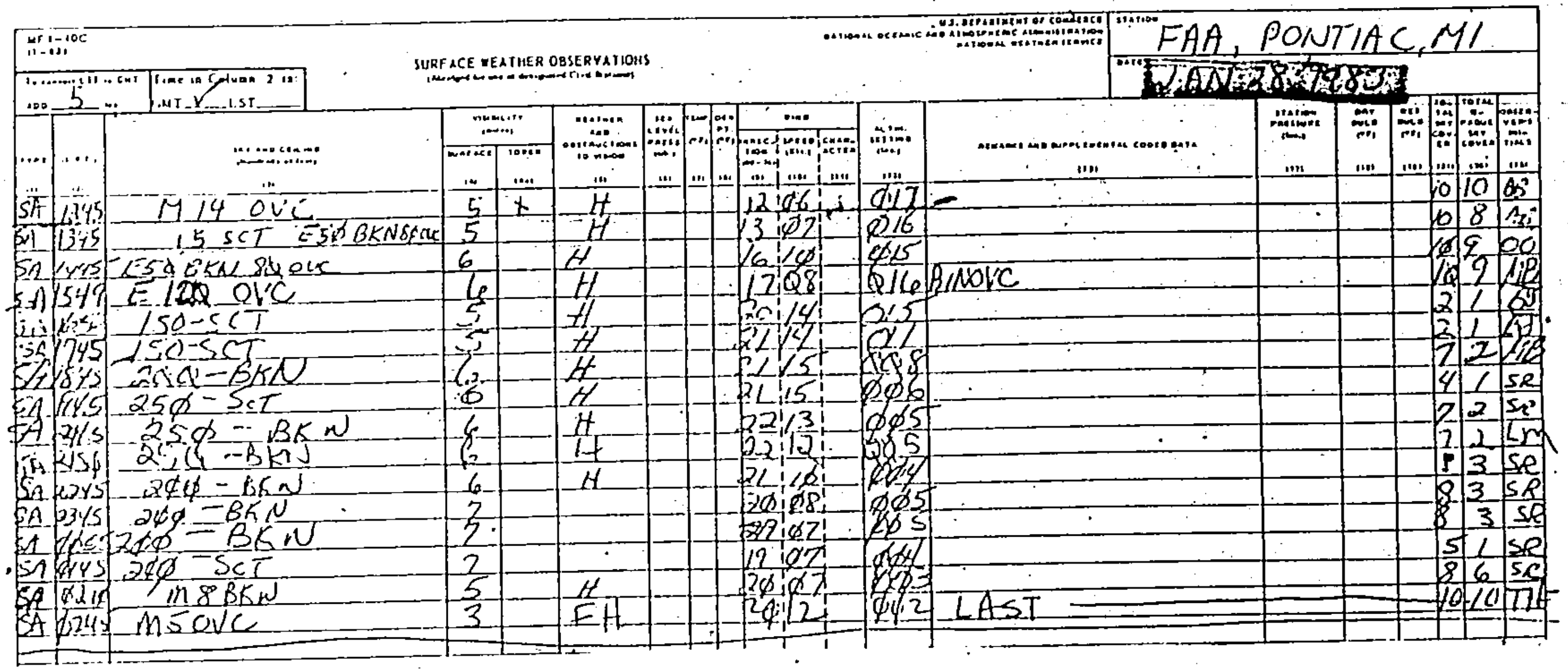

FIGURE 6.15: A Typical Surface Weather Observation Record Made at Pontiac Airport Weather Station

TABLE 6.12: List of "Bad Days" in Relation to Time Periods When Complaints Were Made and Corresponding Surface Weather Observations

Date	Time Period (LST)	Wind Data		No. of Complaints
		Direction (Degrees)	Speed (Knots)	
July 14/82	0818 to 1045	140-170	7-11	9
27/82	1410 to 1953	60-140	8-14	6
Nov. 18/82	1709 to 2139	140-170	5	6
Jan. 28/83	0830 to 0845	120-130	4-7	7
29/83	1630 to 1917	180-160	7-10	6
Feb. 01/83	1035 to 1736	70-110	12-17	7
May 11/83	2017 to 2154	160-180	5	5
June 08/83	2101 to 2300	170-160	6-9	6
12/83	0825 to 0837	250-280	5	7
12/83	1905 to 2117	190-200	6	3
15/83	0707 to 0708	00-00	0	2
15/83	1140 to 1145	280-230	5	2
15/83	1635 to 1648	240	8	2
20/83	2022 to 2150	160-120	5-8	6
22/83	1838 to 2131	160-180	10-6	15
30/83	0610 to 2109	160-220	8-14	8
Aug. 15/83	0855 to 2115	260-160	4-15	9
16/83	1912 to 2036	200-220	6	9
18/83	2038 to 2148	010-000	5	8
Sept. 04/83	2154 to 2205	230-180	8-5	7

(knots x 1.15 = statute mile/hour)

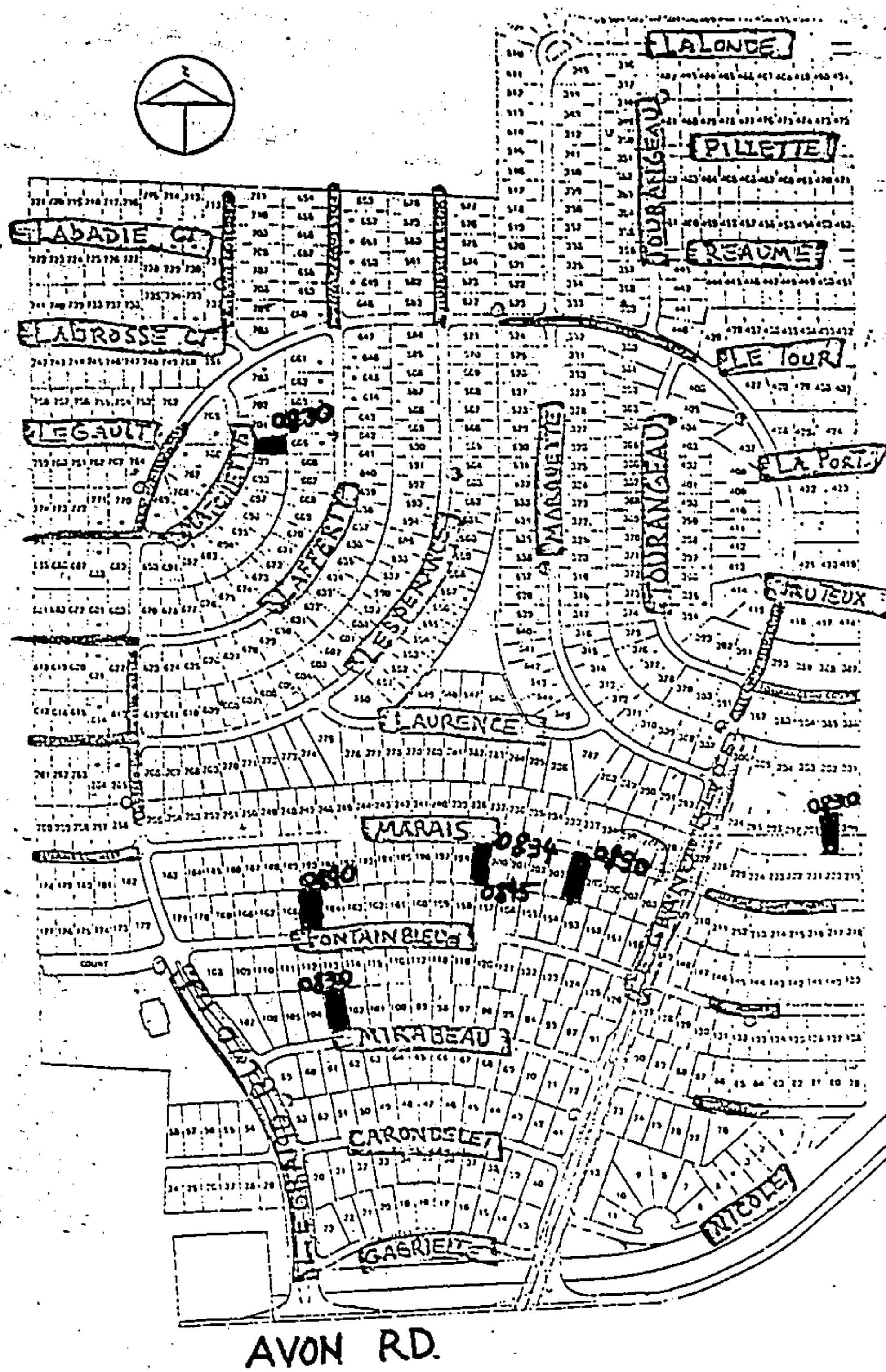

FIGURE 6.16: A Typical Map of Trailer Park With the Locations Where Complaints Were Generated on January 28, 1983

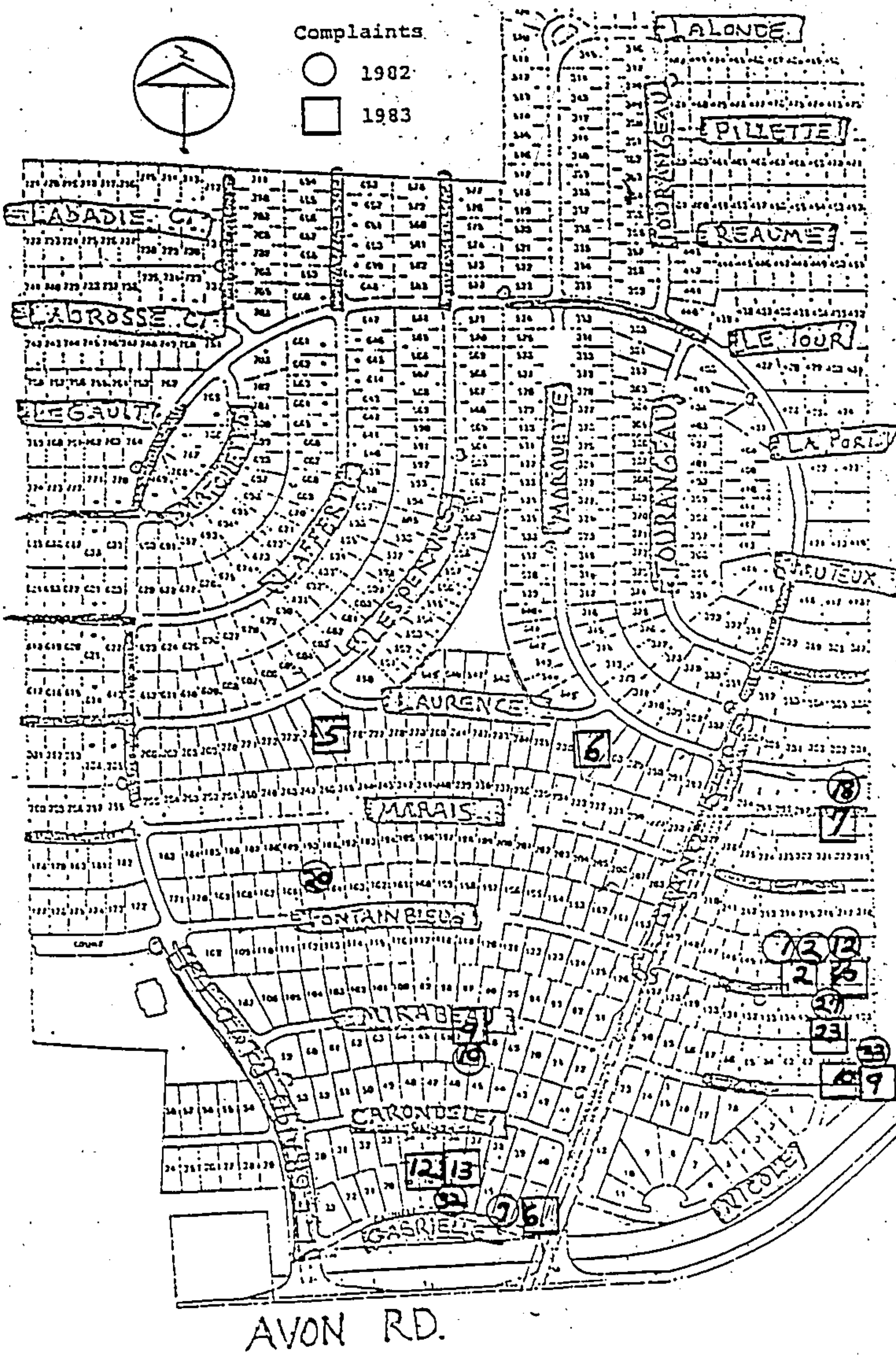

FIGURE 6.17: Major Complaint Locations

corner of the community had registered as many as 40 complaints in one year. Although more than half of all complaints were validated through independent investigations by members of the Municipal Engineering or Fire Departments, frequent complainers were viewed with suspicion by regulatory agencies and the operators of the landfill site.

In order to get a more objective assessment of the community odor problem, the local air pollution control agency surveyed 42 residents in the neighborhoods surrounding the landfill site. The results of this survey are summarized in Figure 6.18. It is evident that 88% of those surveyed were aware of a community odor problem and could identify the landfill site as the suspected source.

The format of the local air pollution control agency community survey was criticized because no efforts were made to control bias. Objections by the operators of the landfill site emphasized the highly leading nature of the 6 questions which tended to encourage participants to respond towards the formulation of a predetermined conclusion.

As a result, the designed questionnaire in Appendix III was implemented in the community adjacent to the landfill site, in order to determine the general reactions of people towards various odors and to assess if there were any odors in the ambient air which would seriously bother them. Out of 774 home units, 282 responded to the survey.

Table 6.13 provides the hedonic ratings of common odors as expressed by the residents in the neighborhood of the landfill site

AIR POLLUTION CONTROL DIVISION
MICHIGAN DEPARTMENT OF NATURAL RESOURCES
COMMUNITY SURVEY

42 Residents Surveyed

1. DO YOU NOTICE ANY POLLUTION PROBLEMS AROUND YOUR NEIGHBORHOOD?
yes 37 no 5.

2. IF SO, COULD YOU PLEASE DESCRIBE THE TYPE OF POLLUTION?
air 37 water - noise - aesthetic - other -

description: Stench; Musty; Rotten Garbage; Landfill smell; Smells Like Someone Died.

3. CAN YOU IDENTIFY THE SOURCE OF THE POLLUTION? yes 37 no 5

identification: Landfill site.

4. DOES THE POLLUTION APPEAR TO BE BOTHERSOME AT ANY PARTICULAR TIMES?

description: Late at Night; When winds from South; In Evenings when Real Humid; Depends on Wind Direction

5. HOW DOES THE POLLUTION AFFECT YOU OR YOUR PROPERTY? Makes Stomach Turn; Cannot Relax Outside in the Evenings; Bothers Friends who Visit; Visitors Leave; Could Not Sell Home; Affects Property Values; Some Nights Must Close Windows.

6. WOULD YOU DESCRIBE THE IMPACT OF THE POLLUTION ON YOU OR YOUR PROPERTY?
slight 6 moderate 11 very much 12 extreme 8 none -

description: God Help Us; Real Nuisance; Mostly Early AM: Bad Between Midnight and Noon; When Wind from Southeast.

NAME ______

ADDRESS ______

CITY ______

NUMBER OF RESIDENTS IN THE LIVING UNIT: ______

DATE: ______ INTERVIEWED BY ______

FIGURE 6.18: Summary of Community Survey

TABLE 6.13: Comparison of the Hedonic Ratings of Common Odors Expressed by the Residents in the Neighborhood of the Landfill Site and the Control Group

Odor Description	Control Group	Landfill Site
cut grass	+2.6	+2.5
car/truck fumes	-8.9	-9.3
fried chicken outlets	-0.7	-0.8
sewers	-9.6	-9.9
vinegar	-3.9	-5.3
garbage	-9.8	-9.9
hospital	-4.7	-5.4
fruit market	+2.0	+0.5
gasoline	-5.5	-5.6
hamburger restaurants	-0.9	-1.8
fresh popcorn	+4.7	+5.2
ammonia	-8.5	-8.6
paint	-5.9	-5.1
roses	+7.4	+7.3
beer	-1.6	-2.9
outside chinese restaurant	-0.7	-1.8
locker/dressing room	-8.4	-8.2
baking bread	+7.9	+7.7
wood fire	+6.0	+5.0
chocolate	+5.0	+3.5
cigarettes	-7.8	-6.3
carnival	-1.5	-3.0
peanuts	+2.8	+2.9
barbeque	+6.2	+5.7
leather jacket	+1.3	-0.7

Statistical t test level of significance > 99%

and the control group. Figure 3.5 illustrated the comparison between the ratings from the two groups. The good agreement between the hedonic values suggests that the reactions to odors in the neighborhood of the solid waste landfill site, are no different from those in the control area.

Table 6.14 summarizes the descriptions of neighborhood odors and the percentages of the people of various age groups bothered by them in the vicinity of the landfill site. It is apparent that the proportion of people of any age that was seriously bothered by the garbage odors in the proximity of the landfill site, was significantly higher than in the control area. Since it has been shown in Table 3.1 that citizen reactions to common odors in this community are normal, the identification of the landfill site as a potential source of odorous emissions and the generation of spontaneous complaints from the neighborhood, are valid.

Extensive on-site observations showed that at a well run landfill site where adequate cover is provided after daily operations are completed, odors are emitted

- during dumping of freshly collected garbage
- during dumping of incinerated garbage
- from invisible cracks in the caps of completed cells
- from stagnant water pools through which gases percolate
- from large cracks that appear suddenly in the caps of completed cells. They can emit very strong odors from depths of 10 to 30 feet.

TABLE 6.14: Descriptions of Neighborhood Odors and Percentages of the People of Various Age Groups that Were Bothered by Them in the Vicinity of the Landfill Site in Comparison to the Responses from the Control Area

Odor Description	Number of People	Percent People Seriously Bothered								
		15	114	57	16	26	40	10	282*	109
	Age Group	10-19	20-29	30-39	40-49	50-59	60-69	70 and up	Landfill Average	Control Area
Garbage		80	77.2	82.5	75	69	75	100	76	11
Auto Emissions		7	23	11	12.5	19.2	15	10	17	22
Factory Smoke		14	13.4	19.5	6.3	3.8	12.5	30	13.5	-
Bus & Truck Fumes		7	9	8.8	18.8	19.2	22.5	20	12.6	21
Cigarette Smoke		7	11	7	12.5	3.8	5	-	8.5	28
Sewers		7	11.4	7	6.3	3.8	5	-	8	9
Gasoline		7	3.6	3.5	6.3	7.6	12.5	-	5.9	13
Skunk		7	7	1.8	6.3	-	2.5	-	4.3	5
Strong Perfumes		-	1	1.8	-	-	5	10	2	4
Burning Leaves		-	3.5	1.8	-	-	-	10	2	2
Fertilizers		-	2	1.8	6.3	3.8	2.5	-	2	-
Paint Fumes		-	2	-	6.3	-	5	-	9	1
Pollution		7	1	-	-	3.8	2.5	10	1.8	22
Tar Roofing		-	1	-	-	3.8	2.5	-	1	2
Sulphur		-	2	-	-	-	2.5	-	1	9

*4 people did not mention their ages

Consequently, odor samples were collected

- during dumping of freshly collected garbage
- during dumping of incinerated garbage
- 18 inches above ground level where odors were detected
- above a stagnant pool of water through which gases percolated
- from a 2-inch observation well pipe sunk 30 feet below the cap of a completed cell.

Acquisition of representative samples during the dumping of garbage trucks or during sporadic gas evolution through the cap on a completed cell still represents a technical challenge. However, reliable samples were collected above the stagnant water pool and from the observation well for the development of Odor Impact Models.

Figures 6.19 and 6.20 illustrate Odor Impact Model profiles for typical odorous emissions from a stagnant water pool and an observation well of the landfill site. The data from these profiles are summarized in Table 6.15. It is evident that the emissions from the observation well have a significantly higher degree of offensiveness (DO = 714) than those from the water pool (DO = 13). Table 6.18 indicates that the odorous emissions from the observation well must undergo 50,000 dilutions before they reach the residents in the neighborhood of the landfill site, if the percent probability of complaint is to be reduced to zero. At 2000 dilutions, the chances of complaints are 50% and the predicted degree of annoyance is 2.9 on a scale of 0 to 10. If the number of dilutions is reduced to 84, the percent probability of annoyance rises to 100 and the predicted

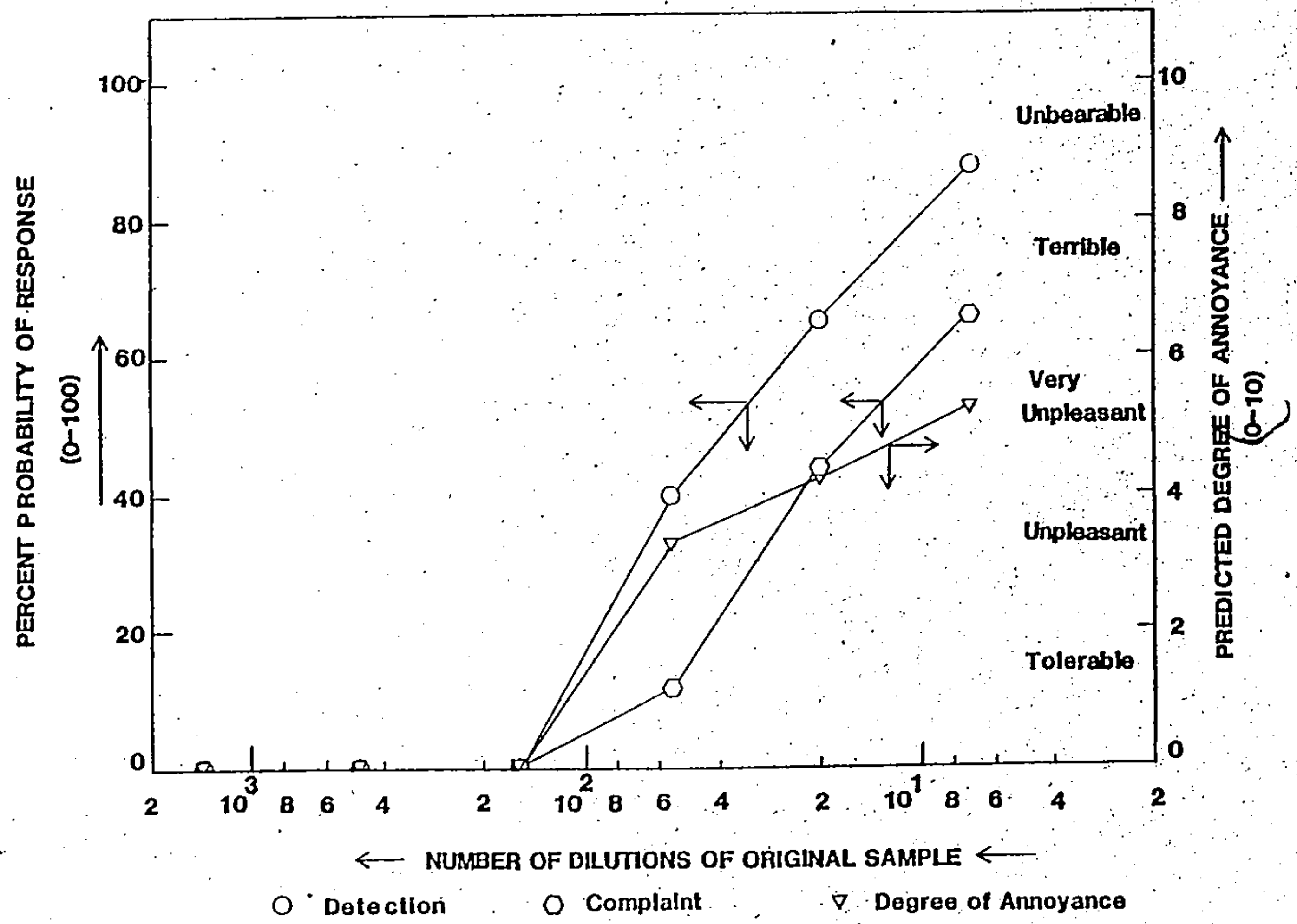

FIGURE 6.19 Odor Impact Model Profiles for Typical Odorous Emissions From The Water Pool

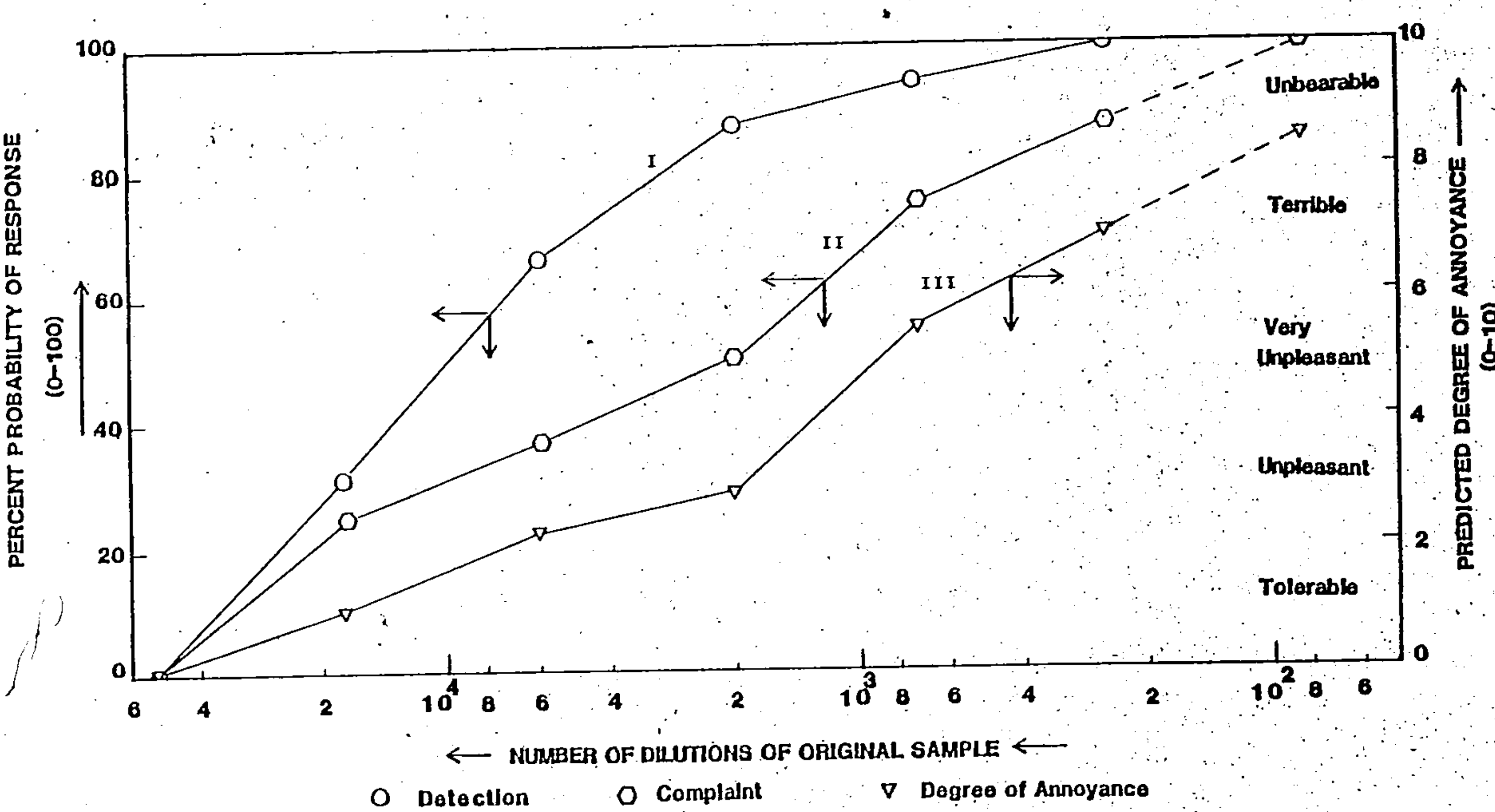

FIGURE 6.20: Odor Impact Model Profiles for Typical Well Sample From Landfill Site

TABLE 6.15: Sensory Characteristics of Odor Samples from Two Landfill Site Locations

Sample	DL @ 50 PPD (ED_{50} or D/T)	MDL @ 100 PPC	PDA_{100} (0-10)	DL @ 50 PPC	PDA_{50} (0-10)	DL @ 0 PPC	Degree of Offensiveness (DO)
From Above Water Pool	33	2	6.7	16	4.5	162	13.4
Observation Well	10,000	84	8.5	2,000	2.9	50,000	714

degree of annoyance to 8.5 on the same scale of 0 to 10.

Extensive on-site observations showed that odors are released from cracks in completed caps as distinct puffs that can move considerable distances without losing their ability to create adverse receptor reactions. Emitted essentially at ground level, the puffs move randomly for long distances along the surface at heights below the normal breathing zone levels of the 6 to 8 human observers tracking their progress. Under favourable atmospheric conditions the odors can reach the neighborhood adjacent to the landfill site to create unpleasant conditions in highly localized areas of the community in the general direction of the prevailing wind.

It is now possible to quantify "how bad" odors are from different locations of a landfill site as long as representative samples can be collected for analysis. Answering the question "how much" is virtually impossible at this stage of development since measurement of flow rates of sporadic emissions from cracks in the caps of completed cells or those associated with the dumping of fresh or incinerated garbage is still difficult.

E. Automotive Foundry

The cooperation of plant management and regulatory agency personnel facilitated the implementation of the Odor Impact Model as a means of assessing the relationship between an odorous stationary source and its surrounding community.

Sporadic spontaneous complaints by the residents in the neighborhood of the foundry have been recorded at the local air pollution control agency since 1979. Analysis of the complaint data showed that most adverse reactions were generated by the residents of highrise apartments located within 1500 meters of the plant. It is not surprising that the apartment residents would complain more severely, since they would be affected by plume center line concentrations rather than ground level impingement values. Table 6.16 summarizes the complaint statistics for the 1979-1984 period. Figure 6.21 shows that the locations of the majority of odor complaints during the 1982-1984 period which were mostly from high rise apartments situated downwind of prevailing south to south-westerly winds.

The public attitude survey described in Appendix III was implemented in the neighborhood of the foundry with full cooperation of plant management and the regulatory agency. Table 6.17 summarizes the average hedonic ratings of the twenty-six commonly encountered odors by the people surveyed. The responses to the same questions from the control group are also included for comparison purposes. The comparison between the hedonic ratings is provided in Figure 3.6. The good agreement between the values from the two groups indicate that the people living in the vicinity of the foundry are no different from those in the control group.

The responses to the question "What odors in the air seriously bother you? Please list" are provided in Table 6.18 for the residents from the foundry area and the control group. It is evident that almost half of those surveyed in the neighborhood of the foundry

TABLE 6.16: Number Of Complaints Per Year Recorded At The Local Air Pollution Control Agency Due To Odors Emitted From The Foundry.

YEAR	NUMBER OF COMPLAINTS
1979	11
1980	1
1981	10
1982	80
1983	42
1984	138

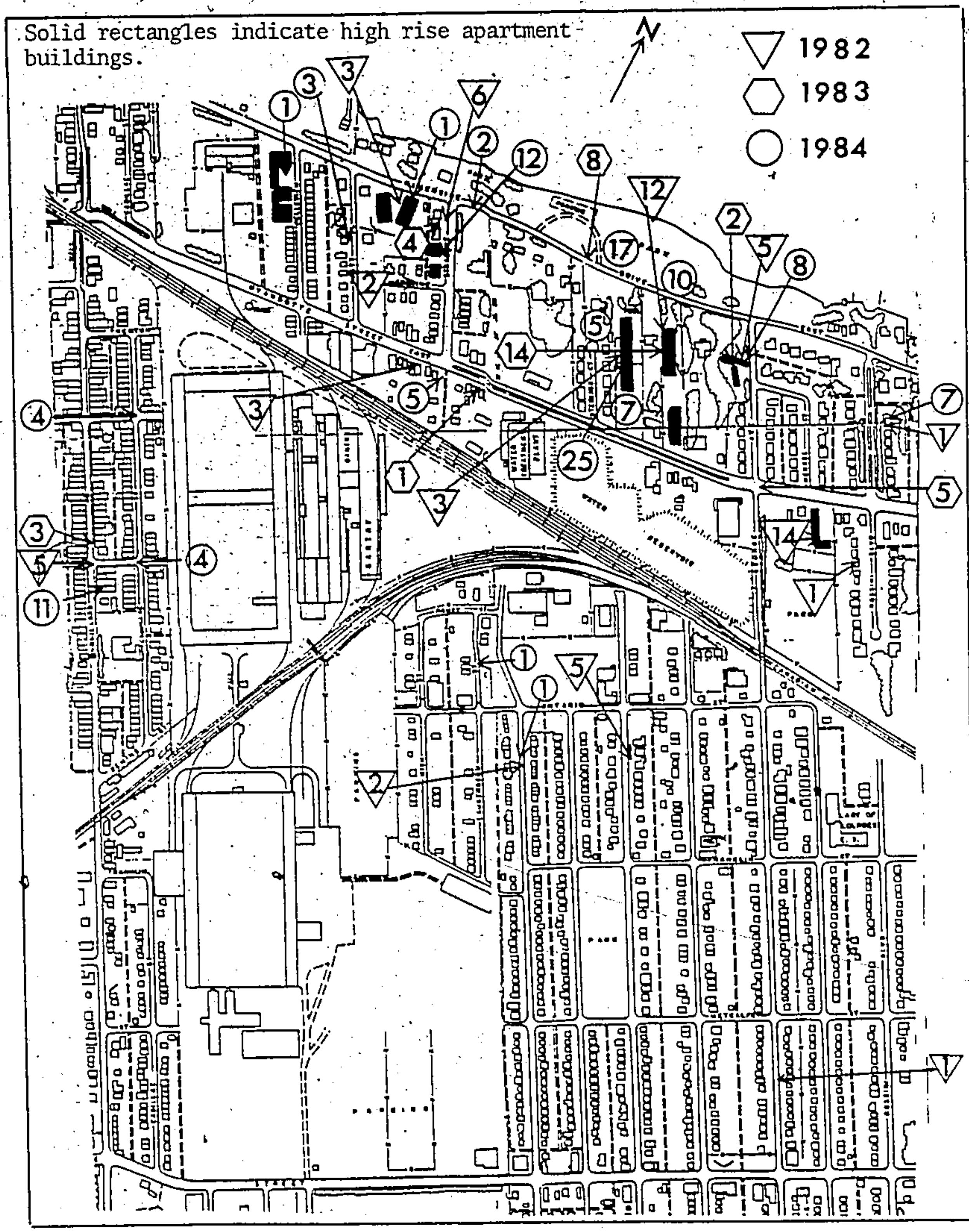

FIGURE 6.21: Major Locations of Odor Complaints During 1982-84 Period

TABLE 6.17: Hedonic Ratings of Odors Expressed by People in the Neighborhood of the Foundry and the Control Group

Odor Description	Control Group	Foundry
cut grass	+2.6	+ 2.8
car/truck fumes	-8.9	- 9.1
fried chicken outlets	-0.7	- 1.4
sewers	-9.6	-10.0
vinegar	-3.9	- 2.9
garbage	-9.8	- 9.8
hospital	-4.7	- 4.2
fruit market	+2.0	+ 1.8
gasoline	-5.5	- 6.4
hamburger restaurants	-0.9	- 2.3
fresh popcorn	+4.7	+ 3.9
ammonia	-8.5	- 7.2
paint	-5.9	- 5.5
roses	+7.4	+ 8.3
beer	-1.6	- 4.3
outside chinese restaurant	-0.7	- 2.7
locker/dressing room	-8.4	- 9.0
baking bread	+7.9	+ 8.8
wood fire	+6.0	+ 6.5
chocolate	+5.0	+ 3.8
cigarettes	-7.8	- 6.9
carnival	-1.5	- 2.3
peanuts	+2.8	+ 3.0
barbeque	+6.2	+ 5.6
leather jacket	+1.3	- 1.9

Statistical t test level of significance > 85%

TABLE 6.18: Comparison of Descriptions of Odors and Percentages of People Bothered by Them in the Neighborhood of the Foundry and the Control Area

Description of Odor	Percent People* Seriously Bothered	
	Control Group	Foundry
Cigarette Smoke	28	17
Auto Emissions	22	18
Pollution	22	8
Bus & Truck Fumes	21	15
Gasoline	13	-
Garbage	11	10
Sewers	9	7
Sulphur	9	-
Skunk	5	-
Strong Perfumes	4	-
Foundry	3	48
Ammonia (bleach)	2	-
Tar Roofing (hot asphalt)	2	-
Burning Rubber	2	3
Methane	2	-
Sewage Treatment Plant	2	-
Melting Metal Fumes	3	-
Brewery	2	5
Burning Leaves	2	-

* Multiple complaints from respondents allow the sum of percentage responses to exceed 100

were seriously bothered by the odorous emissions from the foundry whereas only 3% from the control group expressed annoyance with foundry odors. Such a high community identification indicates that the foundry was a potential source of odorous emissions in the neighborhood and that the odor related spontaneous complaints to the local air pollution control agency regarding the foundry odors were valid. This process established that there was a recognizable odor problem in the community.

A tour of the plant site indicated that the foundry had over one hundred stacks serving various operations. Discussions with the plant personnel suggested that only 16 stacks were major odor emitters. Consequently, odorous samples were collected from these stacks for subsequent analysis. A preliminary screening using traditional ED_{50} values showed that 7 of the 16 stacks were emitting relatively low odor levels. Table 6.19 provides the ED_{50} data for the low odor emitters.

The remaining 9 stacks were subjected to Odor Impact Model analysis. Figures 6.22 and 6.23 illustrate the Odor Impact Model profiles for the sluice #1 and the amine stack emissions. The profiles for other stacks are presented in Appendix VI.

Table 6.20 summarizes the data from the Odor Impact Model profiles for the 9 major odor emitting stacks. The earlier test data, representing the results of 60 to 97 minutes integrated sampling periods, provide average odor levels. The second set of data provides measures of maximum odor levels in the gases exhausted over a 20 minute period.

TABLE 6.19: ED_{50} Date for Low Odor Level Emitters

Stack	Date	Sampling Time (minutes)	ED_{50} ASTM E679 (o.u.)
Bag House	Aug. 22/84 Nov. 6/84	90 20	< 2.0 < 4.0
B8	Aug. 22/84 Nov. 1/84	90 20	< 4.0 < 5.0
D6	Aug. 23/84 Sept. 5/84	79 20	< 2.0 < 3.0
C8	Aug. 23/84 Oct. 31/84	47 20	< 3.0 < 2.0
B3	Aug. 29/84 Nov. 6/84	62 20	≤ 2.0 < 3.0
B7	Aug. 29/84 Nov. 1/84	74 20	< 2.0 < 5.0
Sluice #3	Aug. 31/84 Jan. 15/85	60 20	< 3.0 < 2.0

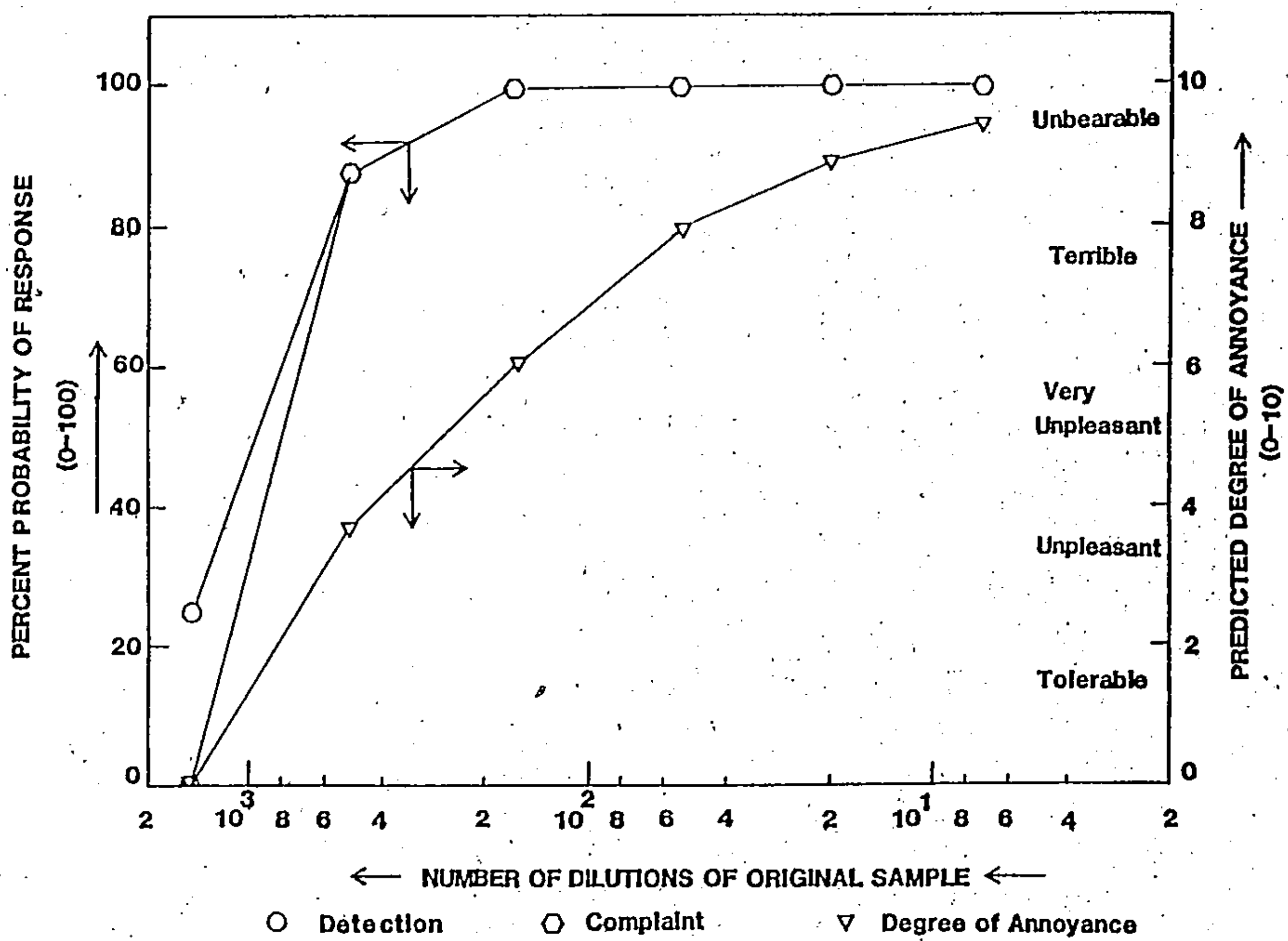

FIGURE 6.22: Odor Impact Model Profiles For Typical Odorous Emissions From Sluice #1 Stack

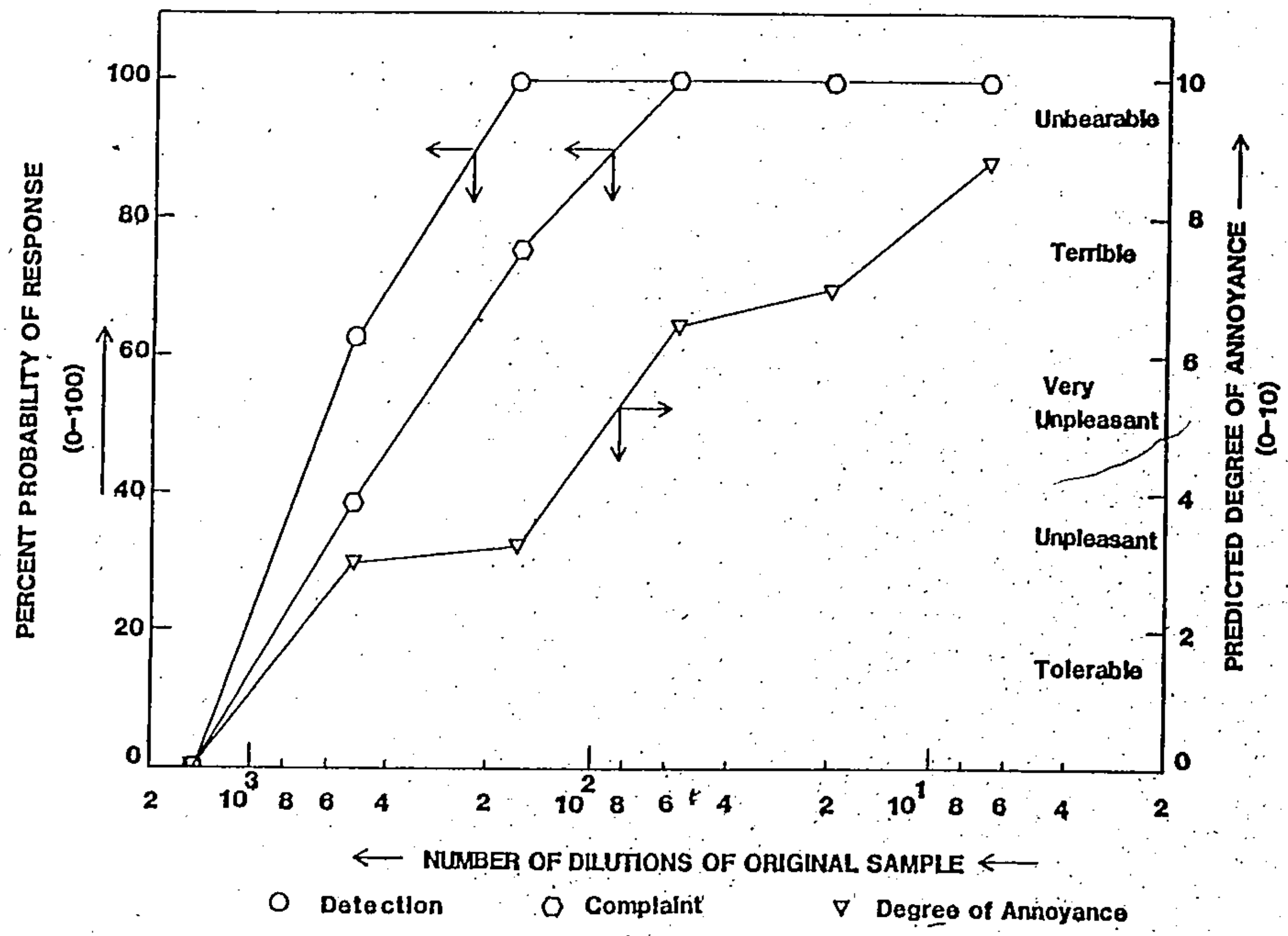

FIGURE 6.23: Odor Impact Model Profiles For Typical Odorous Emissions From The Amine Stack

TABLE 6.20: Summary of the Sensory Characteristics of the Nine Major Odor Emitting Stacks

Stack	Date	Sampling Time (minutes)	ED_{50} ASTM E679 (o.u.)	DL @ 50 PPD (o.u.)	MDL @ 100 PPC (o.u.)	PDA_{100} (0-10)	Degree of Offensiveness DO	DL @ 50 PPC (o.u.)	PDA_{50} (0-10)	Ranking (DO Basis)
Sluice #1	Aug. 31/84	66	640	850	60	7.0	420	500	2.5	1
	Nov. 6/84	20	960	950	160	6.0	960	800	2.1	
Amine	Aug. 31/84	57	250	215	20	7.0	140	160	3.6	2
	Oct. 31/84	20	550	630	60	6.4	384	350	3.0	
C9	Aug. 29/84	50	40	40	3	7.6	23	30	2.4	3
	Oct. 31/84	20	215	160	60	6.1	366	135	2.0	
Cupola #1 (outlet)	Sept. 4/84	55	130	110	20	6.3	126	95	4.0	4
	Nov. 19/84	20	160	160	60	4.5	270	115	2.5	
Cupola #1 (inlet)	Sept. 4/84	97	125	105	60	6.5	390	105	4.8	
	Nov. 19/84	20	140	160	3	8.0	24	100	3.0	
B	Aug. 22/84	60	50	35	3	8.0	24	35	4.0	5
	Jan. 15/85	20	190	230	20	5.1	102	160	1.8	
B11	Aug. 23/84	97	35	35	1	10.0	10	25	3.4	5
	Nov. 1/84	20	125	115	20	5.1	102	80	3.3	
Cupola #3 (outlet)	Sept. 4/84	58	45	45	3	10.0	30	30	5.9	7
	Nov. 19/84	20	140	135	20	4.8	96	110	2.4	
D9	Aug. 21/84	45	80	60	7	7.6	53	45	5.8	8
	Sept. 5/84	20	140	130	1	10.0	10	70	3.6	
DS	Aug. 21/84	45	60	40	7	7.2	50	35	4.7	9
	Sept. 5/84	20	190	160	7	6.8	48	90	2.2	

Using the DO values as criteria the 9 stacks under consideration can be ranked in terms of "how bad" their odorous emissions are for worst case conditions as shown in Table 6.20. It is evident that

- sluice #1 (DO = 960)
- amine (DO = 384)
- C9 (DO = 366)
- cupola #1 (DO = 270)

stacks emit relatively more offensive odors than

- B (DO = 102)
- B11 (DO = 102)
- cupola #3 (DO = 96)
- D9 (DO = 53)
- D8 (DO = 50).

To answer the question "how much odor is there?", it is necessary to evaluate PLSA values for each of the major odor sources by accounting for both the offensiveness of the odorous emissions and their volumetric flow rates. Table 6.21 summarizes the ranking of the 9 major odor emitting stacks on the basis of PLSA magnitudes. On the basis of relative PLSA values, it is clear that the

- cupola #1
- C9
- sluice #1

stacks are responsible for more than 65% of the overall odor problem originating at the foundry.

TABLE 6.21: Ranking of the Nine Major Odorous Sources Based on Their PLSA Ratings

Stack	MDL @ 100 PPC (o.u.)	PDA_{100} (0-10)	Volumetric* Flow Rate (cfm)	Potential Level of Source Annoyance (PLSA) x 10^{-6} o.u./min.	% Contributions To Odor Problem based on PLSA	Ranking (PLSA Basis)	Odor Descriptions as Stated by Panelists
Sluice #1	160	6.0	8,000	7.7	13.6	3	Rotten eggs, H_2S, Acidic (Burning Sensation), Sewage, Rotten Fish, Unpleasant Smell
Amine	60	6.4	11,000	4.2	7.4	6	Spoiled Fish, Rubber Burning, Fishy, Burning Tires, Rotten Old Sharp Smell, Amines, Skunky, Pungent
Cupola #1	60	4.5	60,000	16.2	28.6	1	Burning Garbage, Burnt Polyester, Unpleasant, Coffee Grinds
Cupola #5	20	4.8	60,000	5.8	10.2	4	Irritating and Unpleasant, Awful, Stinky Smell, Burning Sensation, Chlorine
B	20	5.1	25,000	2.6	4.6	7	Amines, Rotten Meat and Fish, Burning Plastics, Rubbish, H_2S, Throat Irritating
C9	60	6.1	40,000	14.6	25.7	2	Exhaust Fumes, Garbage, Sour, Smells Burnt, Rubber Smoldering, Irritating to Nose, Acidic
B11	20	5.1	50,000	5.1	9.0	5	Rotten Fish or Eggs, Burning Rubber, Car Exhaust, Gasoline, Old Stale Beer, Sulphurous Odor
D9	1	10.0	30,000	0.3	0.5	8	Sewer Stench, Burning Rubber or Tires, Amines, Chemical, Rotten Eggs
D8	7	6.8	30,000	0.2	0.4	9	Garbage, Sulphur, Amines, Old Paint, Sour, Burning Tire or Rubber, Burning Sensation in the Nose

* as provided by the foundry

Knowing "how much odor" is being emitted by industrial sources in terms of PLSA values provides management with the background information needed to prioritize the budgeting of funds for implementing appropriate odor control techniques. The selection of the best odor control technology will depend on the

- physical properties of the emissions (whether odorous gases or particulate matter are to be removed)
- chemical properties of the emissions
- levels of odorous components in the exhausted gas stream.

In order to quantify the impact of a particular source on its surrounding community, it is necessary to assess the ambient odor levels in the neighborhood as a result of atmospheric transport over different distances with consideration of meteorological and topographical characteristics of the region. This quantification can be achieved through appropriate dispersion modelling in conjunction with the Odor Impact Model. Estimates of the number of dilutions of the foundry emissions at different downwind distances provided measures of PPC and corresponding PDA values from the Odor Impact Model profiles.

The flat option of the Valley Dispersion Model [40] was used to estimate the annual average dilutions which the foundry odors would undergo from the stacks to the various residential locations in a worse case scenario in the neighborhood of the foundry. Although the Valley Model has been traditionally used for specific pollutants, in this study, the model has been applied to estimate the order of magnitude of dilutions which the odors would undergo from the foundry to the receptors. This was accomplished by dividing the number of odor units per unit volume emitted at the source by the number of odor units per unit volume estimated by the model at the receptor locations. Ten years of meteorological data from Windsor Airport, along with experimentally determined estimates of odors being emitted, were used for modelling purposes. The analysis of the meteorological data by Atmospheric Environment Services, Environment Canada, in the form of joint frequency functions of 6 wind speeds, 16 wind directions and 6 stabilities, is provided in Appendix VII. The model results showed, that on an annual basis, there could not be any odor problems in the community surrounding the foundry.

However, on a short term basis, the Industrial Source Complex Short Term (ISCST) model [41] estimates of the number of dilutions which the odors would undergo during favourable meteorological conditions suggest that odor complaints from the community can be expected. A worst case scenario was created by combining all the odorous emissions from the various sources in the foundry into one hypothetical stack with Odor Impact Model profiles of sluice #1 representing all the foundry odors. This is a reasonable approximation since

- the distances between the foundry stacks are negligible in comparison to the distances from the stacks to the residential locations
- the sluice #1 emissions are most offensive in terms of the DO criterion.

With these simplifications it is possible to quantify the impact of the foundry odors on the surrounding community at various distances from the plant.

Forty-six hours of typical meteorological data were used in the analysis to characterize forty-six atmospheric conditions. The ISCST model provided the maximum number of odor units per unit volume that would be expected to occur at receptor sites located at specified distances from the hypothetical single stack. Application of the Odor Impact Model to the estimated receptor sites odor levels established the percent probabilities of complaint (PPC) and predicted degrees of annoyance (PDA) in the community under the worst meteorological conditions.

Based on the analysis of ten years of meteorological data collected at Windsor Airport [42] for the period 1972-1981, the most dominant atmospheric conditions in the region are Class 4(D) and 6(F) stabilities with wind speed ranges of 5.5 to 8.0 and 0.0 to 3.0 meters per second respectively and southwest wind direction as illustrated in Appendix VIII.

Since most of the spontaneous complaints originated from the high rise apartments in the neighborhood of the facility when the wind direction was from the southwest, it is important to examine receptor concentrations at various elevations with respect to the stack height. Tables 6.22 to 6.25 provide the PPC and PDA estimates in the community for the worst case meteorological conditions when the source elevations above the receptors are 0.0, 10.0, 25.0 and 50.0 meters respectively.

TABLE 6.22: PPC and PDA Estimates Due to Foundry Odors at Various Distances From the Plant For Worst Case Meteorological Conditions when the Difference Between Source and Receptor Elevations is 0.0 Meters.

Wind Speed (meters per sec.)	Stability Category 1-6	Distance from Source to Receptor Site (meters)	Number of Dilutions From Source to Receptor Site	PPC at Receptor Site (0-100)	PDA at Receptor Site (0-10)
7	4	30	3	100	10.0
7	4	50	8	100	9.4
5	6	70	11	100	9.2
5	6	90	15	100	9.1
5	6	100	17	100	9.0
5	6	125	22	100	8.8
5	6	150	28	100	8.6
5	6	250	57	100	7.9
3	6	300	72	100	7.4
2	6	400	85	100	7.1
2	6	500	102	100	6.8
2	6	700	147	100	6.1
2	6	850	287	98	5.7
2	6	1000	231	96	5.2
2	6	1200	294	94	4.7
2	6	1500	396	90	4.1
2	6	2000	581	74	3.1
2	6	2500	777	50	2.1

TABLE 6.23: PPC and PDA Estimates Due to Foundry Odors at Various Distances From the Plant For Worst Case Meteorological Conditions when the Difference Between Source and Receptor Elevations is 10 Meters.

Wind Speed (meters per sec.)	Stability Category 1-6	Distance from Source to Receptor Site (meters)	Number of Dilutions From Source to Receptor Site	PPC at Receptor Site (0-100)	PDA at Receptor Site (0-10)
12.0	4	30	5	100	9.6
10.0	4	50	13	100	9.1
10.0	4	70	25	100	8.7
7.0	4	90	37	100	8.3
7.0	4	100	43	100	8.2
7.0	4	125	61	100	7.8
7.0	4	150	83	100	7.2
5.0	6	250	98	100	6.9
5.0	6	300	112	100	6.6
2.5	6	400	143	100	6.2
2.0	6	500	149	100	6.1
2.0	6	700	184	99	5.7
2.0	6	700	184	99	5.3
2.0	6	1000	265	95	4.9
2.0	6	1200	327	93	4.5
2.0	6	1500	430	89	3.9
2.0	6	2000	613	70	2.9
2.0	6	2500	810	46	2.0

TABLE 6.24: PPC and PDA Estimates Due to Foundry Odors at Various Distances From the Plant For Worst Case Meteorological Conditions when the Difference Between Source and Receptor Elevations is 25 Meters.

Wind Speed (meters per sec.)	Stability Category 1-6	Distance from Source to Receptor Site (meters)	Number of Dilutions From Source to Receptor Site	PPC at Receptor Site (0-100)	PDA at Receptor Site (0-10)
15	3	30	162	100	6.0
15	3	50	100	100	6.8
15	4	70	110	100	6.7
12	4	90	120	100	6.5
10	4	100	123	100	6.5
7	4	125	143	100	6.2
7	4	150	162	100	6.0
4	4	250	258	95	5.0
5	6	300	256	95	5.0
5	6	400	280	94	4.8
2	6	500	315	93	4.6
2	6	700	325	92	4.5
2	6	850	363	91	4.3
2	6	1000	414	90	4.0
2	6	1200	492	88	3.6
2	6	1500	623	70	2.9
2	6	2000	864	43	1.8
2	6	2500	1123	22	1.0

TABLE 6.25: PPC and PDA Estimates Due to Foundry Odors at Various Distances From the Plant For Worst Case Meteorological Conditions when the Difference Between Source and Receptor Elevations is 50 Meters.

Wind Speed (meters per sec.)	Stability Category 1-6	Distance from Source to Receptor Site (meters)	Number of Dilutions From Source to Receptor Site	PPC at Receptor Site (0-100)	PDA at Receptor Site (0-10)
15.0	3	30	-	-	-
15.0	3	50	-	-	-
15.0	3	70	3540	0	0.0
5.0	2	90	1288	10	0.5
5.0	2	100	957	33	1.5
5.0	2	125	683	62	2.6
7.0	3	150	630	68	2.8
3.0	3	250	613	70	2.9
2.0	3	300	600	72	3.0
1.0	1	400	670	63	2.6
1.5	4	500	630	68	2.8
1.0	4	700	650	66	2.7
1.0	4	850	700	60	2.5
0.5	4	1000	786	50	2.0
0.5	4	1200	792	49	2.0
0.5	4	1500	890	40	1.7
0.5	4	2000	1150	20	0.9
0.5	4	2500	1470	0	0.0

An examination of Table 6.22, shows that for receptors within 700 meters of the plant, the percent probability of complaint is 100, and the predicted degree of annoyance varies from 6.1 to 10.0. However, for the range 700 to 2500 meters, the percent probability of complaint (PPC) decreases from 100 to 50 and the corresponding predicted degree of annoyance from 6.1 to 2.1 respectively. It is evident from consideration of Tables 6.22 to 6.25 that as the height of odorous emissions above the receptors increases, the impact at various distances from the plant would decrease.

Table 6.26 summarizes the data from Tables 6.22 to 6.25, in terms of the Potential Odor Impact (POI) of the foundry odors at receptor sites located at selected distances from the plant for various differences in source and receptor elevations. Table 6.26 clearly demonstrates that the impact of the foundry on the residents in the highrise apartments in the vicinity of the plant is much higher than on those at ground level. The impact also increases with proximity to the odorous source.

From the model results in Table 6.26, it is apparent that for the range 250 to 1500 meters from the plant the percent probability of complaint varies from 100 to 40 depending upon source to receptor elevations. The predicted degree of annoyance for this range would vary from 7.9 to 1.7 on a scale of 0-10 and the Potential Odor Impact at the receptor sites from 790 to 68 on a scale of 0-1000.

TABLE 6.26: Impact of Foundry Odors at Various Distances From the Plant For Worst Case Meteorological Conditions when Differences Between Source and Receptor Elevations Are Varied.

Difference Between Source and Receptor Elevations (meters)	Distance from Source to Receptor Site (meters)	PPC at Receptor Site (0-100)	PDA at Receptor Site (0-10)	POI at Receptor Site (0-1000)
0.0	250	100	7.9	790
0.0	500	100	6.8	680
0.0	1000	96	5.2	500
0.0	1500	90	4.1	369
10.0	250	100	6.9	690
10.0	500	100	6.1	610
10.0	1000	95	4.9	466
10.0	1500	89	3.9	347
25.0	250	95	5.0	475
25.0	500	93	4.6	428
25.0	1000	90	4.0	360
25.0	1500	70	2.9	203
50.0	250	70	2.9	203
50.0	500	68	2.8	190
50.0	1000	50	2.1	105
50.0	1500	40	1.7	68

The good agreement, between the model results illustrated in Table 6.26 and the actual complaint data registered at the local air pollution control agency, illustrated in Figure 6.21, and the survey results presented in Figure 3.6 and Table 6.18, shows the validity of this quantification process.

VII. GUIDELINES FOR REGULATORY AGENCIES

If regulatory agencies are to deal with community odor problems objectively they must have some commonly acceptable basis for establishing regulations. Ideally, regulatory action should protect the interests of all members of a community, including the very old, the very young, individuals with specific health problems, and the industries in the neighborhood. When attempts are made to establish standards, it must be recognized that in any population, many individuals may have developed multiple sensitivities to industrial chemicals or other contaminants as a result of their normal activities over their lifetimes. Sweet [43] has suggested that 15-20% of a community may fall into this category. Such individuals may react more severely to environmental insults. As a result they may become chronic complainers to regulatory agencies. In Ontario, a committee has recently been formed [44] by the Ministry of Health to study environmental hypersensitivity disorders.

In this program a convenient procedure has been developed for the quantification of the impact of existing or proposed stationary odorous source emissions on surrounding communities. As a result, to solve an existing odor pollution problem, a three step procedure is recommended.

The first step involves review and analysis of spontaneous complaint data. These data are early indicators that there might be an odor pollution problem in the community.

The second step involves validation of the spontaneous complaints and confirmation that the citizen reactions are generated by the alleged source. A representative number of the residents at least 20 or preferably 30 families [1] should be surveyed using the odor attitude survey that was designed and tested during this program in the neighborhood of

- a fast food restaurant
- a sewage treatment facility
- upwind and downwind communities of an automotive painting plant
- a solid waste landfill site
- a foundry
- an indoor mall serving as a control area.

It is now possible to compare the survey results from an affected community to the control group, to establish whether

- the residents show typical responses to common odors
- their identification of a suspected odor source or sources is valid.

Completion of the first two steps would establish "whether there is a recognizable odor problem in the community".

The third step is concerned with assessing

- "how bad" the odor is at the source
- "how much odor" there is at the source
- the impact of the source on the surrounding community.

In order to complete the third step, the Odor Impact Model (OIM) must be used to relate

- percent probabilities of detection (PPD)
- percent probabilities of complaint (PPC)
- predicted degree of annoyance (PDA)

to the odor levels under investigation.

A. How Bad is the Odor?

To account for the hedonics of the source odors (how bad) it is necessary to quantify the degree of offensiveness (DO) as a product of the

- maximum dilution level at 100 percent probability of complaint (MDL @ 100 PPC)
- corresponding predicted degree of annoyance (PDA_{100}).

The DO would provide "how bad" an odor is at the source.

B. How Much Odor is There?

Since a low emission rate of an odor with a high DO can be less serious than a high volumetric flow rate of an odor with a relatively lower DO, the potential level of source annoyance (PLSA) was introduced as a means of ranking the seriousness of various odor emitting sources with different volumetric flow rates and degrees of offensiveness. This is accomplished by multiplying the degree of offensiveness by the volumetric flow rate. The PLSA rating establishes "how much" odor there is at the source.

C. Impact on the Community

To assess the impact of the emissions from an odorous source or sources on the surrounding community, it is essential to quantify the potential odor impact (POI) values in the downwind neighborhood at various distances and elevations under a variety of meteorological conditions. The POI magnitudes are quantified as can be quantified as the product of the percent probability of complaint (PPC) times the predicted degree of annoyance (PDA). This is achieved by application of the Odor Impact Model in conjunction with appropriate dispersion modelling techniques.

Consequently, the severity of the impacts from different sources in a neighborhood can be ranked according to their POI magnitudes. Figure 7.1 provides comparisons of POI profiles of 4 different odor sources over a wide range of dilutions. According to this illustration the odors from the landfill site test well would be expected to create more adverse reactions in a community than odors from a foundry stack, a wastewater treatment plant or a paint manufacturing facility.

D. Setting Odor Regulations

Ideally, for an odor free environment, POI, PPD, PPC and PDA values should be zero. Realistically, these limits are not attainable. Consequently, some maximum acceptable magnitudes must be agreed to by the community, the associated industries and concerned regulatory agencies.

The establishment of possibly acceptable magnitudes is

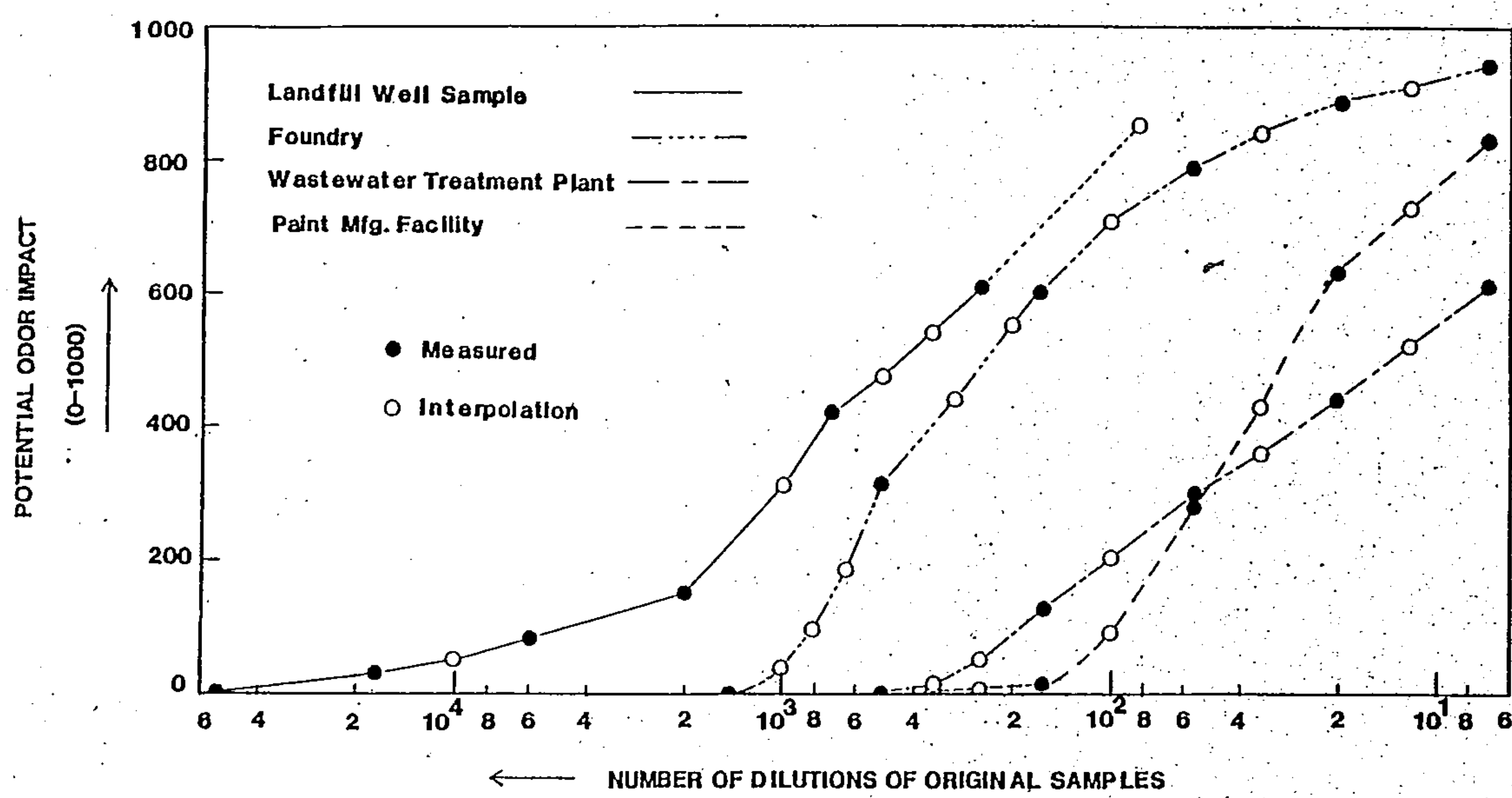

FIGURE 7.1: Comparison of Potential Odor Impact Profiles of Four Different Odor Sources

illustrated from a consideration of Figures 7.1 and 7.2. For example, Figure 7.1 shows that to achieve a POI = 20, the landfill observation well sample must be diluted about 22,000 times. According to Figure 7.2 this number of dilutions will provide values of:

- PPD = 26
- PPC = 20
- PDA = 0.9

Table 7.1 summarizes PPD, PPC and PDA estimates for assumed values of POI = 100; 50 and 20 for 4 different odor sources. The results show that the magnitudes of PPD, PPC and PDA are sensitive to changes in POI. For the landfill well sample, the PPD value decreases from 72 to 26 when the POI decreases from 100 to 20. There are corresponding reductions in PPC and PDA magnitudes.

Selection of POI = 20 as a possibly acceptable standard for a community experiencing odorous insults from 4 stationary sources provides upper limits of 40, 28 and 1.2 for PPD, PPC and PDA values, respectively. This arbitrary standard would provide protection for 72% of the population because only 40% will probably detect the odors from a waste water treatment facility while 28% will be tempted to complain with a PDA of only 0.7. The most severe reaction would be a tolerable zone value of 1.2 to paint odors. Since a POI = 20 apparently does not provide protection for the estimated 15 to 20% of society that may have developed hypersensitivities, regulatory agencies may be urged to adopt even lower POI values as a basis for

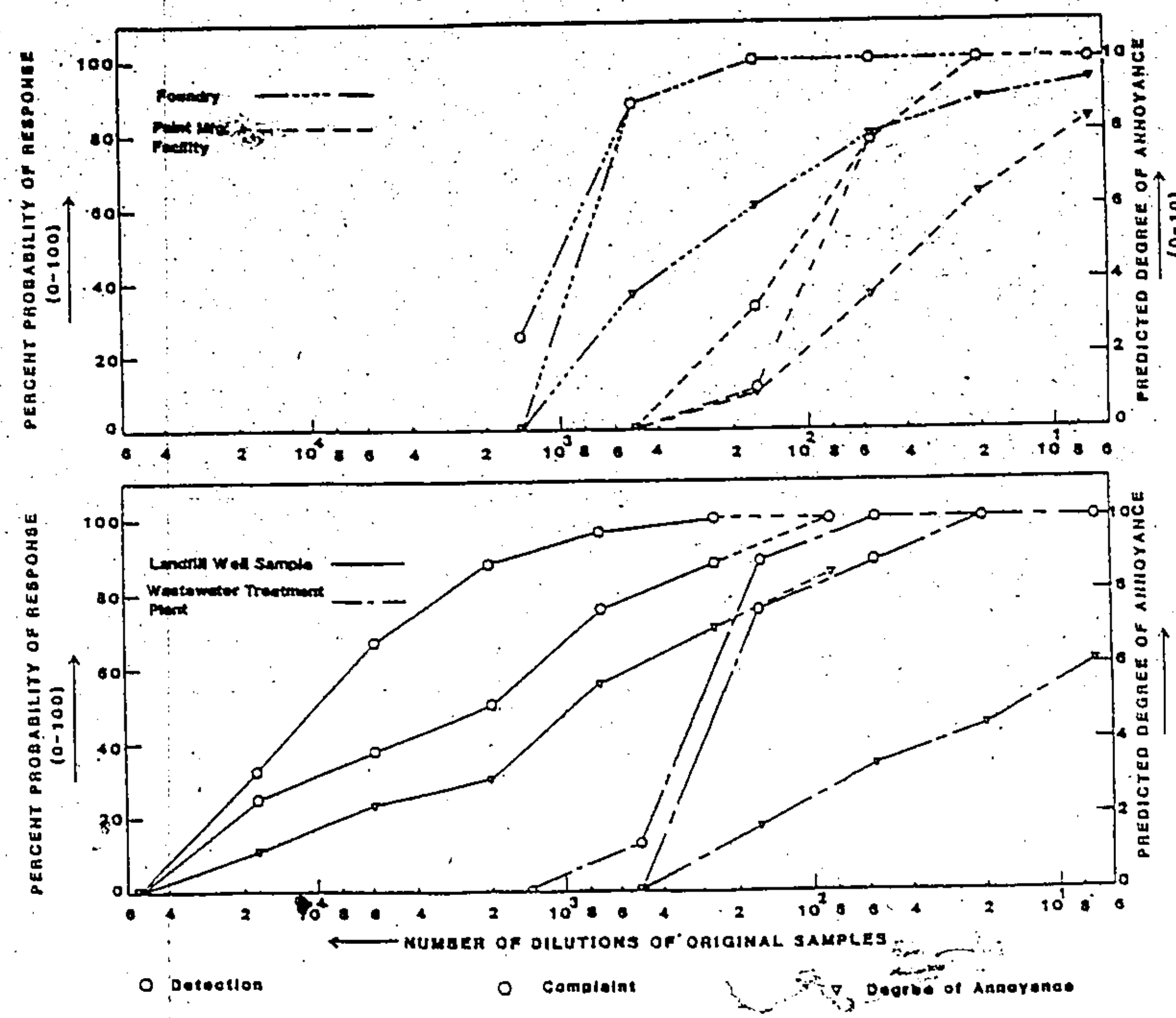

FIGURE 7.2: Comparison of Odor Impact Model Profiles For The Four Different Odorous Sources

TABLE 7.1: Comparison of PPD, PPC and PDA Estimates for POI Values of 100; 50 and 20 for Four Different Odorous Sources

POI	Source	Number of Dilutions of Original Sample	PPD 0-100	PPC 0-100	PDA 0-10
100	Landfill Well Sample	4,500	72	40	2.5
	Foundry	800	60	49	2.0
	Wastewater Treatment Plant	190	77	65	1.5
	Paint Manufacturing Facility	96	55	43	2.3
50	Landfill Well Sample	10,000	50	31	1.7
	Foundry	950	50	34	1.4
	Wastewater Treatment Plant	250	59	46	1.1
	Paint Manufacturing Facility	120	46	31	1.7
20	Landfill Well Sample	22,000	26	20	0.9
	Foundry	1,100	36	23	0.9
	Wastewater Treatment Plant	330	40	28	0.7
	Paint Manufacturing Facility	150	37	17	1.2
Possibly Acceptable Values			50	20	≤ 2

development of standards and regulations that will provide protection for the more sensitive members of a community.

E. Implementation of Odor Regulations

Recent experiences with legal problems involving odorous stationary sources [13] indicate that in order to verify that a suspected source (or sources) is or is not responsible for alleged odor problems in a community, it is necessary to prove that a scientifically and legally valid protocol has been followed with respect to data acquisition.

The protocol recommended on the basis of this investigation specifies measurements to be made at three levels involving the

- source(s)
- ambient air
- affected population

1. On-Site Measurements

In order to characterize the nature of any source emissions experimental programs should

- identify the different locations where odors are released
- determine the frequency and duration of odorous emissions at each location
- determine the quantities (volumes) of typical odorous releases at each location
- establish the odor levels in typical releases at each location, using the Odor Impact Model, in terms of

- percent probability of detection (PPD)
- percent probability of complaint (PPC)
- predicted degree of annoyance (PDA)
- degree of offensiveness (DO) "how bad"
- potential level of source annoyance (PLSA) "how much"
- potential odor impact (POI)

- identify, whenever possible, any key odorants that could be responsible for community complaints, through infrared spectrometry and/or gas chromatography/mass spectrometry.

It must be emphasized that, generally, it is difficult to relate odorous impacts to major components in the source gases because interactions between different chemicals in multicomponent systems can lead to

- odor masking
- odor enhancement
- synergistic effects

In the case of the wastewater treatment plant, the amounts of hydrogen sulphide and total reduced sulphur compounds were reduced by the scrubber but this reduction resulted in the production of sulphur dioxide which is also odorous. Although levels of the major components were lowered, the degree of offensiveness was not significantly changed.

2. Off-Site Measurements

In order to establish the magnitude of a community odor problem it will be important to

- identify the locations where odors have been and are perceived
- determine the frequency and duration of perceived odorous impacts
- assess whenever possible the odor levels at the various locations where odors have been perceived in terms of
    - o percent probability of detection (PPD)
    - o percent probability of complaint (PPC)
    - o predicted degree of annoyance (PDA)
    - o potential odor impact (POI)
- identify, whenever possible, any key odorants that can be related to perceived odors.

During this program a portable IR analyzer was used to track fast food odors in the neighborhood of the facility in terms of oleic acid equivalent. The instrument responded to odorous puffs which could also be detected by the human nose. Figure 7.3 illustrates the frequency and duration of typical odorous puffs detected instrumentally and olfactometrically. In principal, the key odorant, oleic acid, facilitated identification of approaching odorous puffs from the source but instrumental readings could not be correlated to responses from humans tracking the progress of the puffs through the neighborhood. The instrument was not sensitive enough to register low concentrations which could be readily detected by the human

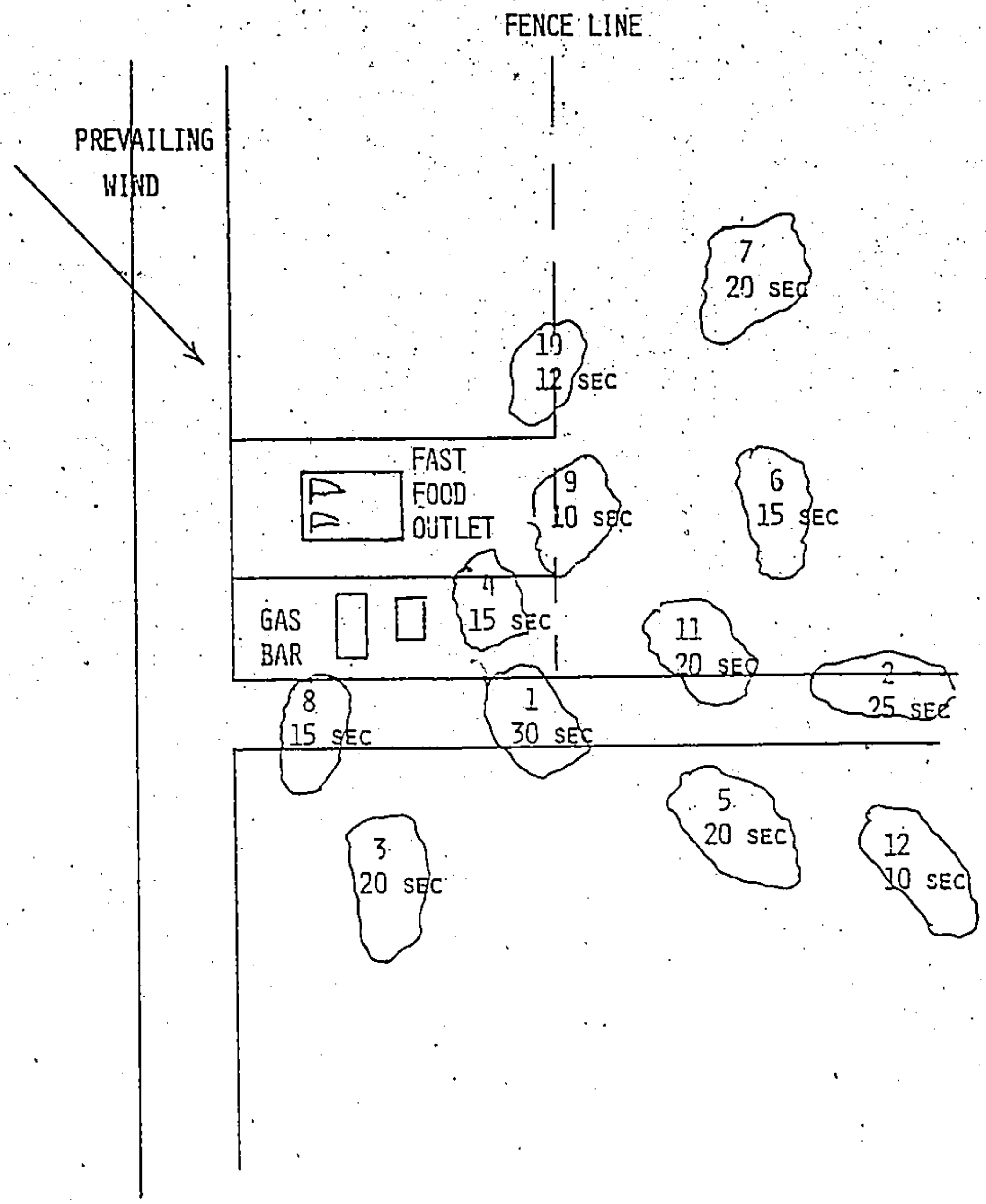

FIGURE 7.3: Typical Results of Tracking Fast Food Restaurant Odor Emissions

nose. Furthermore, interferences by other components produced high signals that were inconsistent with olfactometric assessments. This was specially true during high traffic density periods.

In the neighborhood surrounding the automotive paint facility, the principal odorous components being emitted were the solvents

- methyl amyl ketone
- methyl ethyl ketone
- n-butyl acetate
- xylene
- toluene

Although many residents identified the odors of methyl amyl ketone and/or xylene or toluene, many complained about an odor that reminded them of mushrooms. Investigations with the portable IR device indicated that it would not be possible to relate instrument signals to odor levels. Consequently, the concept of identifying a principal odorant was abandoned. Subsequent collection of gaseous compounds from the stack and ambient upwind and downwind locations, using Tenax collection media, helped to identify the presence of 25 to 35 major compounds in the stack and ambient gases using GC/MS techniques. There were perhaps as many peaks corresponding to trace levels of other compounds that were not identified.

Examination of the Tenax tubes, using a GC/olfactometric method, indicated that up to 45 different odorous compounds could be distinguished. The odor of mushroom was recognized three times over a 35 minute GC/sniffing analytical period. Independent work by Eastman Kodak Company of Rochester, New York confirmed that 1-octen-3-one could exist in ambient air samples. Although the formation of this compound has been explained by the presence of trace contaminants in solvents supplied to the paint manufacturer, ongoing litigation, involving the supplier of the solvents, the paint manufacturer and automotive company limits dissemination of relevant information. Nevertheless, Tressl et al. [45] have indicated that 1-octen-3-one belongs to a family of compounds demonstrating fungal odor qualities.

Although portable instrumentation may not be sensitive enough to detect the presence of, or quantify the levels of perceived odors, it is possible to identify principle odorants at extremely low concentrations through collection techniques that provide highly preconcentrated samples on appropriate adsorption media.

3. Receptor Responses

Community reactions to existing ambient odors must be characterized through valid odor dosage-response correlations for a variety of conditions. This phase of the protocol would involve

- analysis of past and current odor complaints where available
- analysis of the demographic nature of the affected community (age distributions, socio-economic activities and political forces are important)

- analysis of answers to an appropriate public attitude survey conducted in the affected community and a matching control area to determine

  i citizen prejudices

  ii individual reactions to perceived odors

  iii validity of spontaneous complaints.

Successful verification that a suspected source (or sources) is or is not responsible for alleged odor problems in a community will require correlation of the data from on-site, off-site and receptor response studies. The characterization of odor transport from source to receptors would require acquisition of

- topographical data including locations of any wind screens
- meteorological factors including wind speed and direction as well as frequencies of wind directions
- ambient air parameters including temperatures, humidities and cloud covers
- locations of alternate odor sources such as sewer manholes, 'garbage bins and/or mobile sources

Continued studies are still required if North American regulatory agencies are to develop legislation pertaining to odorous emissions. Recent development of objective techniques for the measurement of source and ambient odor levels and community responses to odor episodes will help control agencies to consider odorous industrial discharges to be more than "nuisance" problems.

VIII. CONCLUSIONS

A three step strategy has been developed for quantifying the impacts of existing or proposed stationary odorous sources on their surrounding communities. Successful implementation of the proposed protocols would establish

- whether there is a recognizable odor problem in the neighborhood
- how bad the odor is
- how much odor there is.

The first step involves review and analysis of spontaneous complaint data that are early indicators that there might be an odor pollution problem in the community.

The second step is concerned with the validation of spontaneous complaints and identification of the source or sources suspected of creating the odor problem. This is accomplished by conducting a public attitude survey in the affected community and a socio-economically similar control area using the questionnaire designed and tested during this program. If the comparison of the survey results show that residents in the test area exhibit normal reactions to common odors, then identification of any source by More than 15% of those surveyed is indicative that there is a recognizable odor problem in the community.

The third step is designed to assess

- "how bad" the odor is at the source
- "how much odor" there is at the source
- the impact of the source on the surrounding community.

In order to complete the third step, the Odor Impact Model (OIM) must be used to establish

- percent probabilities of detection (PPD)
- percent probabilities of complaint (PPC)
- predicted degree of annoyance (PDA)

profiles for the odorous emissions under investigation.

Quantification of "how bad" an odor is at the source is provided by the degree of offensiveness (DO) as

$$DO = (MDL \text{ @ } 100 \text{ PPC})(PDA_{100})$$

Since a low emission rate of an odor with a high DO can be less serious than a high volumetric flow rate of an odor with a relatively lower DO, the potential level of source annoyance (PLSA) has been introduced as a means of ranking the seriousness of various odor emitting sources. The PLSA is evaluated as

$$PLSA = (DO)(V_o)$$

To assess the impact of odorous emissions on the surrounding community, it is essential to quantify the potential odor impact (POI) values at downwind locations for various distances and elevations under a variety of meteorological conditions. A POI magnitude is quantified as

$$POI = (PPC)(PDA)$$

The appropriate PPC and PDA values are obtained from the Odor Impact Model after implementation of applicable dispersion modelling techniques.

Ideally, for an odor free environment, POI, PPD, PPC and PDA values should be zero. Realistically, this limit is not attainable. Consequently, some maximum acceptable magnitudes must be agreed to by the community, the associated industries and concerned regulatory agencies.

Application of the quantification process to the odorous emissions from

- a wastewater treatment facility
- a paint manufacturing plant
- a municipal waste landfill site
- an automotive foundry

shows that the magnitudes of PPD, PPC and PDA are sensitive to changes in POI.

Setting POI equal to 20 as a possibly acceptable standard for a community experiencing odorous insults from four stationary sources provides upper limits of 40, 28 and 1.2 for PPD, PPC and PDA values, respectively. Since a POI equal to 20 does not provide protection for the estimated 15 to 20% of society that may have developed hypersensitivities, regulatory agencies may be urged to adopt even lower POI values as a basis for development of standards and regulations that will provide protection for the more sensitive members of a community.

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NOMENCLATURE

DL @ 50 PPD	Dilution Level at 50 Percent Probability of Detection, o.u./ft^3 or ft^3/ft^3
DL @ 0 PPC	Dilution Level at Zero Percent Probability of Complaint, o.u./ft^3 or ft^3/ft^3
DL @ 50 PPC	Dilution Level at 50 Percent Probability of Complaint, o.u./ft^3 or ft^3/ft^3
DO	Degree of Offensiveness, o.u./ft^3 or ft^3/ft^3
D/T	Dilution to Detection Threshold Based on 50 Percent of Panel Responses, o.u./ft^3 or ft^3/ft^3
ED_{50}	Effective Dosage at Which 50 Percent of Panel Members Report Detection of the Odor, o.u./ft^3 or ft^3/ft^3
MDL @ 100 PPC	Maximum Dilution Level at 100 Percent Probability of Complaint, o.u./ft^3 or ft^3/ft^3
MLE	Maximum Likelihood Estimator
OIM	Odor Impact Model

o.u.	Odor Units
PDA	Predicted Degree of Annoyance, (0-10)
PDA_{50}	Predicted Degree of Annoyance at 50 Percent Probability of Complaint, (0-10)
PDA_{100}	Predicted Degree of Annoyance at 100 Percent Probability of Complaint, (0-10)
PLSA	Potential Level of Source Annoyance, o.u./min. or ft^3/min.
POI	Potential Odor Impact, (0-1000)
PPC	Percent Probability of Complaint, (0-100)
PPD	Percent Probability of Detection, (0-100)
PPM	Parts Per Million on Volume Basis
Q	Odor Emission Rate, o.u./min. or ft^3/min.
um	Micrometer
V_o	Volumetric Flow Rate, ft^3/min.

$W_{r,k}$	Expected Proportion of Panelists Who Are Wrong r Times Out of k Trials
$w_{r,k}$	Observed Proportion of Panelists Who Are Wrong r Times Out of k Trials
α	Proportion of People Who Can Discriminate at Any Given Time
$\hat{\alpha}$	An Estimate of α

APPENDIX I

Odor Detection Threshold Determinations

Ranking-Plotting and ASTM E679 Methods

A. Ranking-Plotting Method

According to this approach, responses from panelists participating in a ternary forced choice six level dynamic triangle olfactometer [5,6] are recorded on a preprinted form shown in Figure I.1.

The first dilution level at which any panel member makes a correct choice and continues to be correct is taken to be the correct judgment level. In the event that a panelist is correct at all levels, or wrong at all levels, a hypothetical dilution level that is higher by the appropriate geometric ratio than the highest dilution level available or lower by the appropriate geometric ratio than the lowest dilution level, is taken to be the correct judgement level for the panelist.

The evaluation of the frequency of detection by panelists at each dilution level can be discussed in terms of the data in Figure I.1. Since one panelist detected the odor at the second level, the frequency tally for level No. 2 is 1. Three panelists began to detect the odor at level No. 3. Consequently, the frequency tally at level No. 3 is 3, and so forth.

The next step is to convert the frequencies to average ranks. The small column of numbers under the heading "For Rank Count" is provided for this conversion. The level No. 2 is the first occuped in the tally by one panelist only. This corresponds to an average rank of 1. Level No. 3 is occupied by three panelist. These correspond to ranks 2, 3 and 4, or an average rank of

$$(2 + 3 + 4)/3 = 3$$

Sample: 52.06 ppm n-butanol measured as THC butane equivalent

Evaluation Date: July 11, 1980 RESULT: Log ED_{50} = 2.10 ED_{50} = 125.9 (O.U.) = 0.42 ppm

Cons. No.	Panelist	Dilution Level Number 1	2	3	4	5	6	"7"
	Correct Choice Would Be: (t = top, c = center, b = bottom)	C	B	C	C	C	C	
	Panelist Indicated:							
1	DANA	T	C	B	T	C	C	
2	KIM	T	B	B	C	C	C	
3	ROB	T	B	B	C	C	C	
4	MARY	T	T	B	T	C	C	
5	LAG	B	B	T	B	C	C	
6	NAG	T	C	C	C	C	C	
7	MEH	C	T	C	C	C	C	
8	PRA	T	T	C	C	C	C	
9	MOH	B	C	B	C	C	C	
10	PAL	B	B	C	C	C	C	
Frequency Tally			1	3	3	3		
Average Rank			1	3	6	9		

← from connections in olfactometer

For Rank Count:

1	#2
2, 3, 4	#3
5, 6, 7	#4
8, 9, 10	#5

← how many begin to detect

← from frequency count

X = Plotting Value	-1.33	-0.60	+0.11	+0.91			

← from average rank and table

Y = Log(Tolerance Level)		2.92	2.45	1.98	1.50	1.07	

← average of Log(Dil. Fact.)

Log(Dilution Factor)		3.16	2.69	2.20	1.75	1.30	0.35	
Dilution Level No.	<1	1	2	3	4	5	6	"7"

←from flow calibration

Plot Y versus X
Y at X=0 is Log ED_{50}

Panel Leader E. Poostchi

FIGURE I.1: ED_{50} Evaluation Form By Ranking Plotting Method Using a Six Level Dynamic Triangle Olfactometer

Similarly level Numbers 4 and 5 are ranked accordingly.

The average rank numbers are converted to plotting values corresponding to the appropriate panel sizes using Table I.1. For instance, the plotting value is -1.33 for an average rank of 1, when the panel size is 10. These plotting values correspond to x coordinates. The y coordinates are found by taking averages of the logarithms of the dilution factors.

To evaluate ED_{50} (odor detection threshold) as an average response from the panel, the y coordinates are plotted against corresponding x coordinates. The best straight line is drawn through the graphical representation by using the least squares technique. The y value at x=0, corresponds to log ED_{50}, from which the average effective dosage is obtained. To express the ED_{50} in terms of ppm, the original concentration is divided by the number of odor units obtained from the Plot.

B. ASTM E679 Method

This technique was developed as an alternative to the Ranking-Plotting approach, in order to avoid plotting the panel response data [7,8]. Basically, it involves estimation of the individual maximum likelihood threshold for each panelist and calculating from these values a geometric mean threshold for the entire panel.

For example, consider that a panelist makes the set of judgments corresponding to I/C/I/C/C/C, where the first response from the left is for level No. 1 (highest dilution) and the last is for

TABLE I.1: Conversion of Average Rank Numbers to X-Coordinate Plotting Values [5,6]

Average Rank	Number of Panelists				
	6	7	8	9	10
1.0	-1.07	-1.15	-1.22	-1.28	-1.33
1.5	-0.79	-0.89	-0.97	-1.04	-1.10
2.0	-0.57	-0.67	-0.77	-0.84	-0.91
2.5	-0.37	-0.49	-0.59	-0.67	-0.75
3.0	-0.18	-0.32	-0.43	-0.52	-0.60
3.5	0	-0.16	-0.28	-0.39	-0.47
4.0	+0.18	0	-0.14	-0.25	-0.35
4.5	+0.37	+0.16	0	-0.13	-0.23
5.0	+0.57	+0.32	+0.14	0	-0.11
5.5	+0.79	+0.49	+0.28	+0.13	0
6.0	+1.07	+0.67	+0.43	+0.25	+0.11
6.5		+0.89	+0.59	+0.39	+0.23
7.0		+1.15	+0.77	+0.52	+0.35
7.5			+0.97	+0.67	+0.47
8.0			+1.22	+0.84	+0.60
8.5				+1.04	+0.75
9.0				+1.28	+0.91
9.5					+1.10
10.0					+1.33

level No. 6 (lowest dilution). Capital C represents a correct choice of port at any dilution level whereas a capital I, an incorrect choice. Since this panelist made three correct judgements consistently from the fourth level onwards, the usual statistical assumptions [7,8] imply that this particular individual would be capable of making a correct judgement somewhere between the third and fourth levels, if the instrument provided finer subdivision of dilution levels. Consequently, the most likely dilution threshold for this panelist would be the geometric mean of the dilution factors for levels 3 and 4.

If a panelist misses at the lowest dilution factor available (D), it is assumed that a correct choice would be made at a higher concentration (that is at a lower dilution level). Consequently, a hypothetical dilution factor (of D/3) is postulated as the best estimate. Similarly if a panelist has made correct choices throughout all dilution levels, a hypothetical dilution factor, which is three times the highest dilution provided by the instrument is taken as the best estimate. The individual dilution threshold for each panelist is obtained by taking the geometric mean of the level beyond which the subject has consistently made correct choices and the previous level. The logarithm of the individual dilution threshold of each panelist is also determined. The ED_{50} value of the panel is calculated by adding the logarithms of the individual thresholds, dividing by the number of panelists and taking the antilogarithm of the result.

APPENDIX II

Odor Discrimination Threshold Determination

Maximum Likelihood Estimator Model

The Ranking-Plotting and ASTM E679 methods for the determination of odor detection thresholds depend on forced choice decisions by panelists who often resort to guess work for their responses. Neither approach accounts for the uncertainties experienced by panelists while making their choices. To minimize the effect of guessing during the determination of an effective dosage for an average panel member, the concept of discrimination threshold was introduced. The discrimination threshold is defined as the level at which 50% of a panel can distinguish between the odor and non-odorous air with certainty. To determine an estimate of the discrimination threshold based on all panelist responses and to account for successful guesses, the development of a probability model [9,10,11] was initiated. The pertinent expressions are derived as follows:

For every dilution level, the panel members can be considered to fall into two distinct populations. Those who are sure about the presence of the odor at any dilution level can easily identify which port is delivering a stimulus. On the other hand, panelists who are not positive about the presence of the odor, have to make a guess.

If α represents the proportion of people who are sure about their choices at any dilution level and any number of trials (true discriminators), then $(1-\alpha)$ is the proportion of pure guessors. In general, for a forced ternary choice technique, the proportion of panelists who are correct k times out of k trials (no wrong in k trials) will be:

$$W_{o,k} = \alpha + (1/3)^k(1-\alpha) \qquad (1)$$

Similarly, the proportion of panelists who are wrong in all of k trials can be expressed by:

$$W_{k,k} = (2/3)^k(1-\alpha) \qquad (2)$$

More generally, the proportion of panelists who are wrong r times out of k trials for a ternary forced choice situation will be:

$$W_{r,k} = \binom{k}{r} (2/3)^r (1/3)^{k-r} (1-\alpha) \qquad (3)$$

where r = 1,2,3, ... k

and $$\binom{k}{r} = k!/(k-r)!\, r! \qquad (4)$$

The method of maximum likelihood estimate provides a value $\hat{\alpha}$, an estimate of α. It involves multiplication of the logarithm of the number expected in each class $W_{o,k}$ and $W_{r,k}$ (Equations [1] and [3] by the number observed ($w_{o,k}$ and $w_{r,k}$), summation for all classes and determination of the expression for the unknown parameter ($\hat{\alpha}$) for which the sum is a maximum. Accordingly, the logarithm of the likelihood function is:

$$L = w_{0,k}\log[\alpha + (\tfrac{1}{3})^k(1-\alpha)] + \sum_{r=1}^{k} w_{r,k}\log[\binom{k}{r}(\tfrac{2}{3})^r(\tfrac{1}{3})^{k-r}(1-\alpha)] \qquad (5)$$

Differentiation of L with respect to α and setting the derivative equal to zero gives:

$$\hat{\alpha} = \frac{(3^k-1)w_{o,k} - \sum_{i=1}^{k} w_{i,k}}{(3^k-1)\sum_{i=0}^{k} w_{i,k}} \qquad (6)$$

For one trial, Equation (6) reduces to:

$$\hat{\alpha} = \frac{2\,w_{0,1} - w_{1,1}}{2(w_{1,1} + w_{0,1})} \qquad (7)$$

Similarly, for two and three trials,

$$\hat{a} = \frac{8\, w_{0,2} - w_{1,2} - w_{2,2}}{8(w_{0,2} + w_{1,2} + w_{2,2})} \tag{8}$$

and

$$\hat{a} = \frac{26\, w_{0,3} - (w_{1,3} + w_{2,3} + w_{3,3})}{26(w_{0,3} + w_{1,3} + w_{2,3} + w_{3,3})} \tag{9}$$

respectively.

A plot of log concentration of odorant versus $\hat{a}$ determined for each dilution level provides the discrimination threshold of the panel in terms of the odorant concentration corresponding to $\hat{a} = 0.5$.

APPENDIX III

A Sample of

Odor Survey Questionnaire

University of Windsor

DEPARTMENT OF CHEMICAL ENGINEERING

Environmental Study

1. Age ____________

2. Sex (circle one)   M   F

3. Address ________________________________
____

4. Occupation ____________________

5. Health (check one)
   - Excellent ☐
   - Good ☐
   - Average ☐
   - Fair ☐
   - Poor ☐

If problems, please list: ________________________________
____

The following statements relate to various odours normally present in the air. Please read carefully and then rate each one individually based on your personal reactions. To complete the question circle the arrow (↑) which most closely matches how you feel about it.

Example: I like baseball.

↑ ↑ ↑ (↑) ↑

Not at all   O.K.   Very much

6. I like the smell of cut grass.

↑ ↑ ↑ ↑ ↑

Not at all   O.K.   Very much

7. I like the smell of car and truck fumes.

↑ ↑ ↑ ↑ ↑

Not at all   O.K.   Very much

8. I like the smell of fried chicken outlets.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

9. I like the smell from the sewers.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

10. I like the smell of vinegar.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

11. I like the smell of garbage.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

12. I like the smell of a hospital.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

13. I like the smell at a Fruit Market.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

14. I like the smell of gasoline.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

15. I like the smell of hamburger restaurants in the neighbourhood.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

16. I like the smell of fresh popcorn.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

17. I like the smell of ammonia.

↑ ↑ ↑ ↑ ↑
Not at all O.K. Very much

18. I like the smell of paint.

Not at all — O.K. — Very much

19. I like the smell of roses.

Not at all — O.K. — Very much

20. I like the smell of beer.

Not at all — O.K. — Very much

21. I like the smell outside a Chinese restaurant.

Not at all — O.K. — Very much

22. I like the smell of a locker/dressing room.

Not at all — O.K. — Very much

23. I like the smell of baking bread.

Not at all — O.K. — Very much

24. I like the smell of a wood fire.

Not at all — O.K. — Very much

25. I like the smell of chocolate.

Not at all — O.K. — Very much

26. I like the smell of cigarettes.

Not at all — O.K. — Very much

27. I like the smell of a carnival.

Not at all — O.K. — Very much

28. I like the smell of peanuts.

Not at all — O.K. — Very much

29. I like the smell of a barbeque.

Not at all — O.K. — Very much

30. I like the smell of a leather jacket.

Not at all — O.K. — Very much

31. I like the smell of coffee.

Not at all — O.K. — Very much

32. What smells in the air seriously bother you ? Please list:

____

____

____

____

33. This last question requires that you rank (in order of preference) 5 odors. Write the number which indicates your preference, below each odour.

1 = I like it best.

5 = I like it the least.

Example:	football	baseball	hockey	soccer	basketball
	(3)	(2)	(1)	(4)	(5)

Please rank:

Hay Swimming Pool Barbeque Hamburger Joint Garbage

Many thanks for your cooperation.

APPENDIX IV

Odor Impact Model

The Odor Impact Model is [11] basically an extension of the currently used principle of ternary forced choice detection threshold determination with a five or six level dynamic olfactometer. In addition to identifying the ports which are perceived to be emitting odorous material, panelists are also required to specify the levels at which they are sure, beyond a doubt, about the presence of the odor. Furthermore, panel members are provided with a preprinted form on which they are asked to indicate at which dilutions (concentrations) they would complain if they were exposed to similar odorous stimuli for an average period of eight hours and to rate the degree of complaint at each level on a scale ranging from 0 to 10, using zero as no annoyance and 10 as the maximum measure of annoyance.

The first dilution levels beyond which individual panelists make continuous correct choices are taken as the basis for the evaluation of the detection threshold profile, relating percent probabilities of detection (PPD) to different odor levels as illustrated by curve I of Figure IV.1.

The odor discrimination thresholds profile is based on the first dilution levels (concentrations) from which the panel members continue to be certain about the presence of the odor. Curve II of Figure IV.1 illustrates the location of a typical discrimination threshold profile with respect to the detection threshold profile.

Similarly, the dilution levels (concentrations) at which panelists express a tendency to complain and their magnitudes of annoyance provide data for the generation of percent probability of complaint (PPC) and predicted degree of annoyance (PDA) profiles as shown by curves III and IV in Figure IV.1.

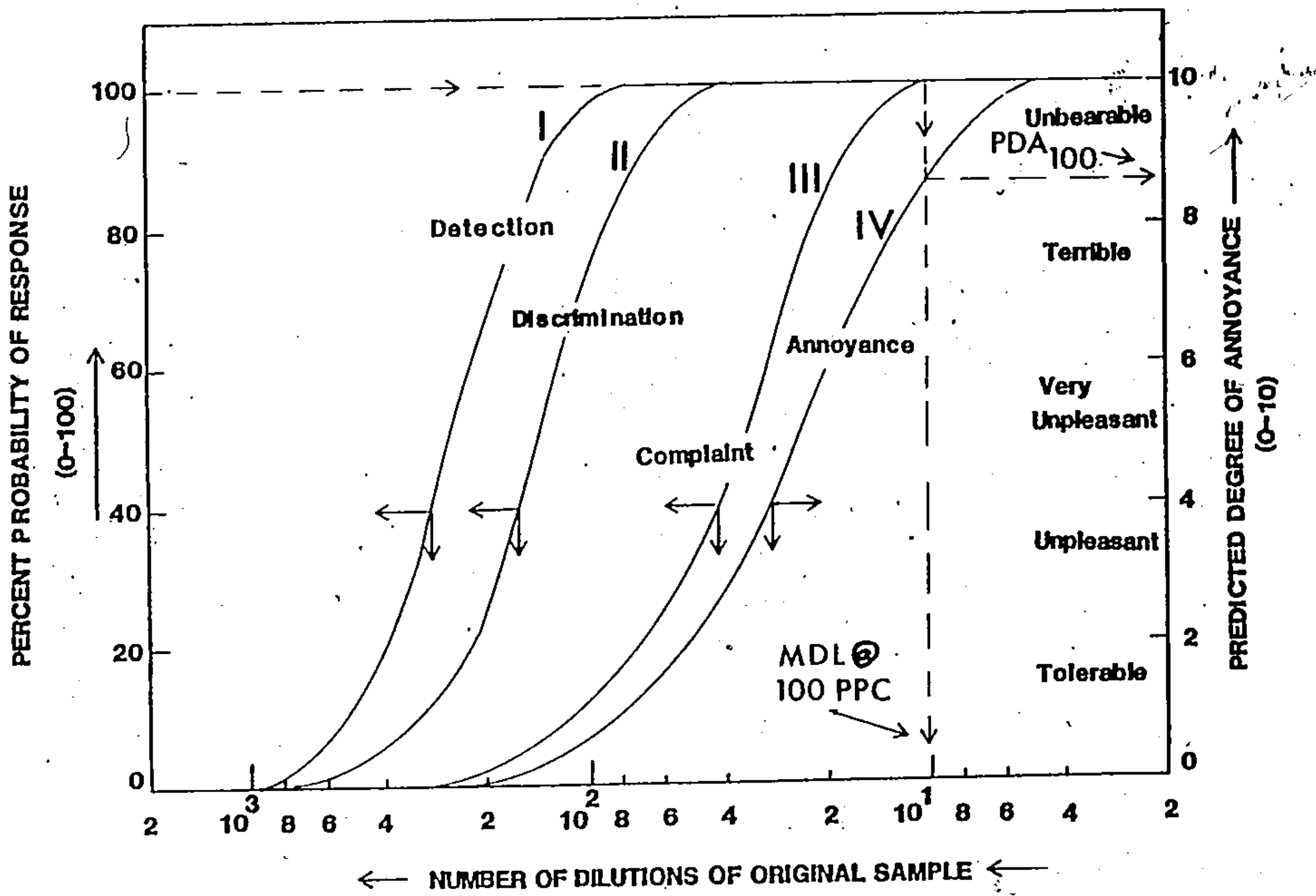

FIGURE IV.1: Idealized Odor Impact Model Profiles

For illustration purposes, consider a panel of 10 members evaluating an odor stimulus through a six level dynamic olfactometer using a ternary forced choice technique in an ascending series of concentration.

Now, for the sake of argument, suppose that at the first level, no panel member begins to consistently detect the presence of the odor under investigation. This means that the percent probability of detection of the panel at this level is zero. At level No. 2, let us assume that two of the panelists begin to consistently detect the presence of the odorous stimulus. Accordingly, the percent probability of detection of the panel at this level would be (2/10) x 100 = 20. At level No. 3, let us say that three more panelists begin to detect. At this level the percent probability of detection of the panel on a cumulative basis would be ((0 + 2 + 3)/10) x 100 = 50. This process is repeated until all dilution levels have been examined.

A plot of the percent probabilities of detection versus the corresponding dilution levels on semi-log coordinates, provides the detection profile of the panel.

The percent probabilities of discrimination and complaint profiles of the panel are determined in a similar manner and results are plotted on the original coordinate system.

The magnitudes of annoyance evaluated in terms of individual panel member ratings at each odor level are averaged over the number of complainers for each odor concentration. The mean values define the predicted degree of annoyance (PDA) profile of the panel which is plotted on the same coordinate system.

APPENDIX V

Ranking Plotting Diagrams for Typical Emissions From the Paint Manufacturing Plant

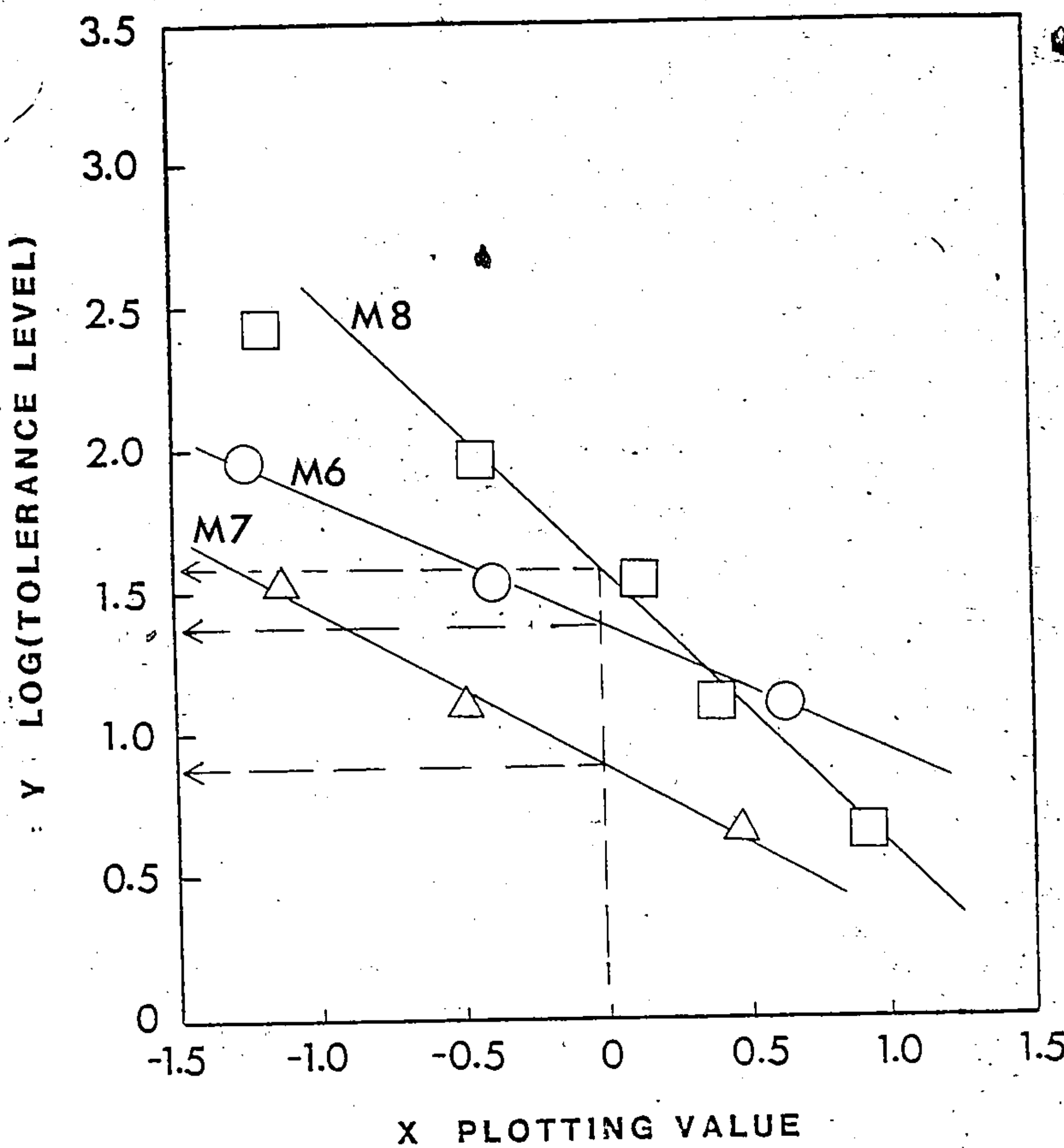

FIGURE V.1: Ranking Plotting Diagram for Odorous Emissions from M6, M7 and M8 Stacks Sampled on December 8, 1982

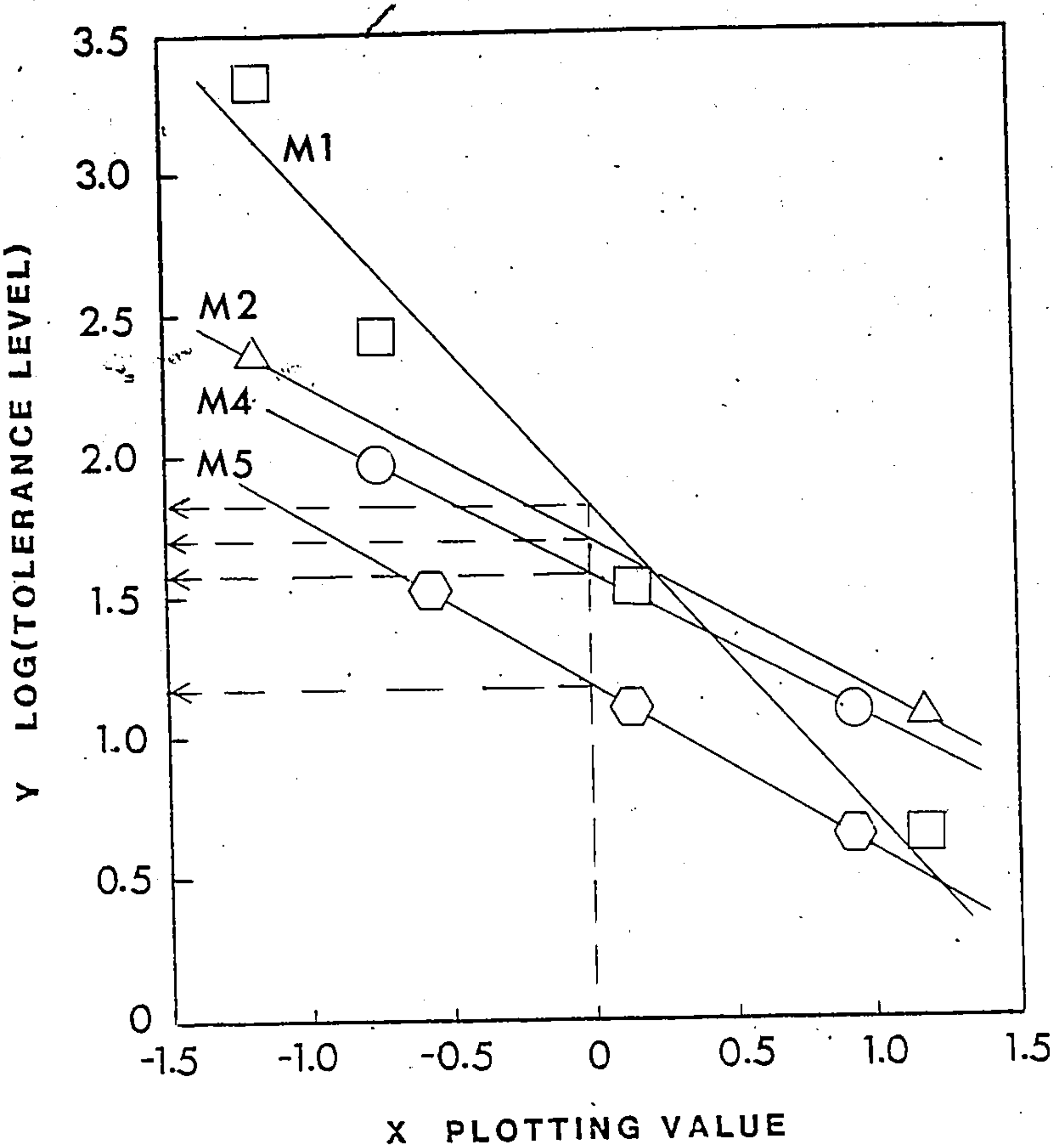

FIGURE V.2: Ranking Plotting Diagram for Odorous Emissions from M1, M2, M4 and M5 Stacks Sampled on December 8, 1982

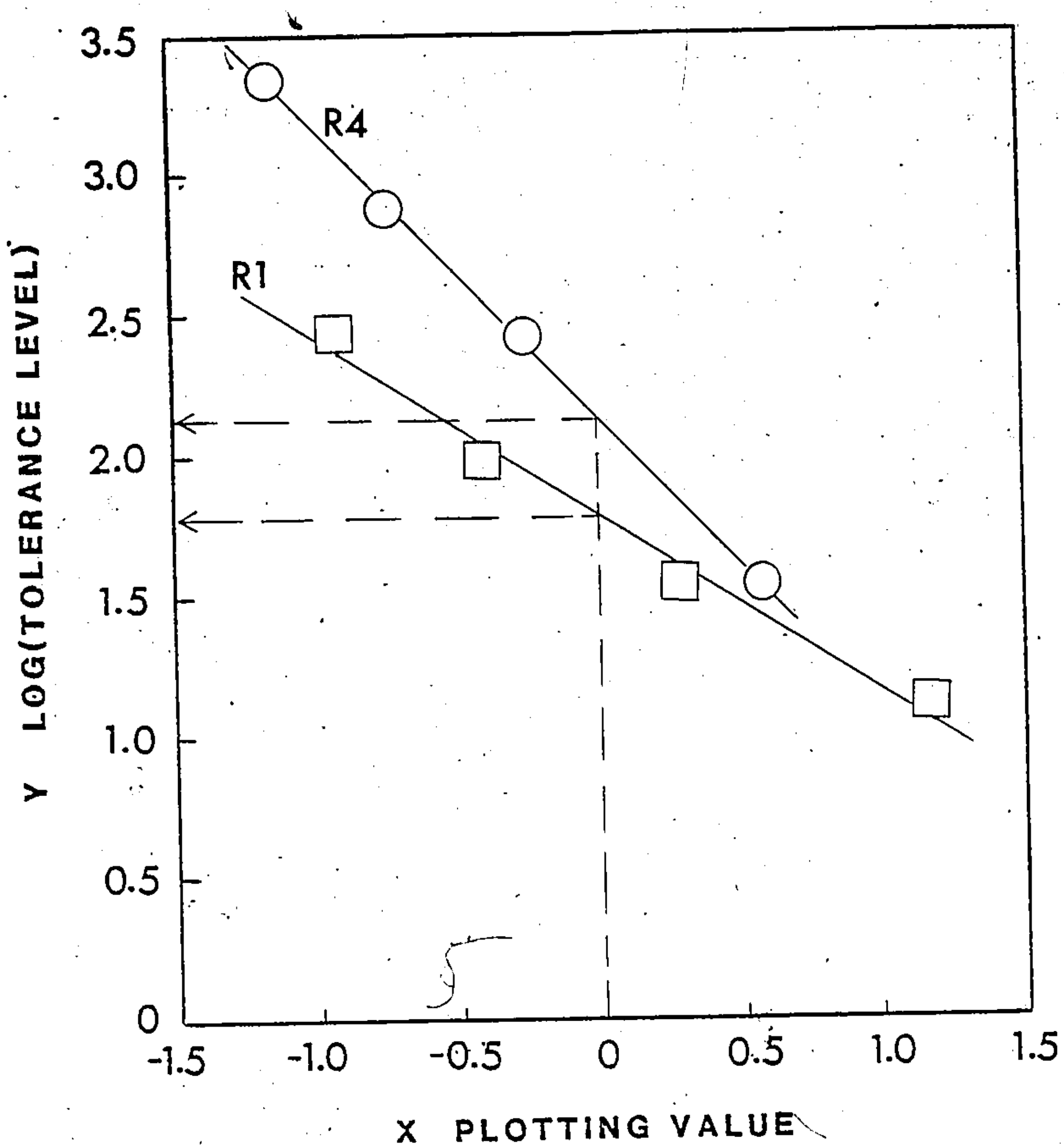

FIGURE V.3: Ranking Plotting Diagram for Odorous Emissions from R1 and R4 Stacks Sampled on December 9, 1982

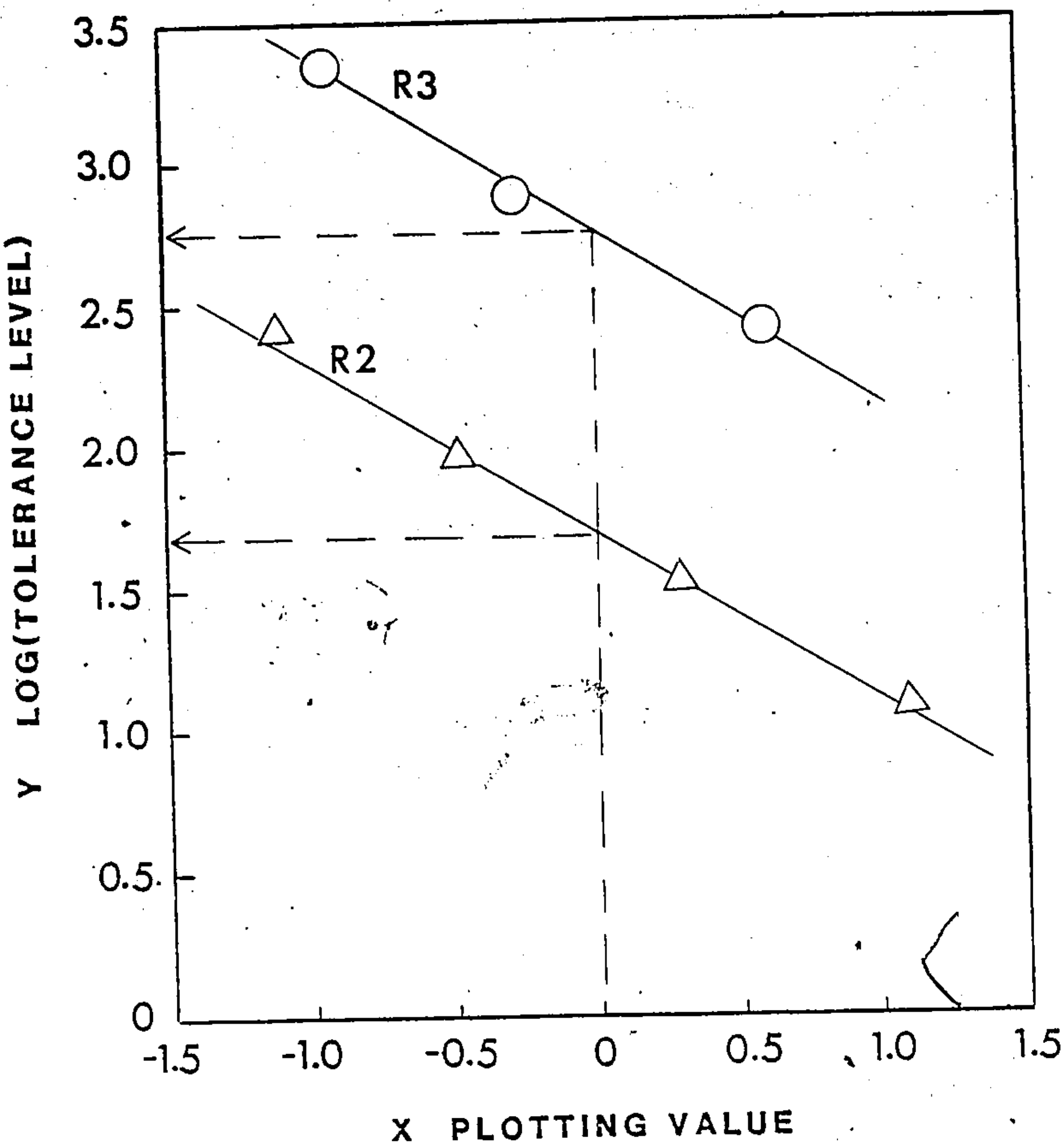

FIGURE V.4: Ranking Plotting Diagram for Odorous Emissions from R2 and R3 Stacks Sampled on December 9, 1982

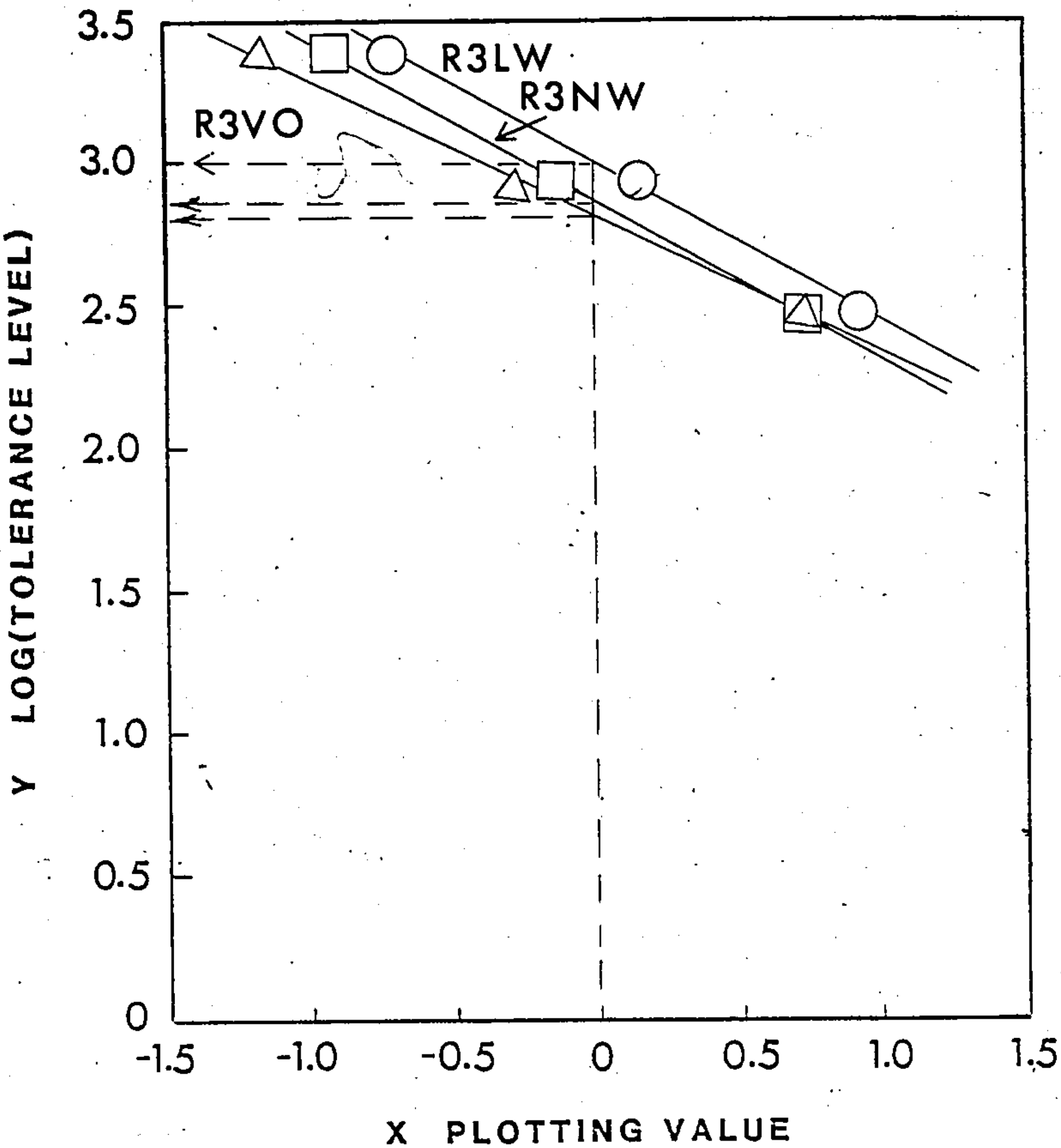

FIGURE V.5: Ranking Plotting Diagram for Odorous Emissions from R3 Stack During Low Water (LW), No Water (NW) and Venturi Only (VO) Conditions Sampled on December 9, 1982

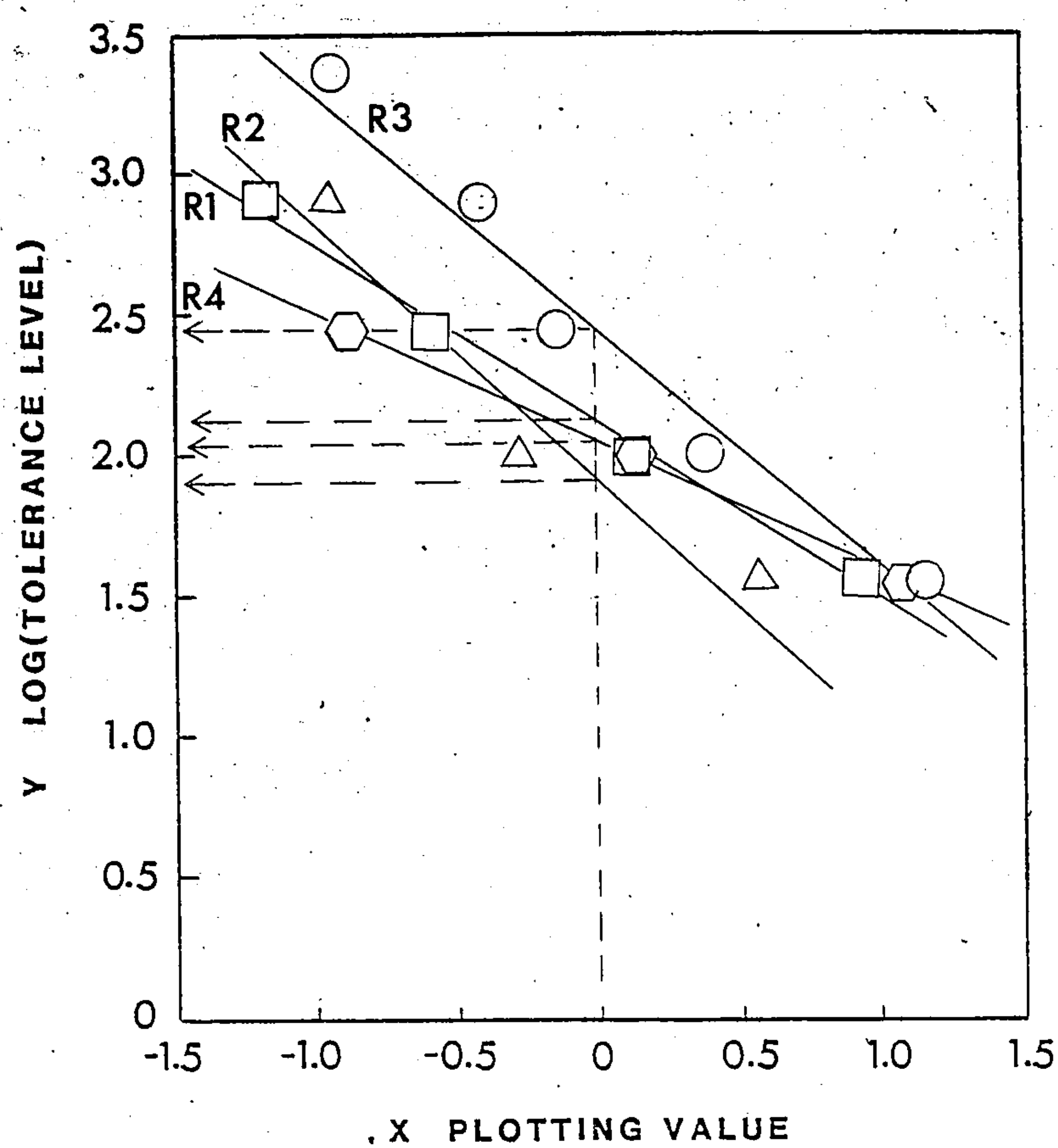

FIGURE V.6: Ranking Plotting Diagram for Odorous Emissions from R1, R2, R3 and R4 Stacks Sampled on December 10, 1982

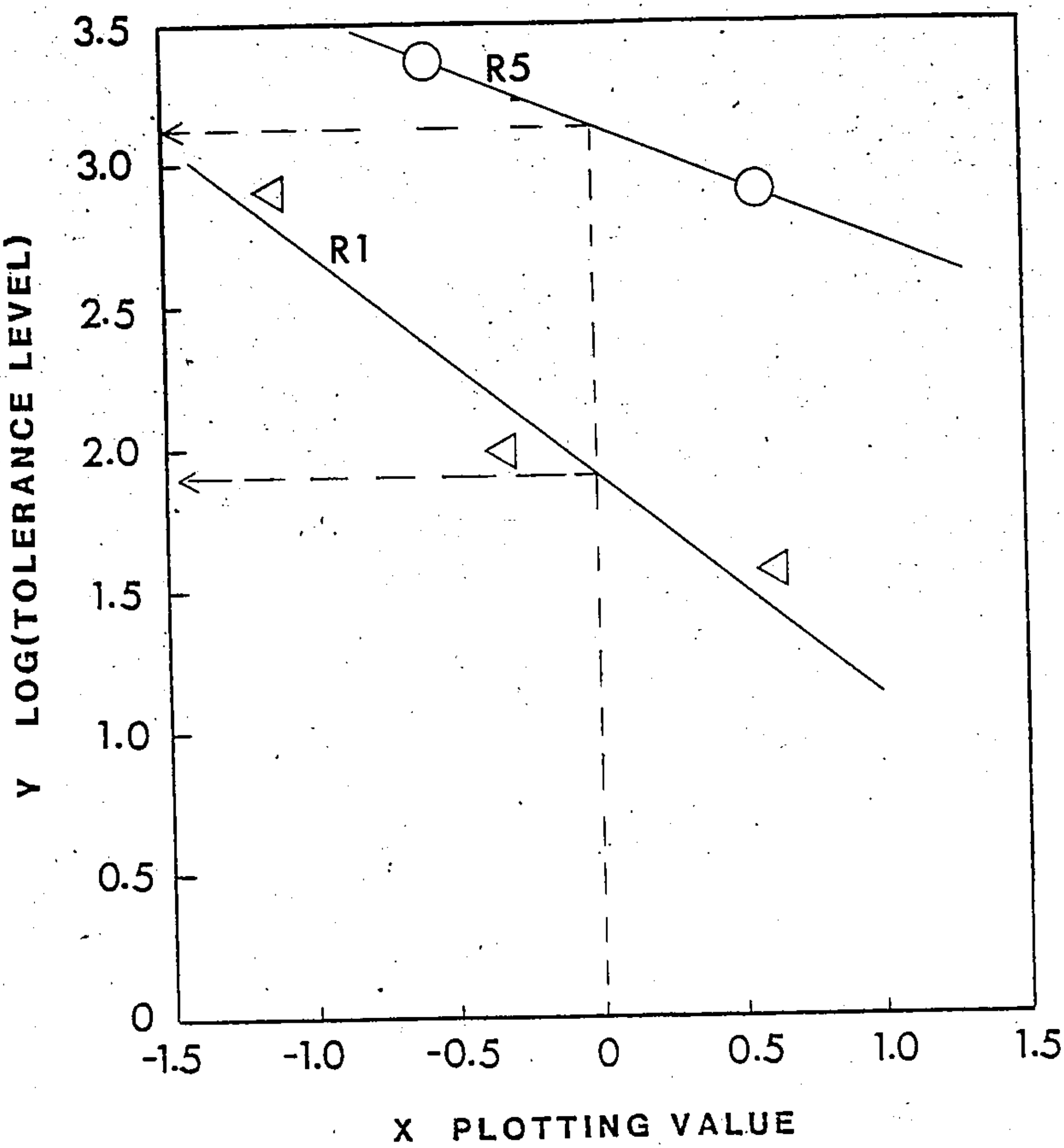

FIGURE V.7: Ranking Plotting Diagram for Odorous Emissions from R1 and R5 Stacks Sampled on December 13, 1982

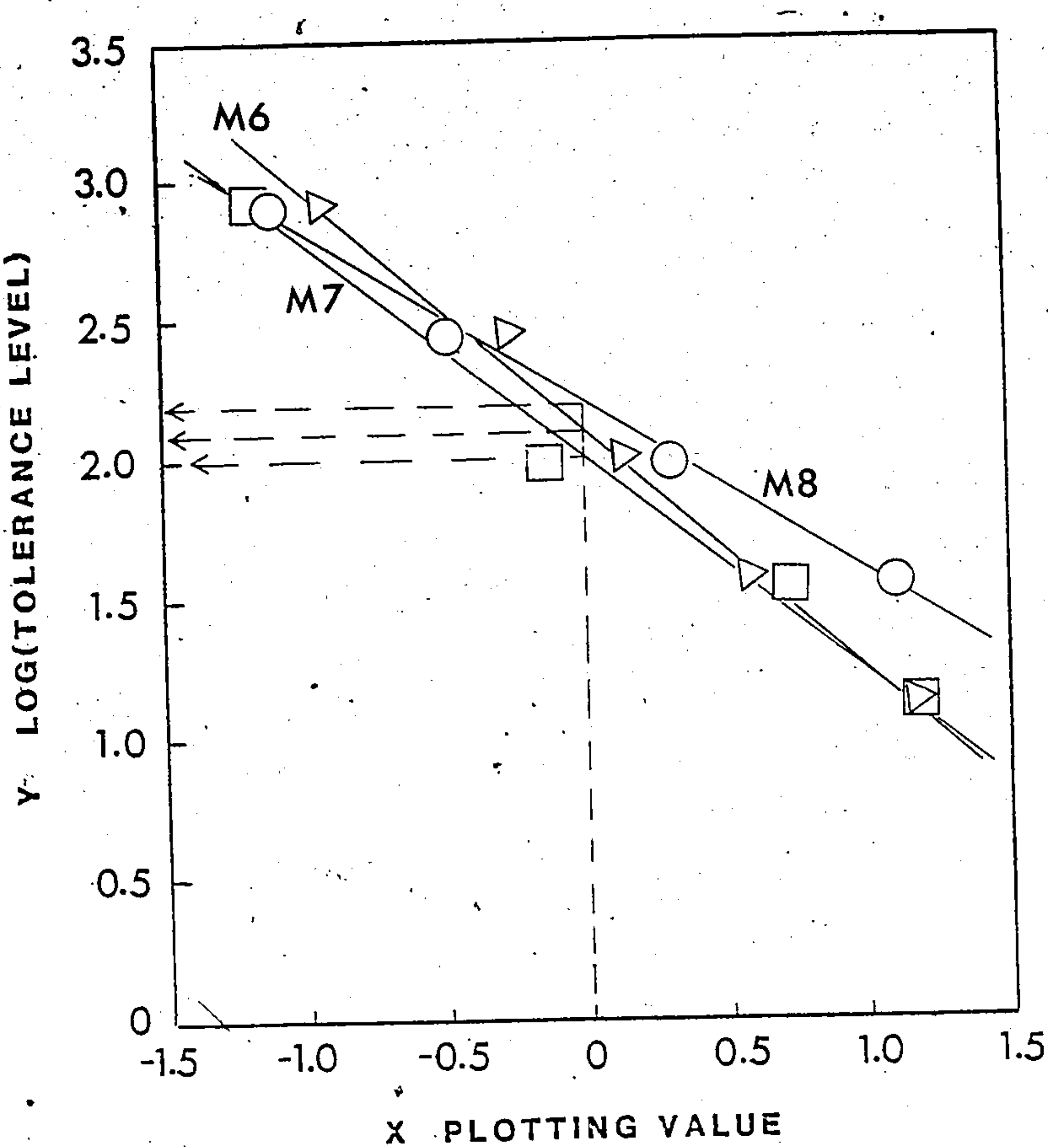

FIGURE V.8: Ranking Plotting Diagram for Odorous Emissions from M6, M7 and M8 Stacks Sampled on December 13, 1982

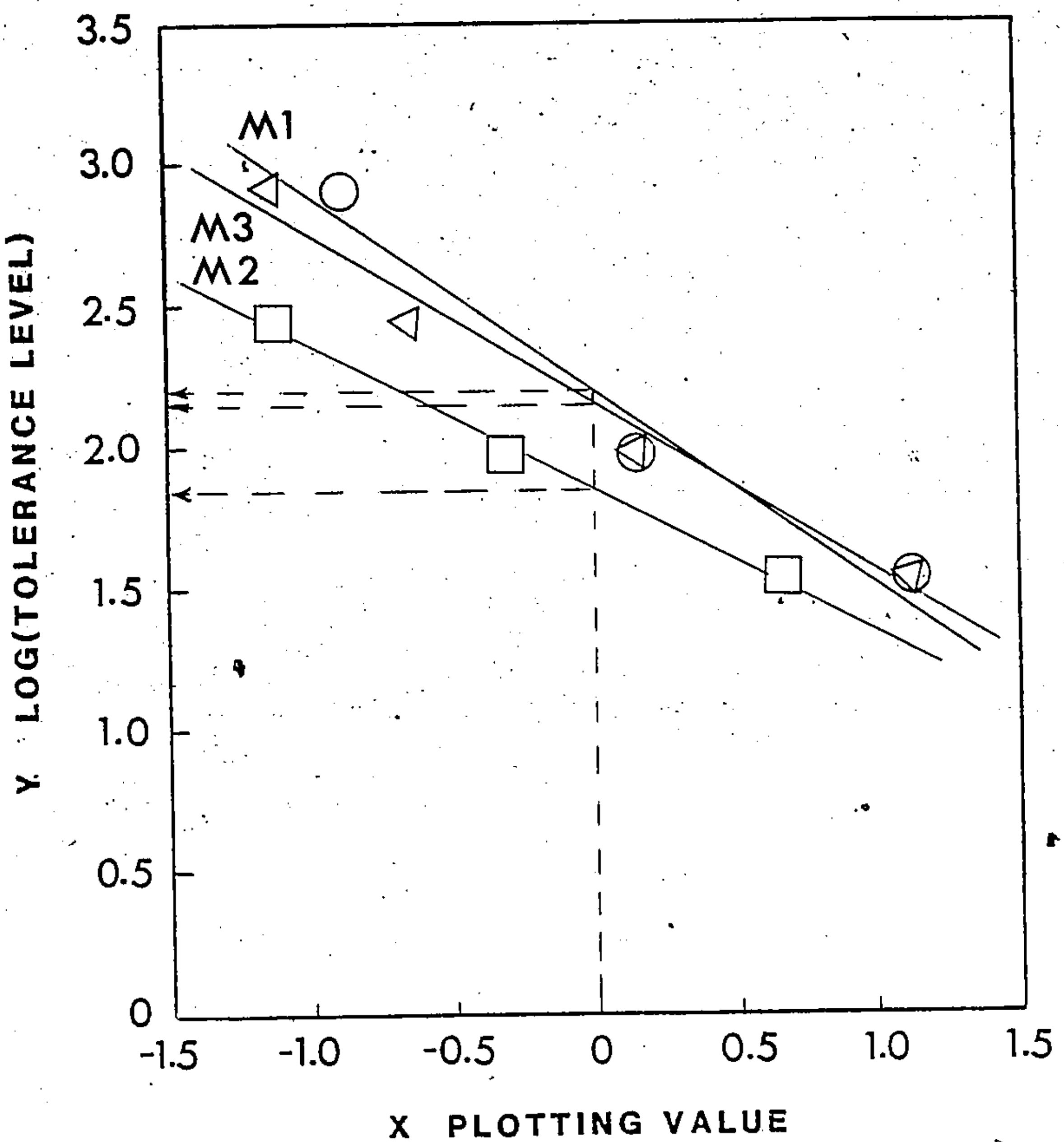

FIGURE V.9: Ranking Plotting Diagram for Odorous Emissions from M1, M2 and M3 Stacks Sampled on December 14, 1982

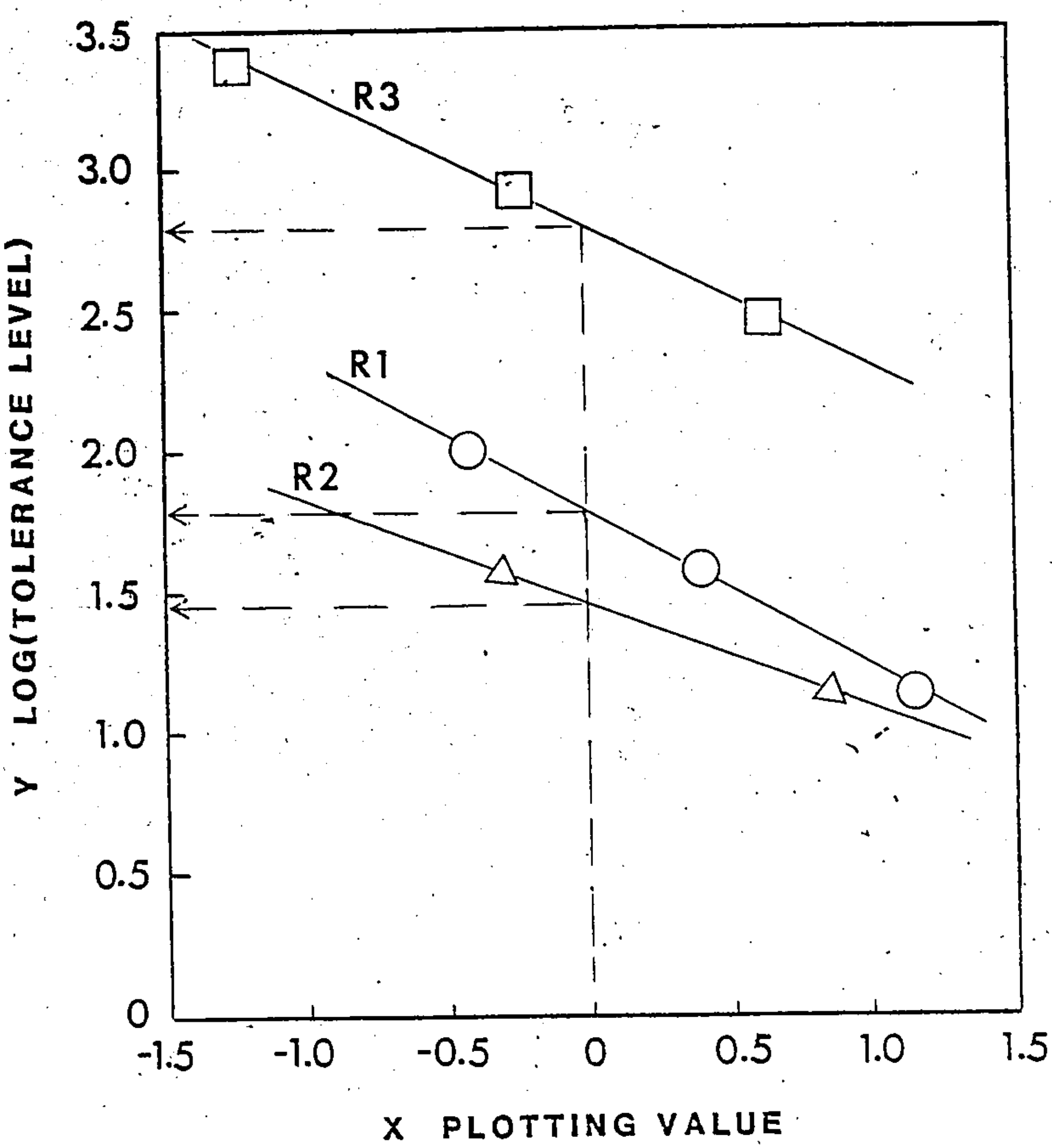

FIGURE V.10: Ranking Plotting Diagram for Odorous Emissions from R1, R2 and R3 Stacks Sampled on December 14, 1982

APPENDIX VI

Odor Impact Model Profiles

For Typical Emissions From

the Foundry

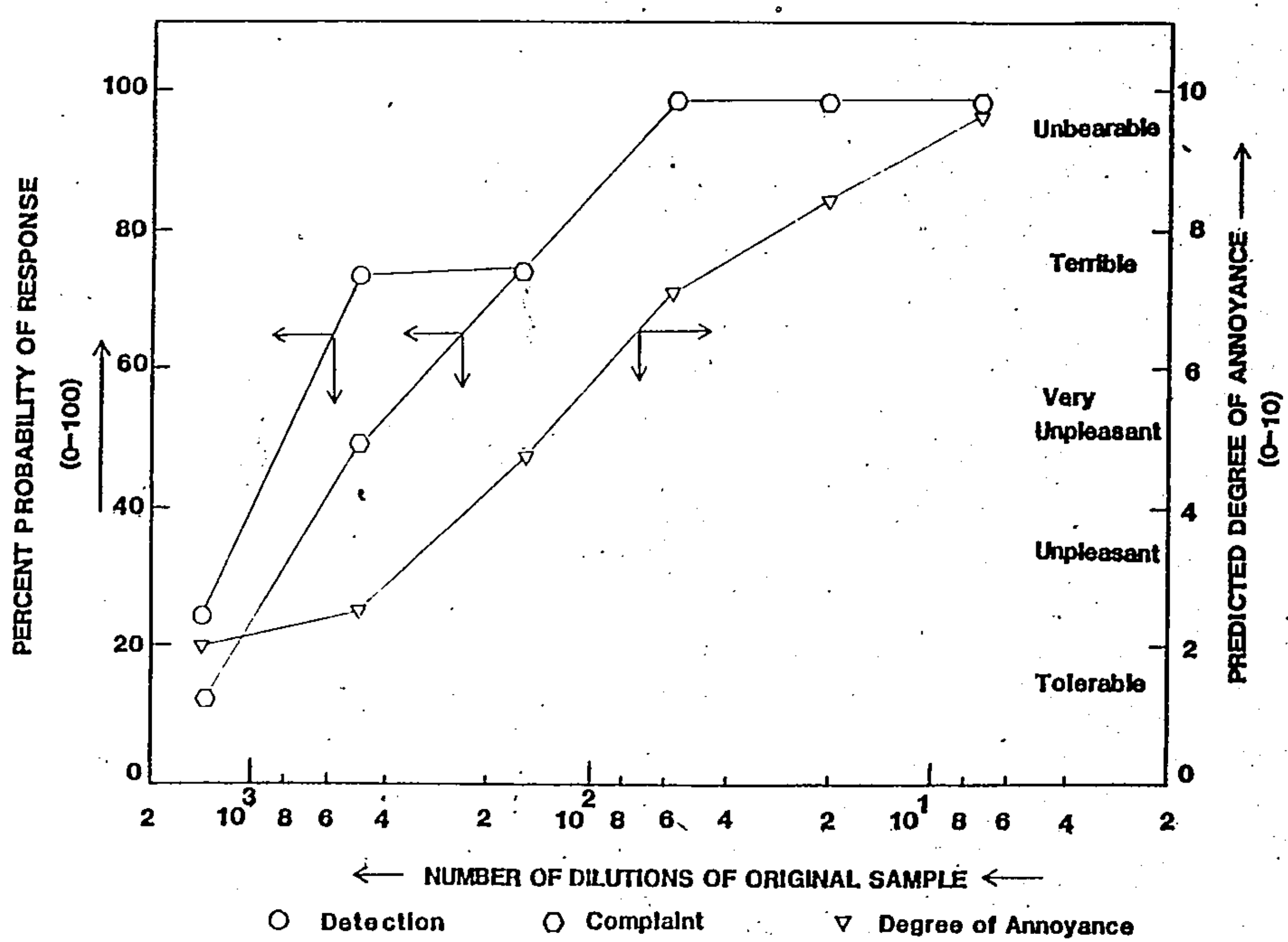

FIGURE VI.1: Odor Impact Model Profiles for Typical Odorous Emissions from Sluice #1 Stack Sampled on August 31, 1984

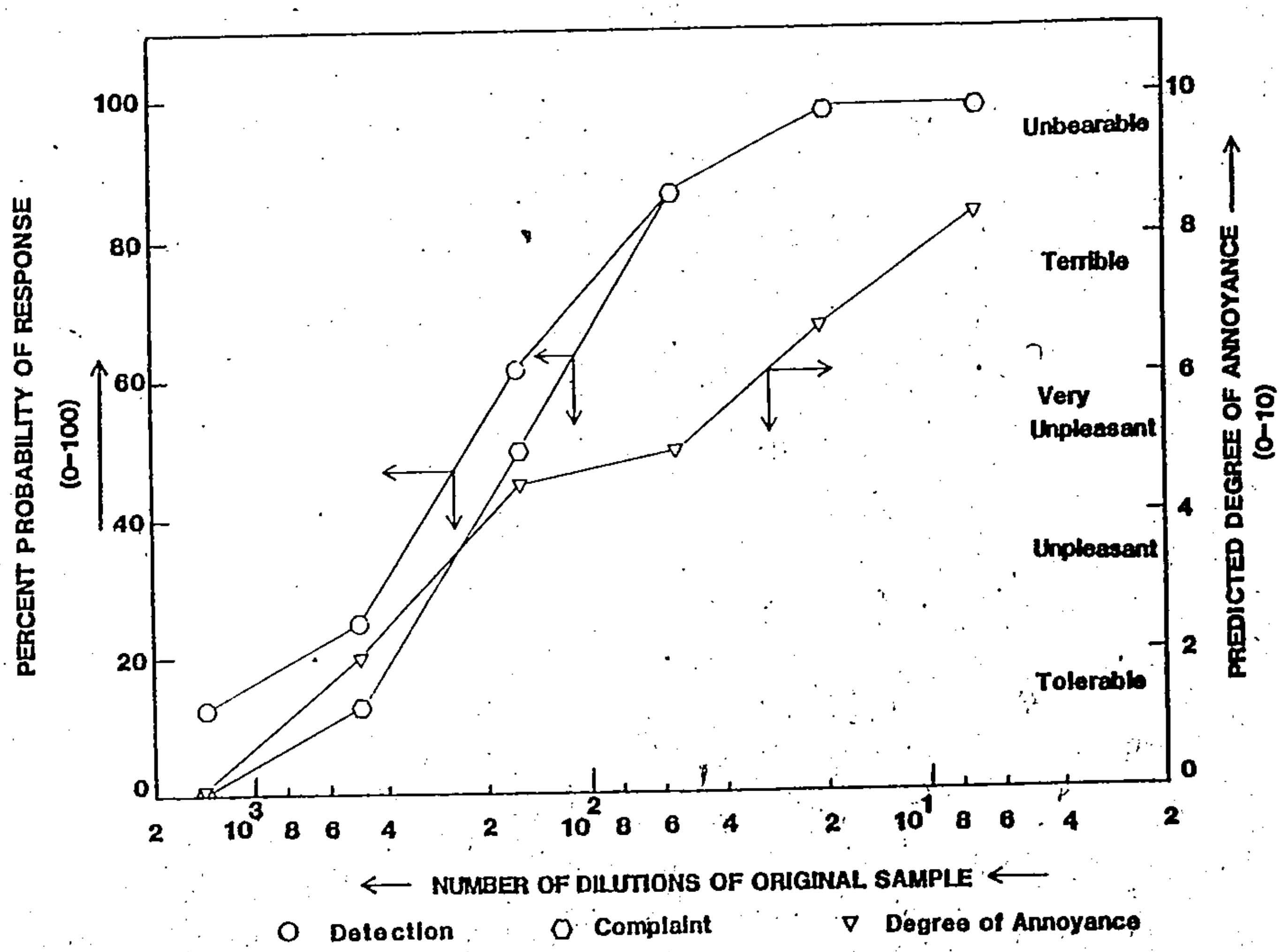

FIGURE VI.2: Odor Impact Model Profiles for Typical Odorous Emissions from Amine Stack Sampled on August 31, 1984

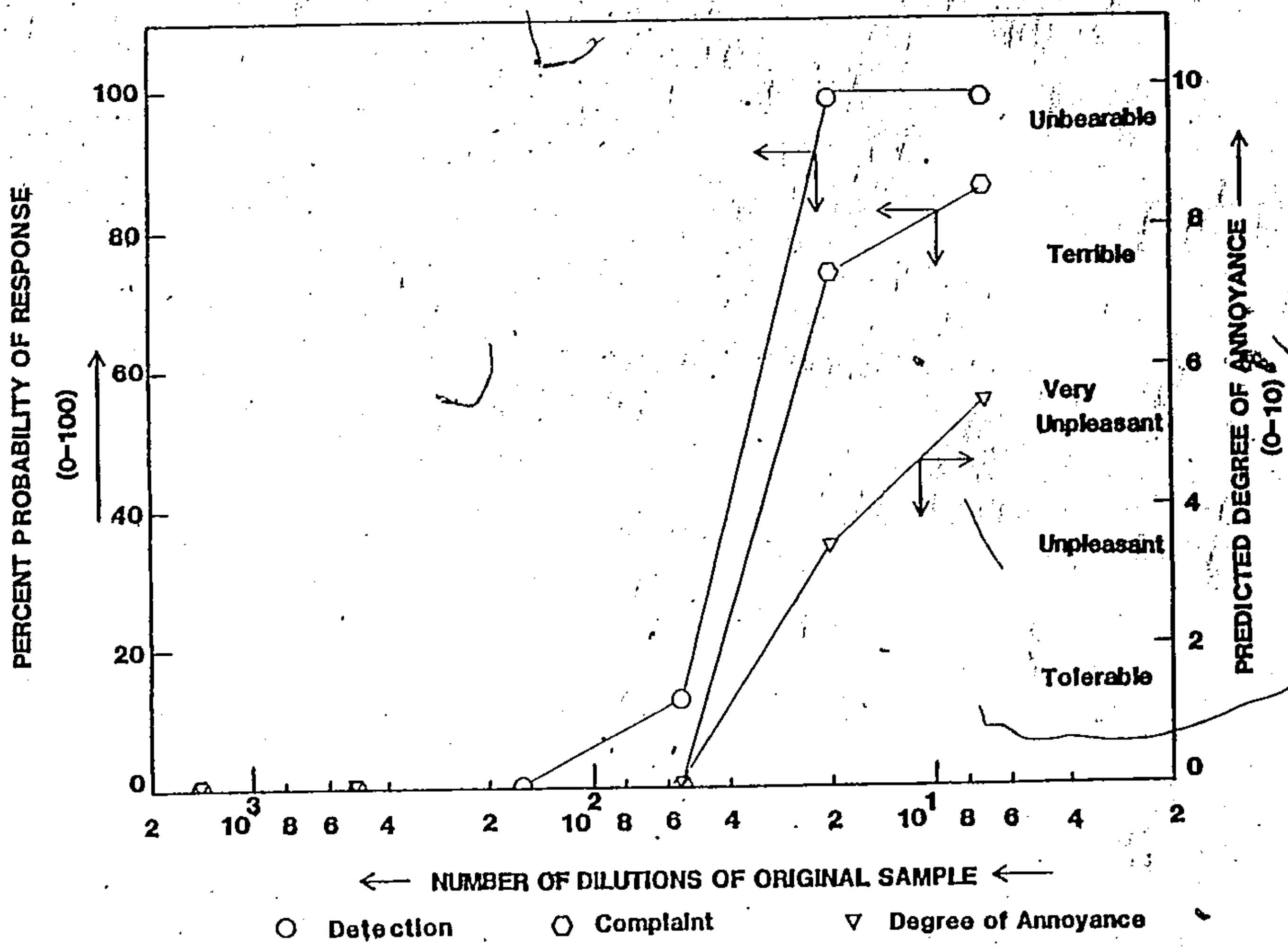

FIGURE VI.3: Odor Impact Model Profiles for Typical Odorous Emissions from C9 Stack Sampled on August 29, 1984

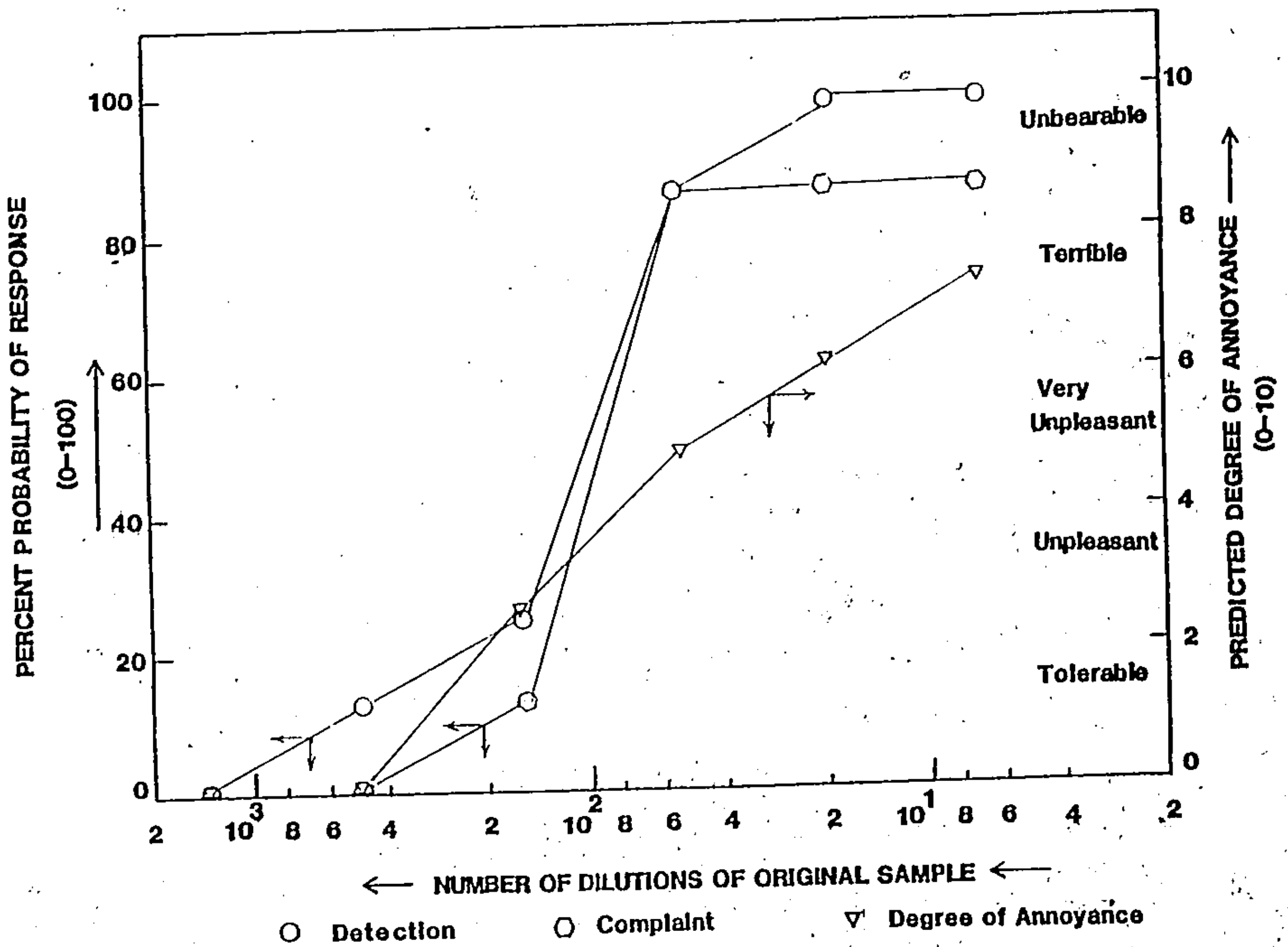

FIGURE VI.4: Odor Impact Model Profiles for Typical Odorous Emissions from Cupola #1 (outlet) Stack Sampled on September 4, 1984

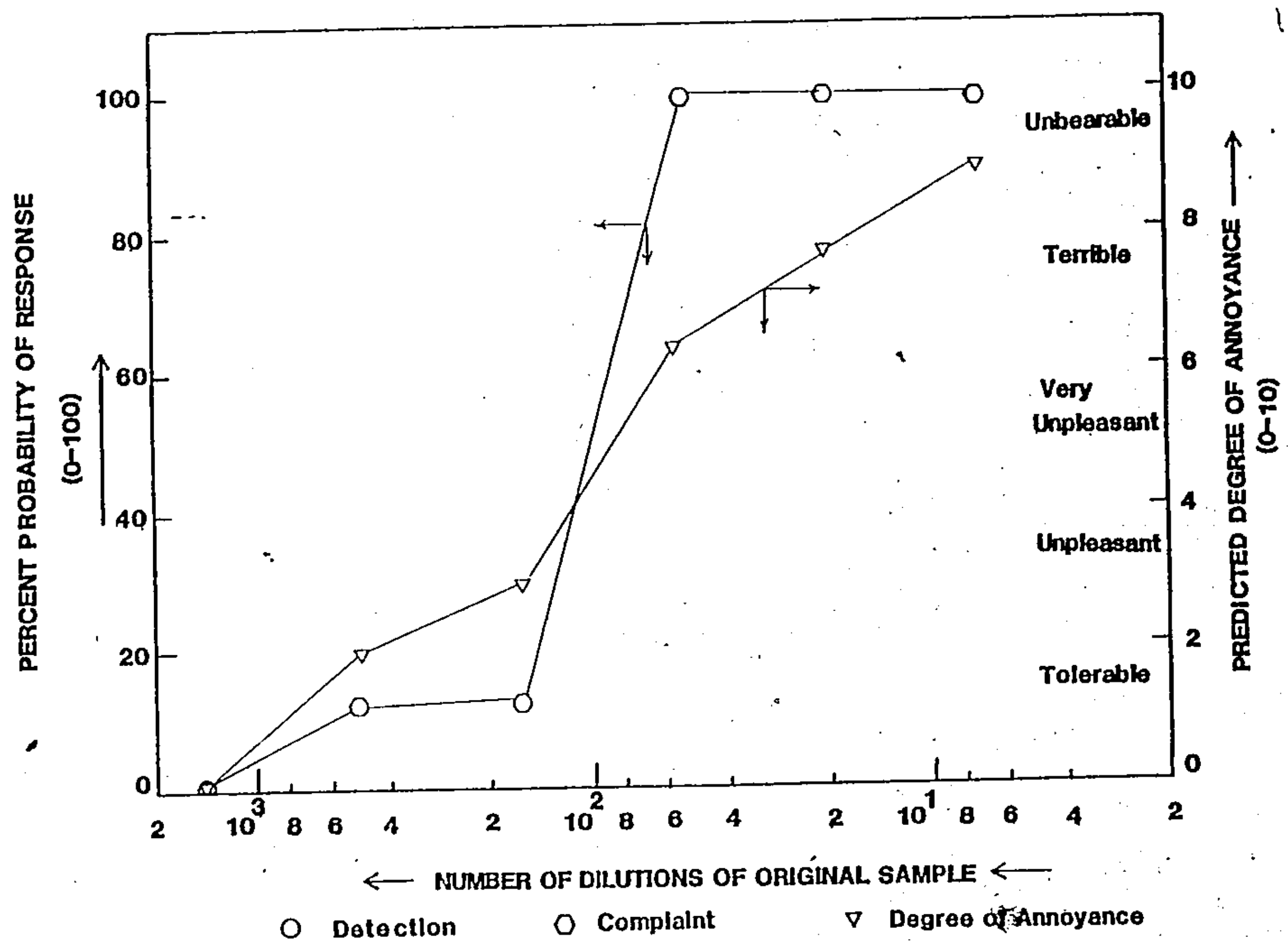

FIGURE VI.5: Odor Impact Model Profiles for Typical Odorous Emissions from Cupola #1 (inlet) Stack Sampled on September 4, 1984

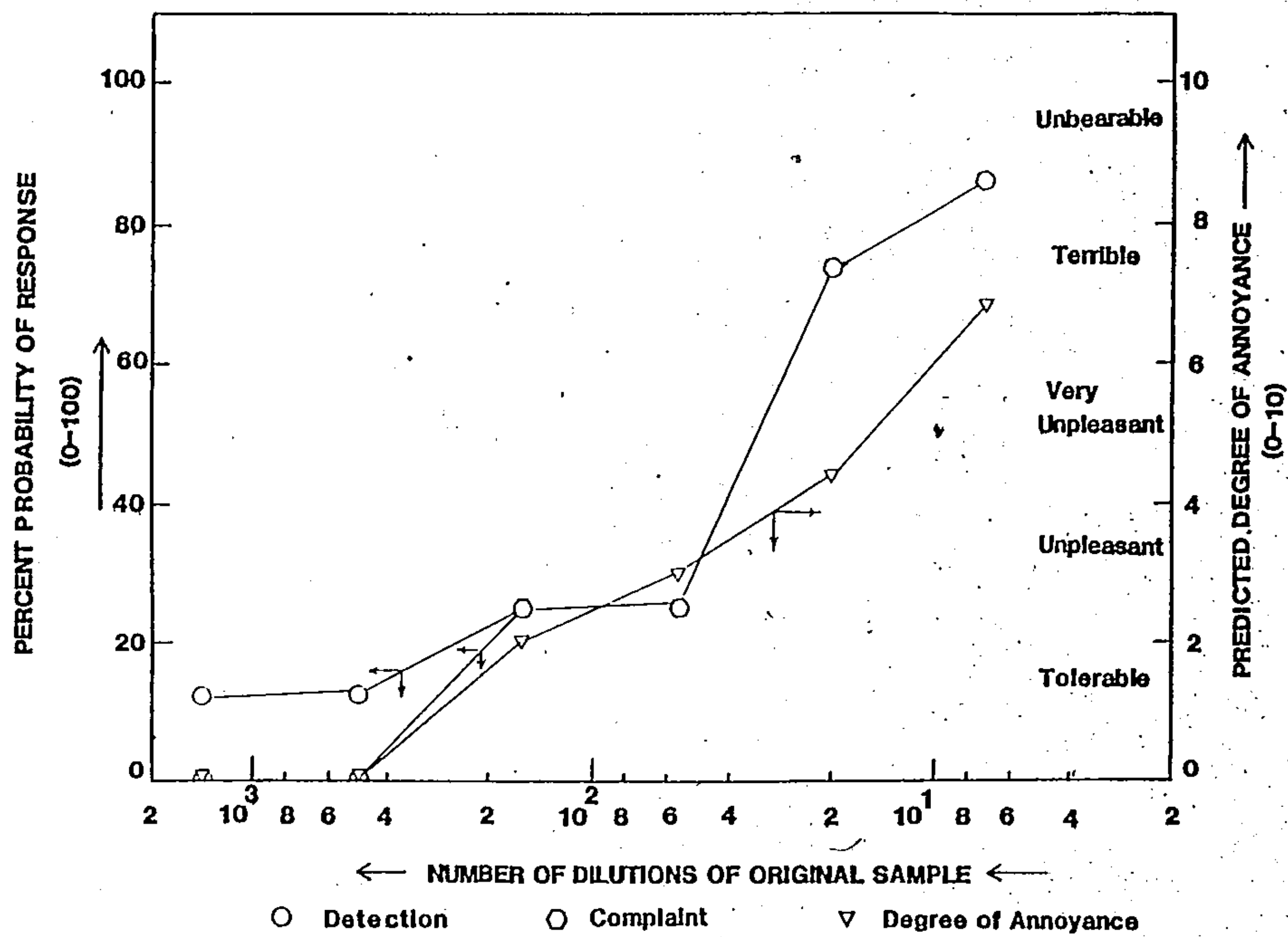

FIGURE VI.6: Odor Impact Model Profiles for Typical Odorous Emissions from B Stack Sampled on August 22, 1984

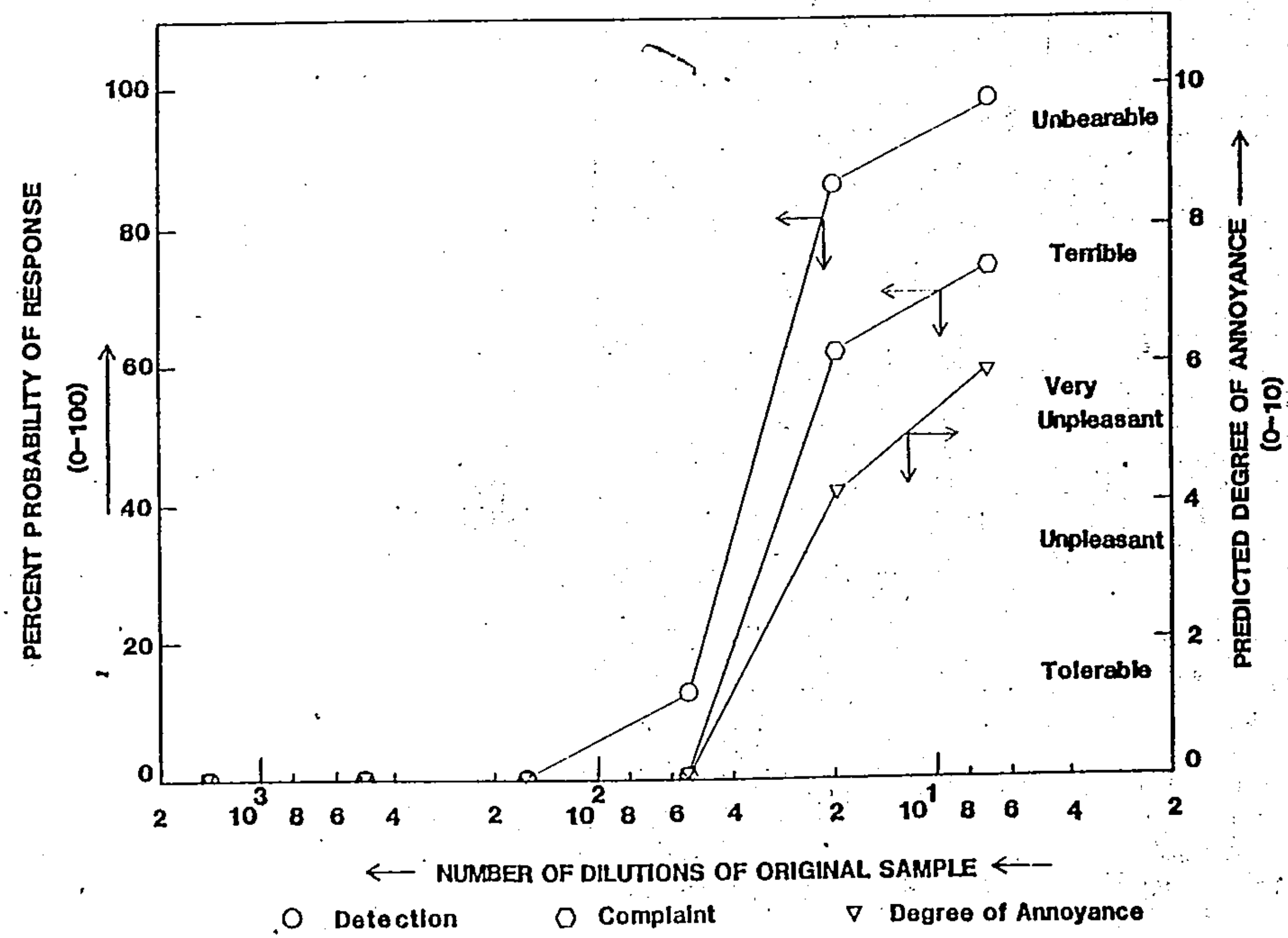

FIGURE VI.7: Odor Impact Model Profiles for Typical Odorous Emissions from B11 Stack Sampled on August 23, 1984

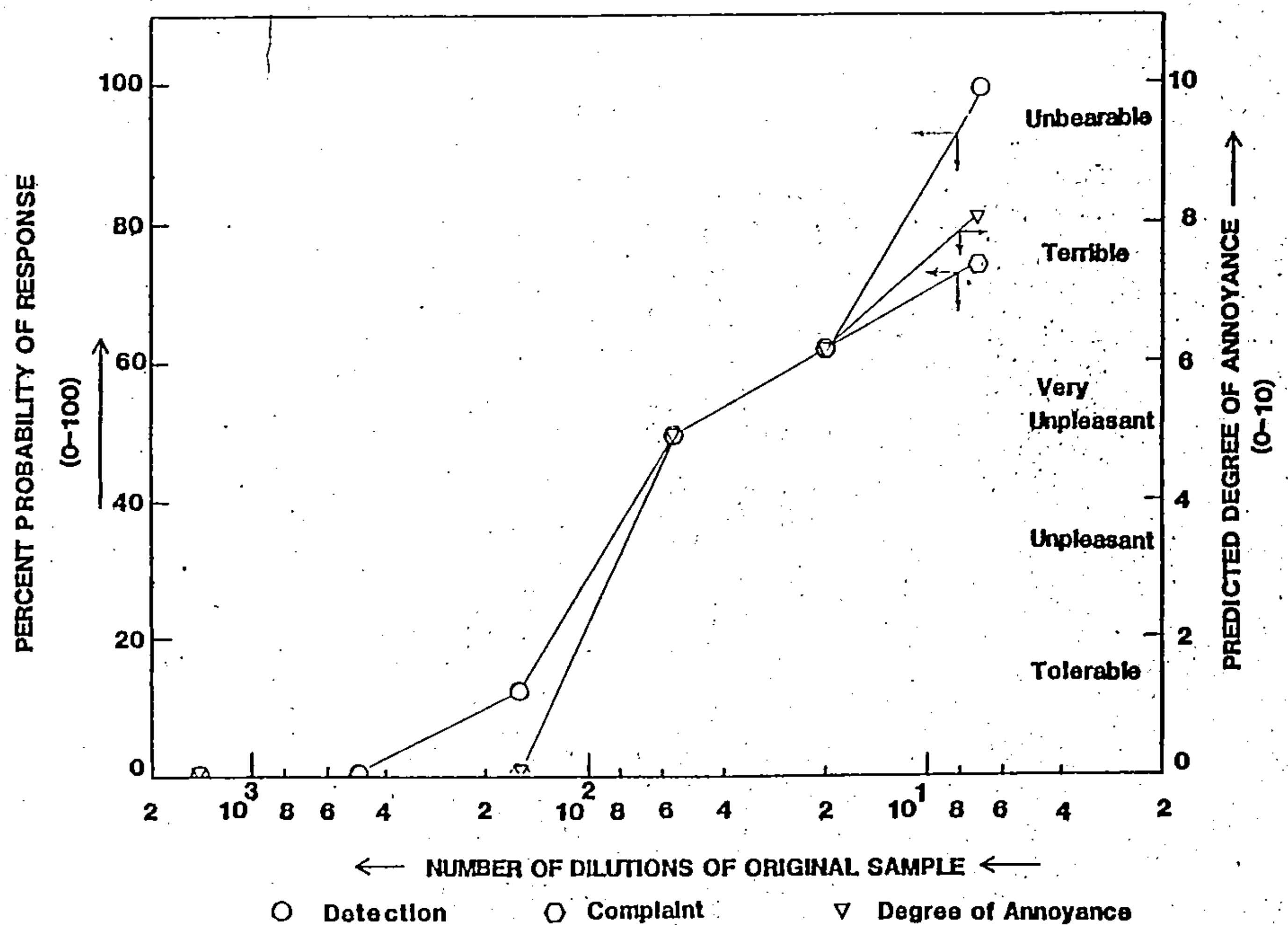

FIGURE VI.8: Odor Impact Model Profiles for Typical Odorous Emissions from Cupola #3 (outlet) Stack Sampled on September 4, 1984

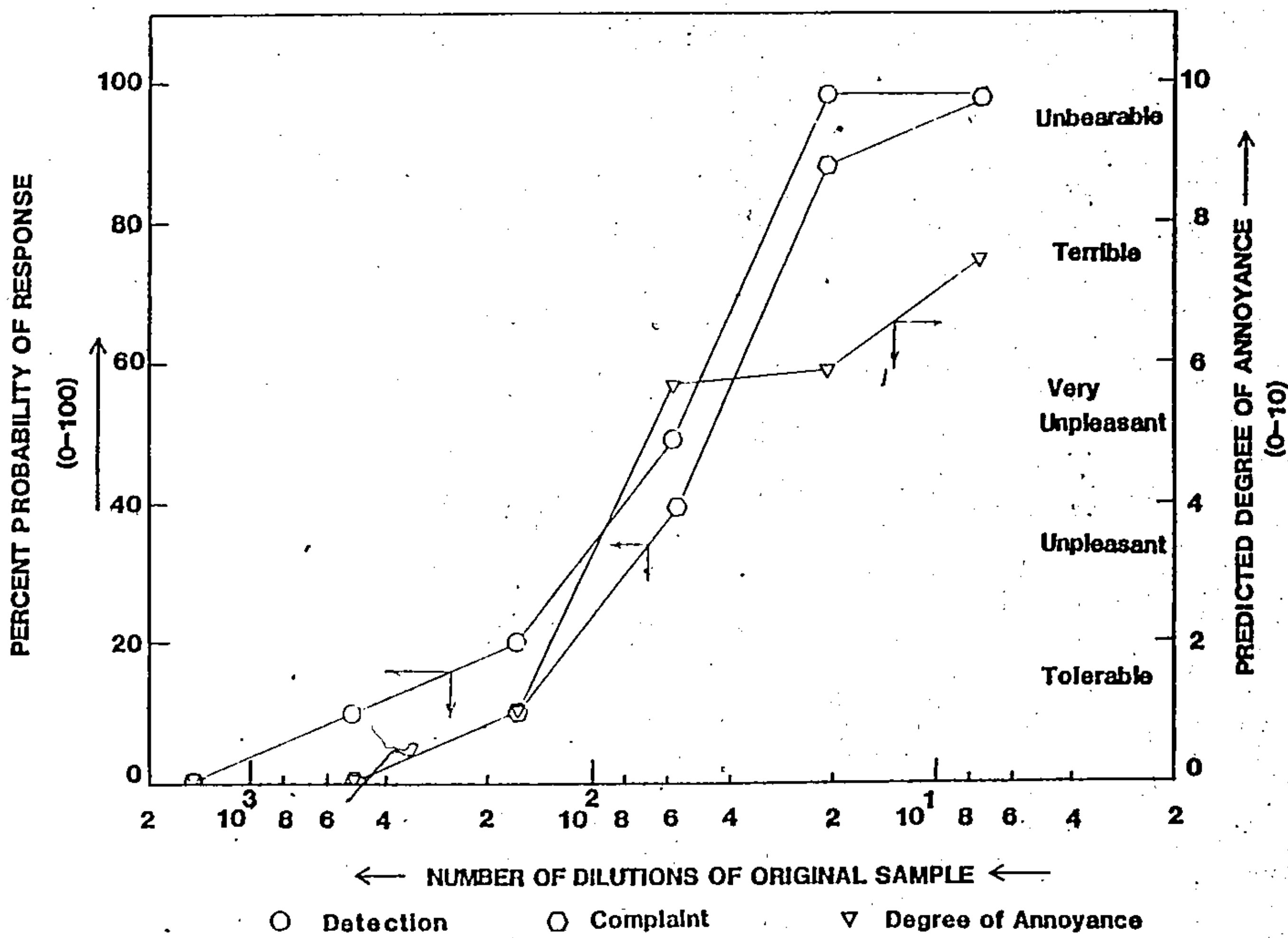

FIGURE VI.9: Odor Impact Model Profiles for Typical Odorous Emissions from D9 Stack Sampled on August 21, 1984

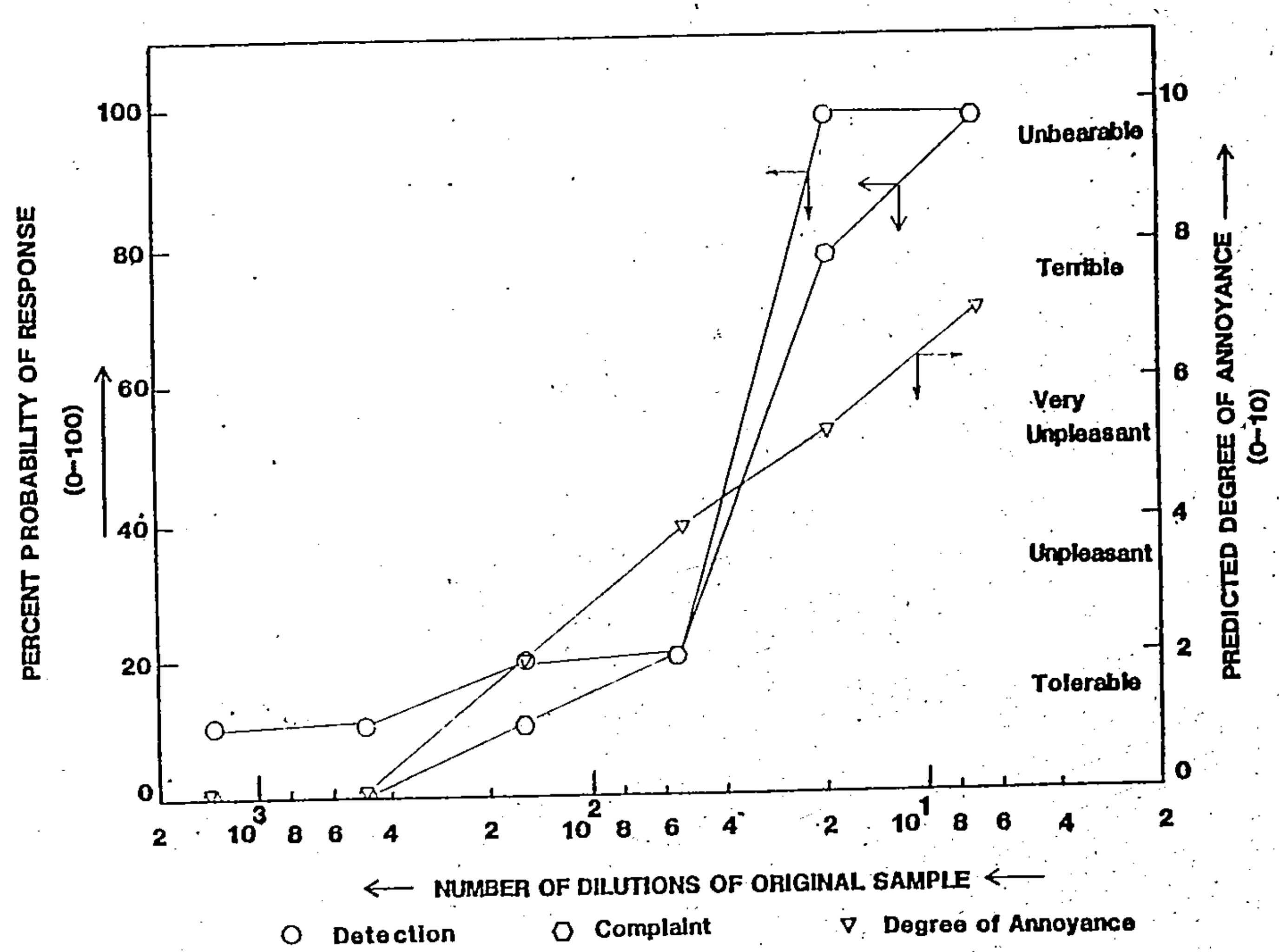

FIGURE VI.10: Odor Impact Model Profiles for Typical Odorous Emissions from DS Stack Sampled on August 21, 1984

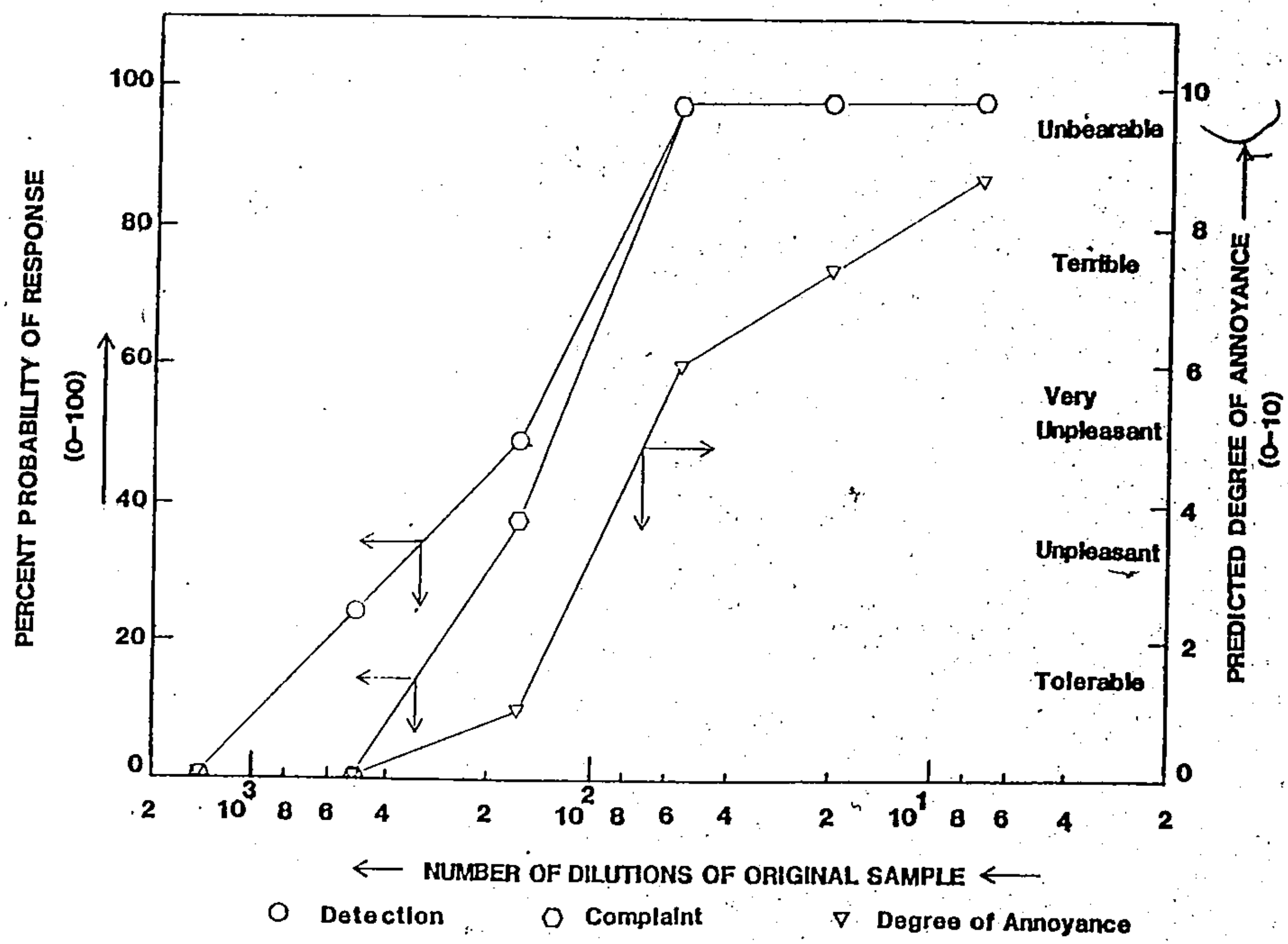

FIGURE VI.11: Odor Impact Model Profiles for Typical Odorous Emissions from C9 Stack Sampled on October 31, 1984

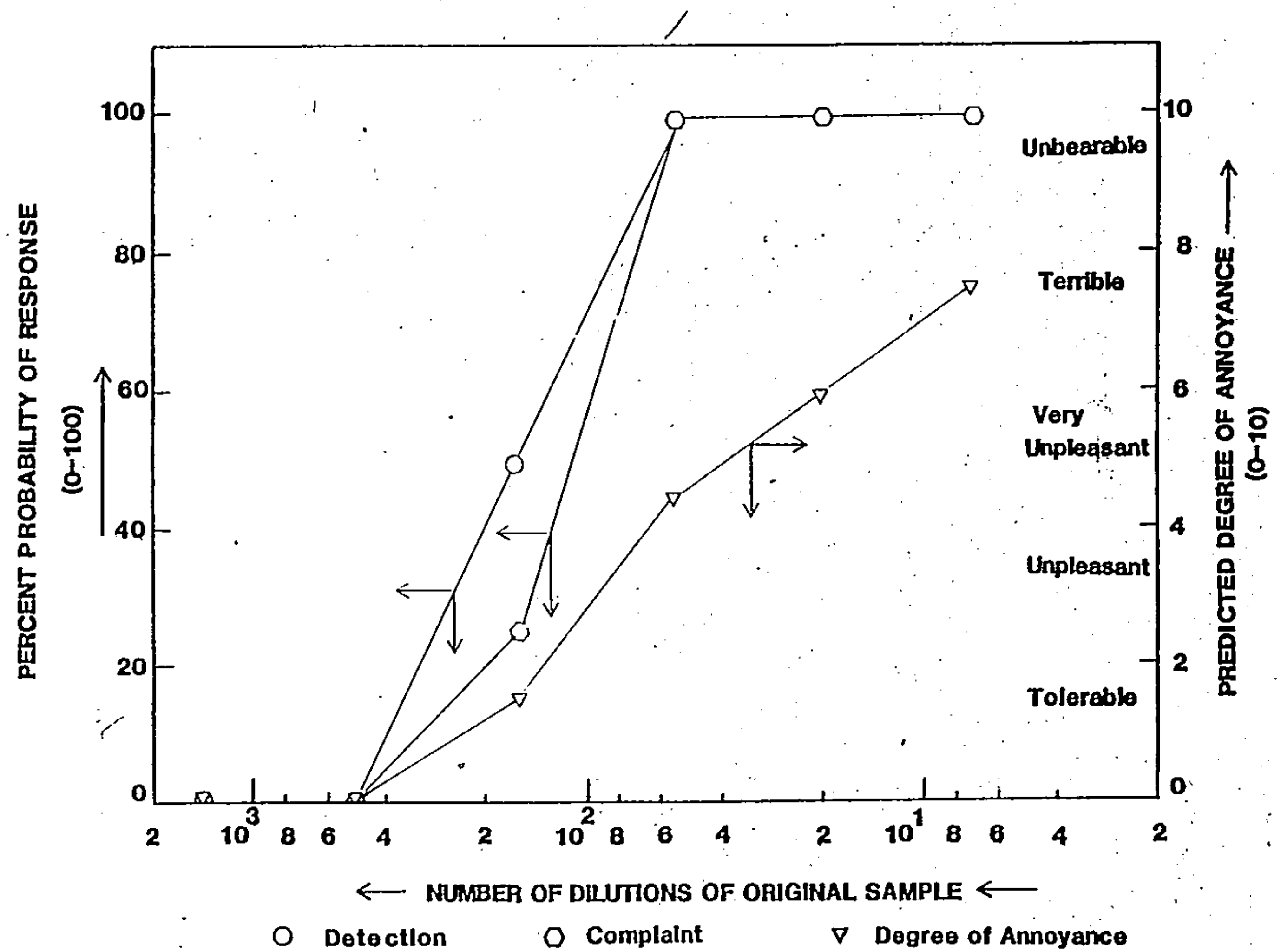

FIGURE VI.12: Odor Impact Model Profiles for Typical Odorous Emissions from Cupola #1 (outlet) Stack Sampled on November 19, 1984

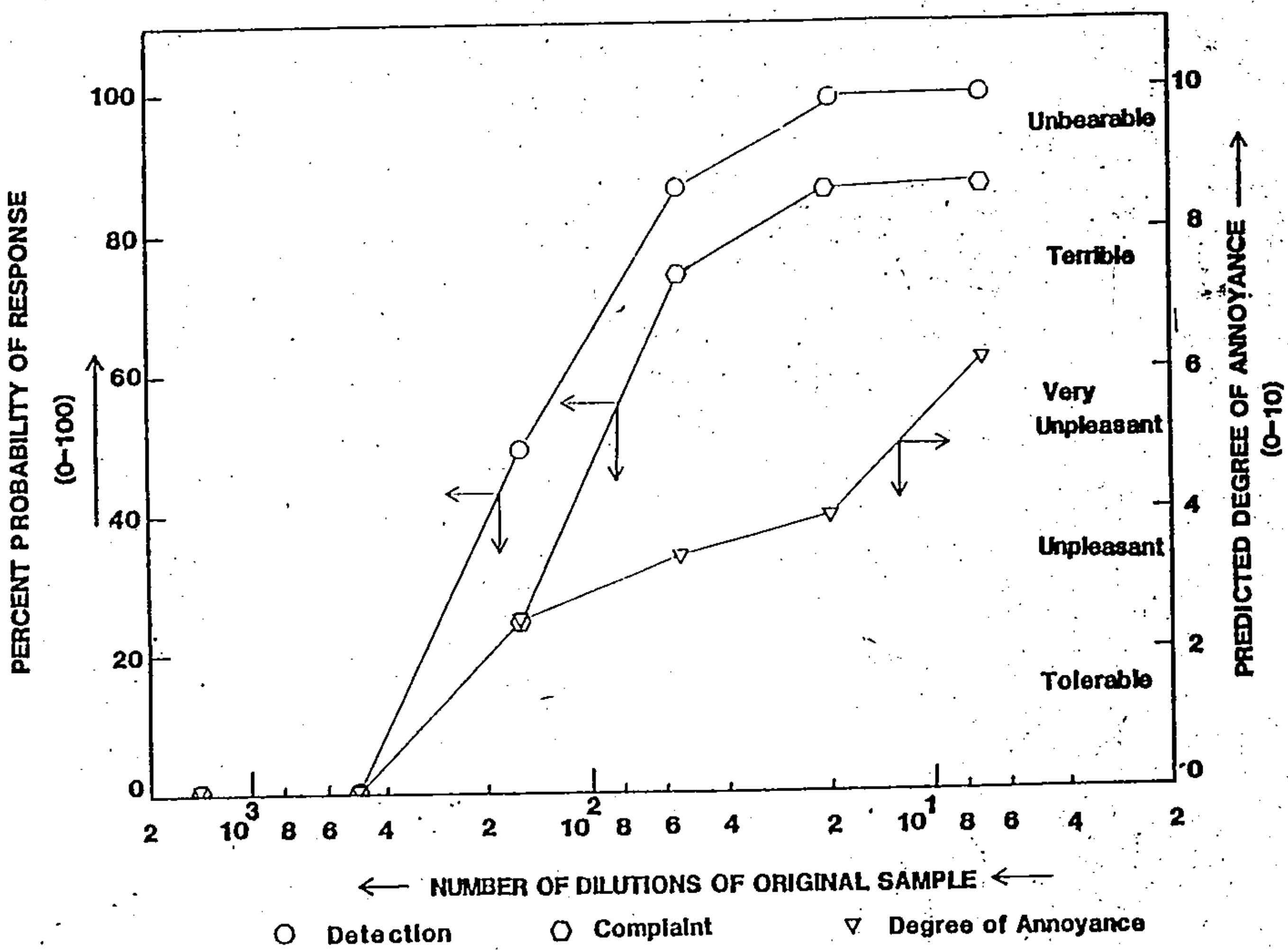

FIGURE VI.13: Odor Impact Model Profiles for Typical Odorous Emissions from Cupola #1 (inlet) Stack Sampled on November 19, 1984

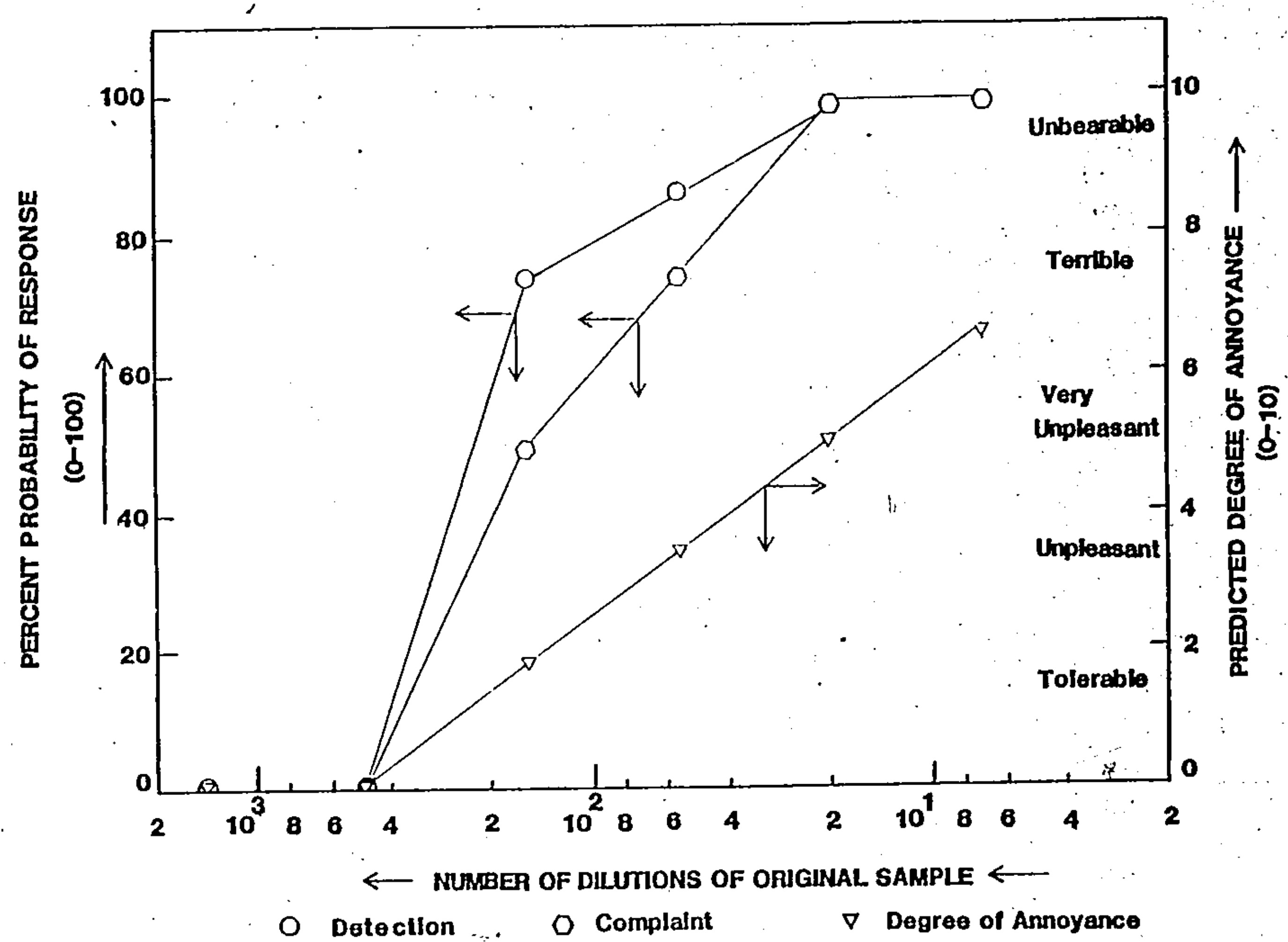

FIGURE VI.14: Odor Impact Model Profiles for Typical Odorous Emissions from B Stack Sampled on January 15, 1985

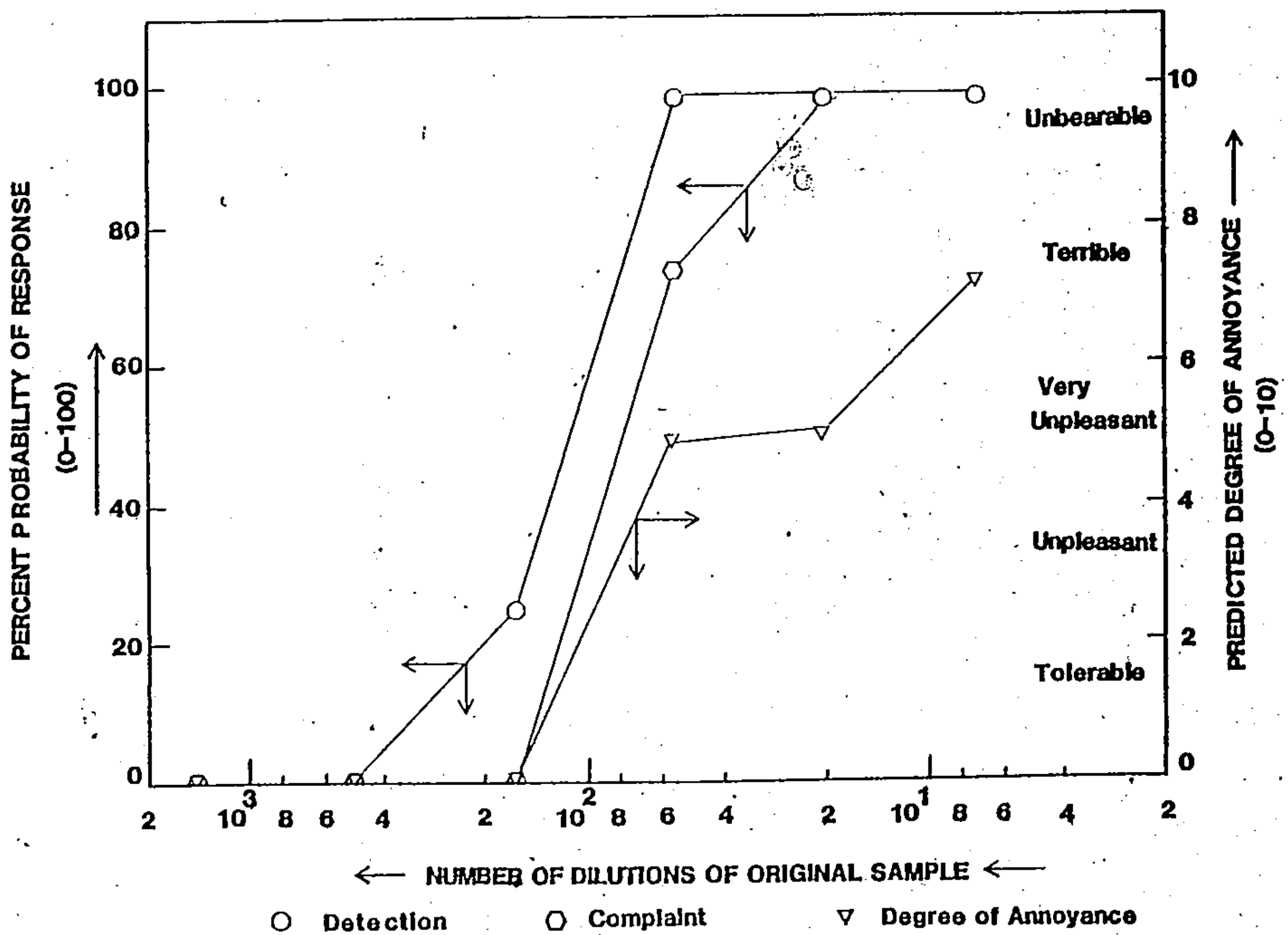

FIGURE VI.15: Odor Impact Model Profiles for Typical Odorous Emissions from B11 Stack Sampled on November 1, 1984

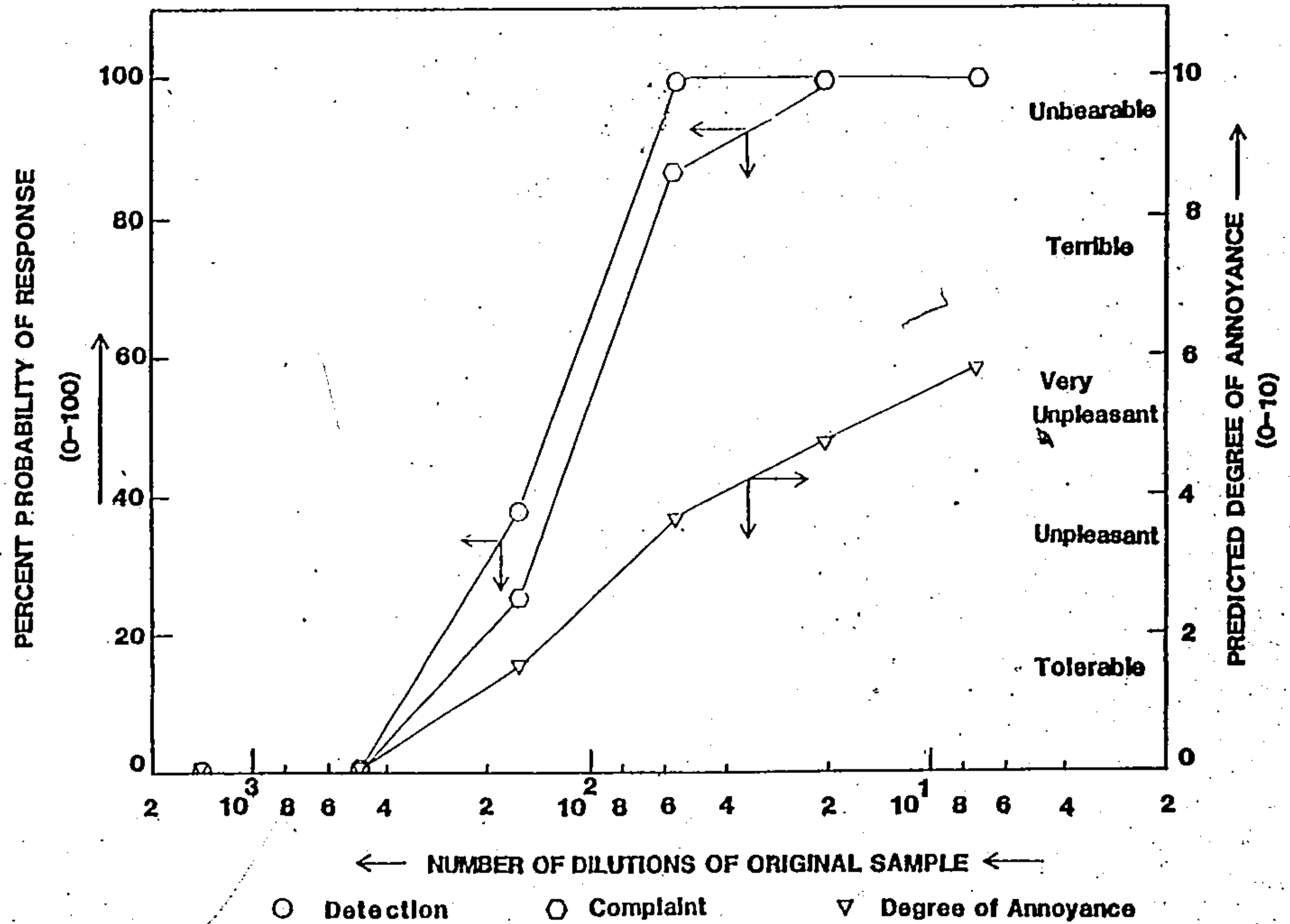

FIGURE VI.16: Odor Impact Model Profiles for Typical Odorous Emissions from Cupola #3 (outlet) Stack Sampled on November 19, 1984

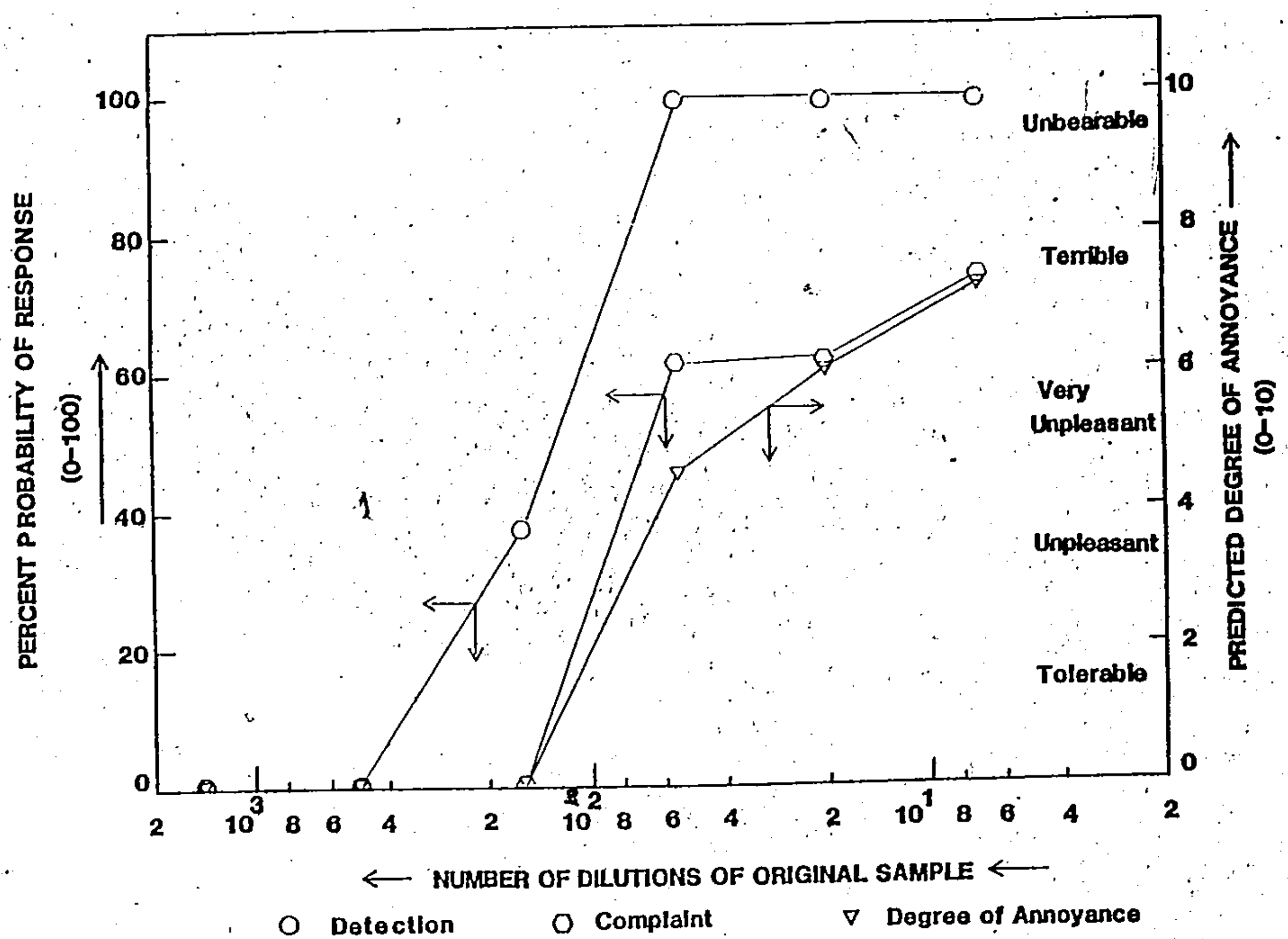

FIGURE VI.17: Odor Impact Model Profiles for Typical Odorous Emissions from D9 Stack Sampled on September 5, 1984

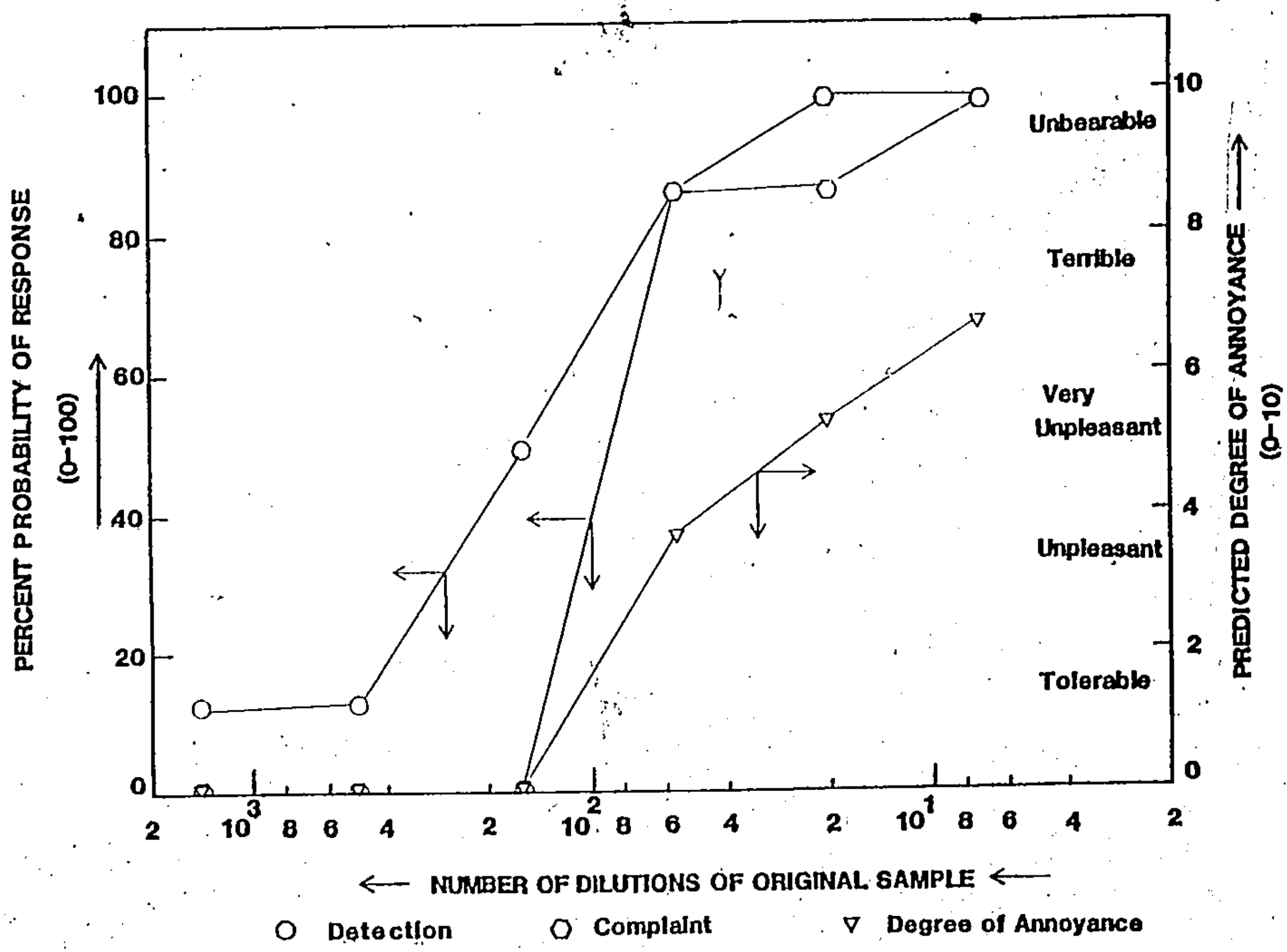

FIGURE VI.18: Odor Impact Model Profiles for Typical Odorous Emissions from D8 Stack Sampled on September 5, 1984

APPENDIX VII

Meteorological Data from Windsor Airport in Terms of Joint Frequency Functions of Wind Speed, Wind Direction and Stability [42]

ANNUAL RELATIVE FREQUENCY DISTRIBUTION STATION = WINDSOR A 1972-81

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000198	0.000148	0.0	0.0	0.0	0.0	0.000347
NNE	0.000213	0.000148	0.0	0.0	0.0	0.0	0.000362
NE	0.000272	0.000331	0.0	0.0	0.0	0.0	0.000603
ENE	0.000438	0.000377	0.0	0.0	0.0	0.0	0.000814
E	0.000468	0.000331	0.0	0.0	0.0	0.0	0.000799
ESE	0.000270	0.000137	0.0	0.0	0.0	0.0	0.000407
SE	0.000191	0.000126	0.0	0.0	0.0	0.0	0.000317
SSE	0.000199	0.000103	0.0	0.0	0.0	0.0	0.000302
S	0.000351	0.000343	0.0	0.0	0.0	0.0	0.000694
SSW	0.000303	0.000240	0.0	0.0	0.0	0.0	0.000543
SW	0.000183	0.000194	0.0	0.0	0.0	0.0	0.000377
WSW	0.000288	0.000194	0.0	0.0	0.0	0.0	0.000483
W	0.000296	0.000217	0.0	0.0	0.0	0.0	0.000513
WNW	0.000134	0.000137	0.0	0.0	0.0	0.0	0.000271
NW	0.000097	0.000069	0.0	0.0	0.0	0.0	0.000166
NNW	0.000116	0.000080	0.0	0.0	0.0	0.0	0.000196
TOTAL	0.004019	0.003174	0.0	0.0	0.0	0.0	

RELATIVE FREQUENCY OF OCCURRENCE OF A STABILITY = 0.007193

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = 0.001747

ANNUAL — RELATIVE FREQUENCY DISTRIBUTION — STATION = WINDSOR A 1972-81

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001292	0.000765	0.000502	0.0	0.0	0.0	0.002560
NNE	0.000850	0.000925	0.000674	0.0	0.0	0.0	0.002448
NE	0.000990	0.001530	0.001633	0.0	0.0	0.0	0.004153
ENE	0.001305	0.001678	0.001621	0.0	0.0	0.0	0.004604
E	0.001746	0.001610	0.000696	0.0	0.0	0.0	0.004052
ESE	0.001091	0.000594	0.000411	0.0	0.0	0.0	0.002095
SE	0.001018	0.000525	0.000274	0.0	0.0	0.0	0.001817
SSE	0.001218	0.000685	0.000457	0.0	0.0	0.0	0.002360
S	0.001655	0.001496	0.000833	0.0	0.0	0.0	0.003984
SSW	0.001533	0.001553	0.001393	0.0	0.0	0.0	0.004479
SW	0.001346	0.001496	0.001450	0.0	0.0	0.0	0.004292
WSW	0.001224	0.001142	0.001085	0.0	0.0	0.0	0.003451
W	0.001767	0.001165	0.001085	0.0	0.0	0.0	0.004016
WNW	0.000882	0.000571	0.000457	0.0	0.0	0.0	0.001910
NW	0.000515	0.000411	0.000365	0.0	0.0	0.0	0.001291
NNW	0.000648	0.000445	0.000274	0.0	0.0	0.0	0.001367
TOTAL	0.019078	0.016509	0.013210	0.0	0.0	0.0	

RELATIVE FREQUENCY OF OCCURRENCE OF D STABILITY = 0.048878

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = 0.003996

ANNUAL RELATIVE FREQUENCY DISTRIBUTION STATION = WINDSOR A 1972-81

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000628	0.001519	0.002603	0.000540	0.000011	0.0	0.005309
NNE	0.000304	0.000993	0.002124	0.000445	0.000034	0.000011	0.003992
NE	0.000429	0.001370	0.003688	0.000891	0.000011	0.0	0.006389
ENE	0.000794	0.001427	0.003676	0.000457	0.0	0.0	0.006354
E	0.000861	0.001633	0.002249	0.000206	0.000034	0.0	0.004983
ESE	0.000707	0.000993	0.001233	0.000194	0.000011	0.0	0.003139
SE	0.000591	0.000948	0.001313	0.000148	0.000011	0.0	0.003012
SSE	0.000627	0.000936	0.001564	0.000206	0.0	0.0	0.003333
S	0.000945	0.002021	0.004282	0.000879	0.000046	0.0	0.008172
SSW	0.000803	0.001964	0.006165	0.001072	0.000171	0.000046	0.011022
SW	0.000655	0.002261	0.005480	0.001416	0.000046	0.000023	0.009801
WSW	0.000628	0.001804	0.004282	0.001096	0.000126	0.000034	0.007969
W	0.000821	0.002021	0.003013	0.001187	0.000206	0.000011	0.008059
WNW	0.000308	0.000891	0.002854	0.000788	0.000114	0.000011	0.005046
NW	0.000283	0.000400	0.001461	0.000400	0.000034	0.000011	0.002589
NNW	0.000446	0.000845	0.001941	0.000537	0.000046	0.0	0.003814
TOTAL	0.009990	0.022024	0.048729	0.011269	0.000902	0.000148	

RELATIVE FREQUENCY OF OCCURRENCE OF C STABILITY = 0.093063

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = 0.002557

ANNUAL — RELATIVE FREQUENCY DISTRIBUTION — STATION = WINDSOR A 1972-81

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001727	0.004407	0.011600	0.016156	0.003060	0.000708	0.037658
NNE	0.001334	0.002535	0.009141	0.010367	0.002535	0.000879	0.025790
NE	0.001011	0.004110	0.011771	0.013815	0.002204	0.000742	0.034454
ENE	0.001905	0.004304	0.010310	0.009134	0.001199	0.000194	0.027046
E	0.002767	0.005583	0.009716	0.008163	0.001096	0.000034	0.027360
ESE	0.001904	0.003128	0.006519	0.005366	0.000605	0.0	0.017523
SE	0.001453	0.002729	0.006691	0.004019	0.000320	0.000023	0.015233
SSE	0.001619	0.003391	0.007239	0.005252	0.000628	0.000046	0.018234
S	0.002535	0.006291	0.016213	0.015048	0.002478	0.000411	0.042975
SSW	0.001867	0.005332	0.022172	0.031980	0.006359	0.001587	0.069297
SW	0.002191	0.005195	0.018473	0.026317	0.006291	0.001370	0.059838
WSW	0.001443	0.004053	0.015539	0.027504	0.007547	0.002420	0.058587
W	0.002084	0.005115	0.013552	0.027058	0.009865	0.003357	0.061831
WNW	0.000906	0.002637	0.012011	0.024639	0.006645	0.001872	0.048710
NW	0.000558	0.001370	0.006394	0.015813	0.003905	0.001039	0.029078
NNW	0.000780	0.002249	0.007946	0.015973	0.003163	0.000708	0.030819
TOTAL	0.026945	0.062430	0.184207	0.257484	0.057897	0.015391	

RELATIVE FREQUENCY OF OCCURRENCE OF D STABILITY = 0.604434

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = 0.007067

ANNUAL RELATIVE FREQUENCY DISTRIBUTION STATION = WINDSOR A 1972-81

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.0	0.002021	0.004727	0.0	0.0	0.0	0.006748
NNE	0.0	0.001484	0.002295	0.0	0.0	0.0	0.003779
NE	0.0	0.002478	0.003197	0.0	0.0	0.0	0.005674
ENE	0.0	0.003322	0.002089	0.0	0.0	0.0	0.005412
E	0.0	0.004464	0.001747	0.0	0.0	0.0	0.006211
ESE	0.0	0.002877	0.001016	0.0	0.0	0.0	0.003893
SE	0.0	0.003391	0.001267	0.0	0.0	0.0	0.004658
SSE	0.0	0.004190	0.001918	0.0	0.0	0.0	0.006108
S	0.0	0.006930	0.004772	0.0	0.0	0.0	0.011703
SSW	0.0	0.005435	0.008894	0.0	0.0	0.0	0.014329
SW	0.0	0.004476	0.008449	0.0	0.0	0.0	0.012924
WSW	0.0	0.003151	0.006280	0.0	0.0	0.0	0.009431
W	0.0	0.003334	0.006736	0.0	0.0	0.0	0.010070
WNW	0.0	0.001519	0.005652	0.0	0.0	0.0	0.007170
NW	0.0	0.000811	0.002146	0.0	0.0	0.0	0.002957
NNW	0.0	0.001096	0.003482	0.0	0.0	0.0	0.004578
TOTAL	0.0	0.050978	0.064668	0.0	0.0	0.0	

RELATIVE FREQUENCY OF OCCURRENCE OF E STABILITY = 0.115646

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = 0.0

ANNUAL | RELATIVE FREQUENCY DISTRIBUTION | STATION = WINDSOR A 1972-81

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.004094	0.004693	0.0	0.0	0.0	0.0	0.008786
NNE	0.002317	0.002877	0.0	0.0	0.0	0.0	0.005194
NE	0.003107	0.003836	0.0	0.0	0.0	0.0	0.006943
ENE	0.003695	0.002911	0.0	0.0	0.0	0.0	0.006607
E	0.005681	0.002957	0.0	0.0	0.0	0.0	0.008638
ESE	0.003542	0.001827	0.0	0.0	0.0	0.0	0.005369
SE	0.003943	0.002489	0.0	0.0	0.0	0.0	0.006432
SSE	0.005226	0.003722	0.0	0.0	0.0	0.0	0.008948
S	0.008035	0.008906	0.0	0.0	0.0	0.0	0.016940
SSW	0.005686	0.007809	0.0	0.0	0.0	0.0	0.013496
SW	0.004367	0.005846	0.0	0.0	0.0	0.0	0.010213
WSW	0.004022	0.004967	0.0	0.0	0.0	0.0	0.008988
W	0.004898	0.007239	0.0	0.0	0.0	0.0	0.012137
WNW	0.002052	0.002980	0.0	0.0	0.0	0.0	0.005032
NW	0.001383	0.001187	0.0	0.0	0.0	0.0	0.002570
NNW	0.002199	0.002295	0.0	0.0	0.0	0.0	0.004494
TOTAL	0.064245	0.066540	0.0	0.0	0.0	0.0	

RELATIVE FREQUENCY OF OCCURRENCE OF F STABILITY = 0.130786

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = 0.019809

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.007804	0.013552	0.019432	0.016704	0.003071	0.000708	0.061271
NNE	0.005028	0.008963	0.013233	0.010812	0.002569	0.000891	0.041495
NE	0.006567	0.013655	0.020289	0.014706	0.002215	0.000742	0.058173
ENE	0.008184	0.014021	0.017697	0.009591	0.001199	0.000194	0.050890
E	0.011646	0.016578	0.014409	0.008369	0.001130	0.000034	0.052166
ESE	0.007620	0.009556	0.009180	0.005560	0.000617	0.0	0.032533
SE	0.007301	0.010207	0.009545	0.004167	0.000331	0.000023	0.031574
SSE	0.009030	0.013027	0.011178	0.005457	0.000628	0.000046	0.039365
S	0.013528	0.025986	0.026100	0.015927	0.002523	0.000411	0.084475
SSW	0.010198	0.022332	0.038625	0.033852	0.006531	0.001633	0.113171
SW	0.008847	0.019467	0.033852	0.027733	0.006337	0.001393	0.097628
WSW	0.007562	0.015311	0.027185	0.028680	0.007672	0.002455	0.088864
W	0.009708	0.019090	0.025107	0.029046	0.010070	0.003368	0.096468
WNW	0.004314	0.008734	0.020974	0.025426	0.006759	0.001884	0.068091
NW	0.002812	0.004247	0.010367	0.016213	0.003939	0.001050	0.038628
NNW	0.004126	0.007010	0.013644	0.016509	0.003208	0.000708	0.045206
TOTAL	0.124278	0.221736	0.310894	0.260751	0.058799	0.015539	

TOTAL RELATIVE FREQUENCY OF OBSERVATIONS = 1.000000

TOTAL RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE = 0.035976

APPENDIX VIII

Dominant Meteorological Conditions in Windsor, Ontario [42]

TABLE VIII.1: Dominant Stabilities in Relation to Wind Data from Windsor Airport, 1972-81 [42]

CLASS	REL.FREQ. %	DOMINANT WINDSPD m/s	WIND DIRECTION 1st	WIND DIRECTION 2nd	CALMS %
A	0.7	0 - 1.5	NE	SW	0.2
B	4.9	0 - 1.5	NE	SW	0.4
C	9.3	3.5 - 5.0	SW	NE	0.3
D	60.4	5.5 - 8.0	SW	NE	0.8
E	11.6	5.5 - 8.0	SW	NE	0.0
F	13.1	0 - 3.0	SW	NE	2.0

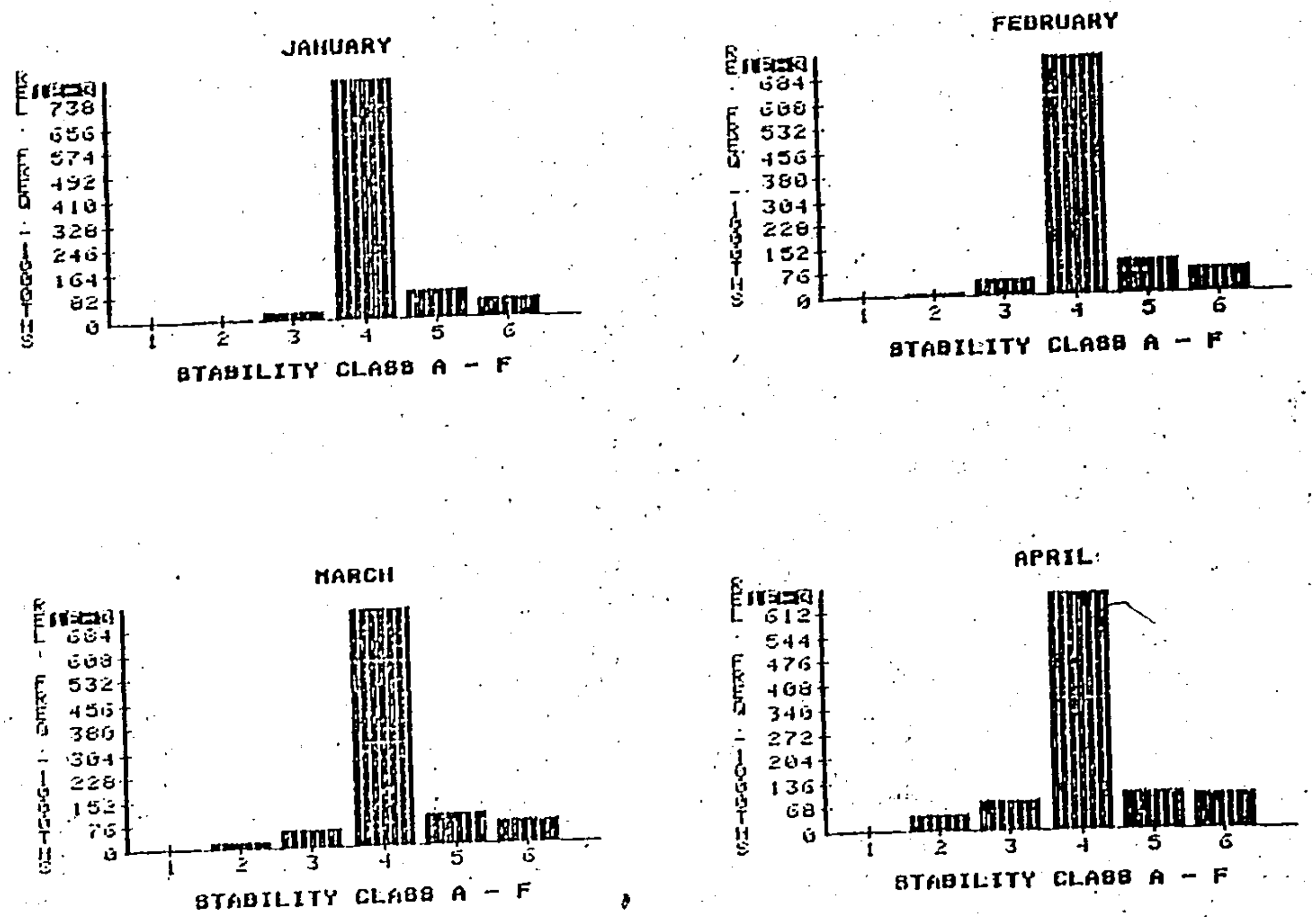

FIGURE VIII.1: Monthly Stability Data in Windsor Area [42]

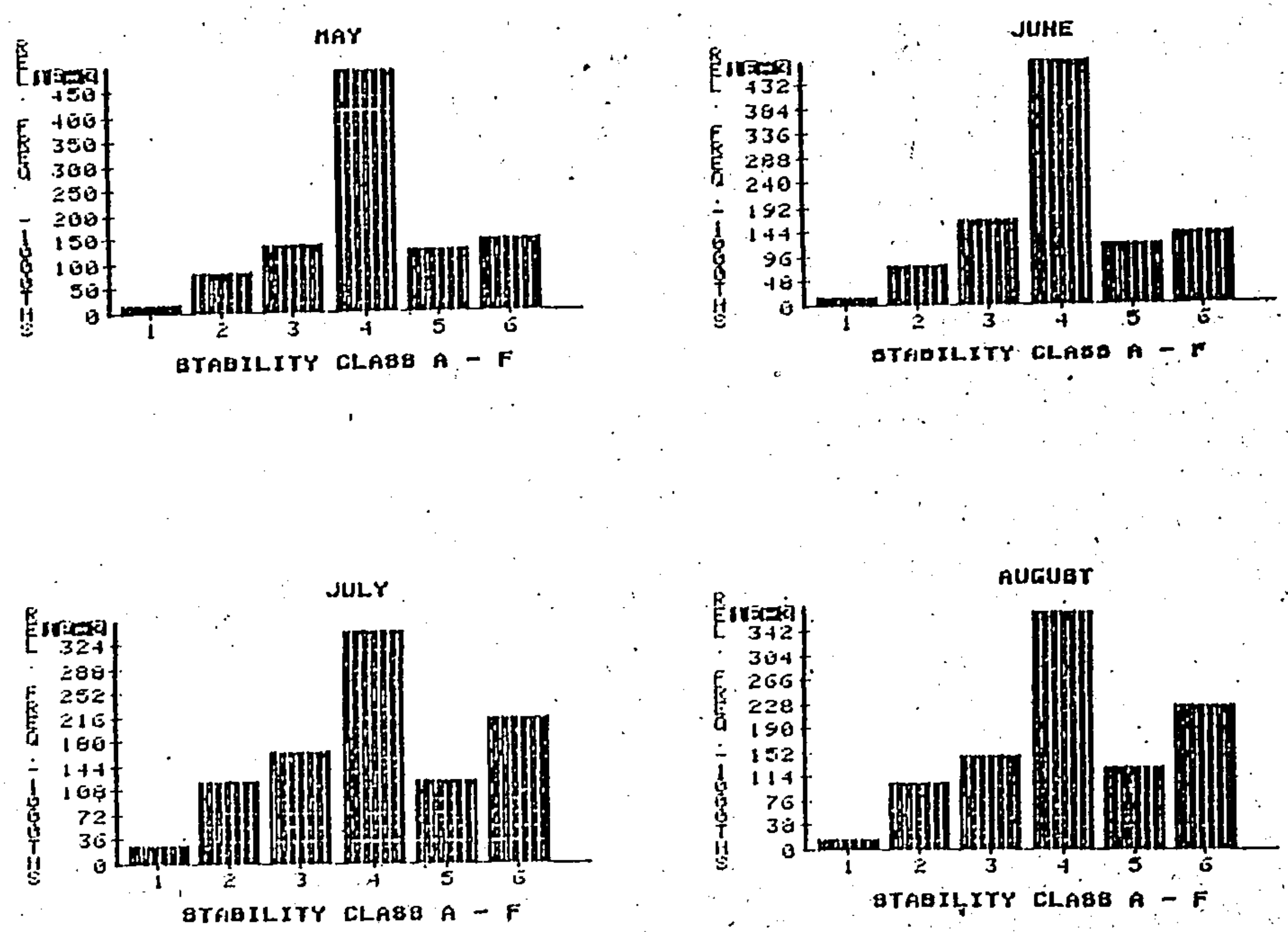

FIGURE VIII.1: (cont'd) Monthly Stability Data in Windsor Area [42]

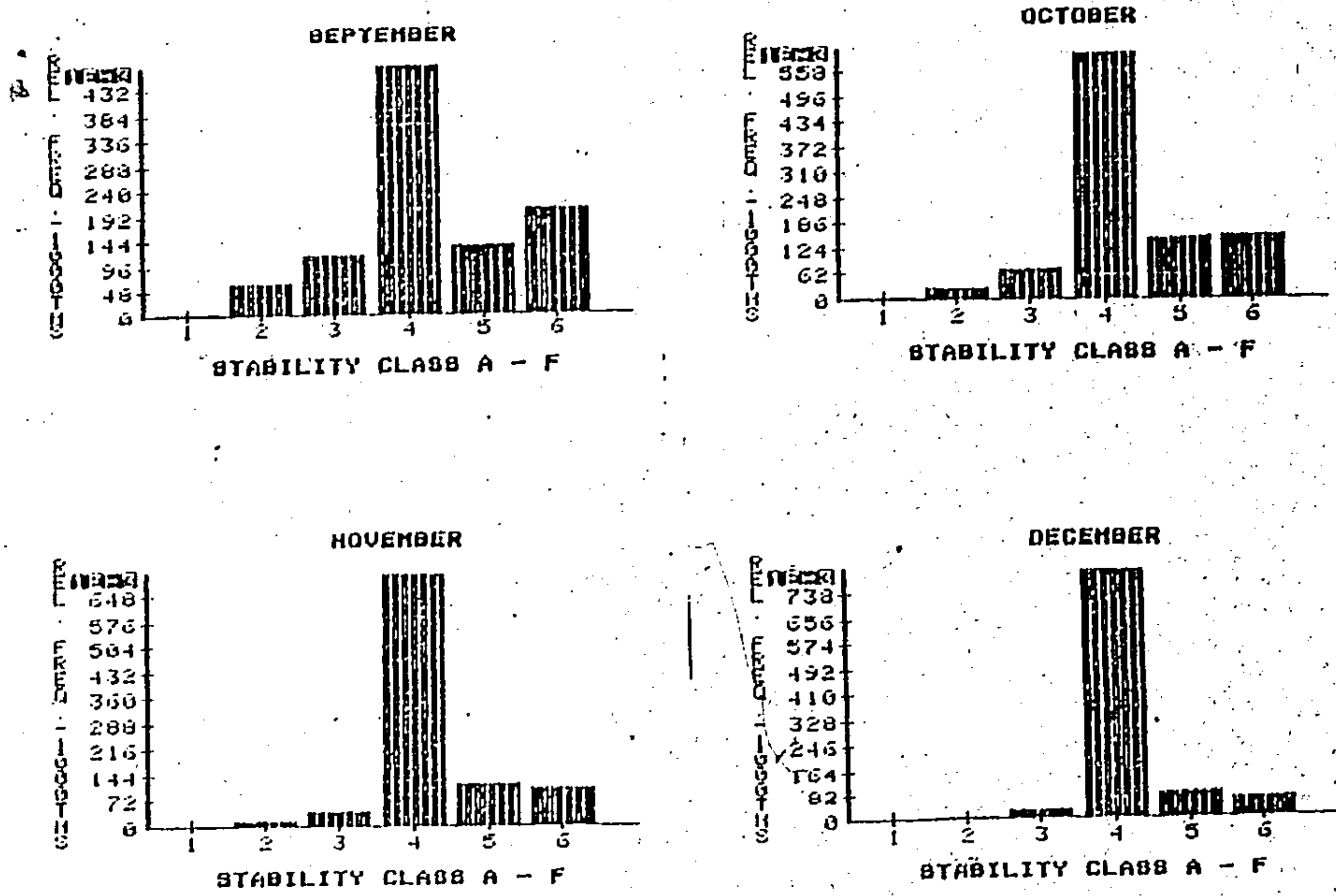

FIGURE VIII.1: (cont'd) Monthly Stability Data in Windsor Area [42]

VITA AUCTORIS

1955 Born in Shiraz, Iran, on August 2nd.

1973 Awarded Secondary School Certificate from Dastur Secondary High School, Poona, India.

1974 Completed Pre-University Course at New College, Madras University, India.

1979 Completed Bachelor of Technology in Chemical Engineering at Regional Engineering College, Madras University, India.

1981 Granted the degree of Master of Applied Science in Chemical Engineering at the University of Windsor, Windsor, Ontario, Canada.

1983 Atmospheric Transport Modeller, Great Lakes Institute, University of Windsor, Windsor, Ontario, Canada.

1985 Candidate for the degree of Doctor of Philosophy in Chemical Engineering at the University of Windsor, Windsor, Ontario, Canada.

Some Technical Presentations and Publications

1. Development of a Strategy for Predicting the Impact of Odorous Pollutants From Fast Food Restaurants on the Surrounding Community, Technology Transfer Conference No. 4, sponsored by Ontario Ministry of Environment, Toronto (Ontario), (November, 1983), A.W. Gnyp, C.C. St. Pierre and E.B.M. Poostchi.
2. Resolution of Source Contributions to the Ambient Levels of Lead and Cadmium in the Windsor Area, presented at the 27th International Conference on the Great Lakes Research, St. Catharines (Ontario), (May, 1984), E.B.M. Poostchi, A.A. Gnyp and A.W. Gnyp.
3. Comparison of Models for the Determination of Odor Thresholds (accepted for publication in the Journal of Atmospheric Environment), A.W. Gnyp, C.C. St. Pierre and E.B.M. Poostchi.
4. Quantification of Community Annoyance Due to Odorous Emissions From Stationary Sources, presented at the Joint Annual Conference of Air Pollution Control Association Ontario Section Pollution Control Association of Ontario, Toronto (Ontario), (April, 1985), A.W. Gnyp, C.C. St. Pierre and E.B.M. Poostchi.
5. Assessing the Impact of Odorous Emissions From Municipal Waste Landfill Sites on the Surrounding Community, presented at the 78th Annual Meeting of the Air Pollution Control Association, Detroit (Michigan), (June, 1985), A.W. Gnyp, C.C. St. Pierre and E.B.M. Poostchi.