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Preliminary assessment of the odour impact model as a regulatory strategy.

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PRELIMINARY ASSESSMENT
OF THE
ODOUR IMPACT MODEL
AS A
REGULATORY STRATEGY

By

James A. Nicell

A Thesis Submitted to the
Faculty of Graduate Studies and Research
Through the Department of Chemical Engineering
in Partial Fulfillment of the Requirements for the
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Dedicated, with love, to
my family.

ABSTRACT

The University of Windsor Odour Impact Model was created as a means of evaluating the impact of odourous emissions from stationary sources on surrounding communities by providing measures of

- probability of detection
- probability of discrimination
- probability of complaint
- degree of annoyance

as functions of the dilution (concentration) of the odour.

Odour impact models have been developed for

- n-Butyl Acetate
- Propylene Glycol Monomethyl Ether
- Methyl Isoamylketone
- Isobutanol
- n-Butanol
- Octane

using a wide spectrum of panelists who differed in terms of sex, age and odourous or non-odourous working conditions. The models for these six chemicals provide the following data:

Chemical	Detection Threshold ($\mu g/M^3$)	Discrimination Threshold ($\mu g/M^3$)
n-Butyl Acetate	1000	3100
Propylene Glycol Monomethyl Ether	121000	215000
Methyl Isoamylketone	630	1400
Isobutanol	2640	6700
n-Butanol	3100	6900
Octane	61800	129000

Statistical analysis of the responses of panelists between 18 and 27 years of age indicate that panelist gender and employment in odourous or non-odourous environments do not contribute to the differences in olfactory sensitivities among panelists. However, trends indicate that there is a loss of sensitivity to odours with increasing age. Therefore, sensory panels should be composed of a variety of panelists who reflect the age distribution in the population.

Representative panels consisting of ten members demonstrate the responses and variations in responses of the population. However, a single panel evaluation of an odour will not provide a measure of the confidence limts associated with each odour impact model curve. Multiple panels should be subjected to the odour so that sufficient data are generated to determine the confidence limits.

The evaluation of odours during sessions separated by a period of one week demonstrates that no significant variations occur in the Odour Impact Model as a result of temporal differences except for the Degree of Annoyance curve. Future research should concentrate on the development of a panelist training/educating procedure that would make individual expressions of annoyance more consistent and, therefore, more reproducible.

Several features of the Odour Impact Model must be refined before it can be implemented as a testing procedure. It is recommended that

- the degree of annoyance curve at any dilution level be calculated by averaging all annoyance levels registered by panelists.

- the probability of complaint curve be eliminated from the Odour Impact Model and the probability of discrimination curve be used instead.
- the probability of discrimination curve should replace the probability of detection curve as a measure of panelists' abilities to perceive an odour. The detection profile should be eliminated from the Odour Impact Model.

Mathematical relationships have been developed to

- provide a measure of the effect of a single panelist on the evaluation of panel thresholds.
- predict the number of panelists required to reduce the effect of a single panelist to an acceptable tolerance.
- relate the mean panel discrimination threshold to the mean detection threshold through the application of probability theory.

In addition, it was confirmed that the volumetric calibration technique which is normally used to calibrate the olfactometer is capable of producing accurate measures of the dilution levels provided by the device.

ACKNOWLEDGEMENTS

I wish to take this opportunity to express my sincere gratitude to my advisors, Dr. A.W. Gnyp and Dr. C.C. St. Pierre, for their guidance, constructive criticisms and encouragement throughout the period of this investigation.

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I. INTRODUCTION

The University of Windsor Odour Impact Model was developed as a procedure for assessing the impact of odourous source emissions on surrounding communities [15]. Successful implementation of this modelling procedure would furnish measures of

- the hedonic character of the odour
- the quantity of odour emitted at the source
- the potential impact of the odour on the surrounding community

The Odour Impact Model (OIM) provides the

- probability of detection (PD)
- probability of discrimination (PDn)
- probability of complaint (PC)
- degree of annoyance (DA)

profiles as functions of the number of dilutions of the odour from the source.

Prior to the development of the Odour Impact Model, regulatory agencies had no objective methods for assessing the impact of odourous emissions on residential areas surrounding stationary sources [15]. The Odour Impact Model will provide these agencies with a strategy for the control of industrial odours. However, there is still a need for further development of the Odour Impact Model before it can be implemented as an effective odour testing procedure. It was the intention of this investigation to study these areas of concern.

The objectives of this investigation were to

(i) verify that the technique normally used to calibrate the olfactometer is capable of producing accurate measures of the dilution levels provided by the instrument.

(ii) establish whether factors such as sex, age, and employment in odourous or non-odourous conditions should be considered important in the selection of odour judges.

(iii) determine the minimum number of panelists necessary to evaluate an odour so that consistent and reliable odour impact models could be produced.

(iv) determine whether the results of the evaluation of an odour by a sensory panel are dependant upon the session during which they were evaluated.

(v) refine parameters of the Odour Impact Model which presently leave the compliance testing procedure open to criticism. Such criticism would hinder the effectiveness of regulatory agencies in enforcing their guidelines for odour control.

(vi) develop a mathematical relationship which provides a measure of the effect of a single panelist on the results of a sensory panel's evaluation of an odour. This expression could then be used to predict the minimum number of panelists required to evaluate an odour given a tolerance value which describes the maximum allowable effect of an individual on the panel results.

(vii) develop a mathematical expression relating the mean panel detection and discrimination thresholds based on probability theory.

These objectives were accomplished through the analysis of data collected during the development of odour impact models for

- n-Butyl Acetate
- Propylene Glycol Monomethyl Ether
- Methyl Isoamylketone
- Isobutanol
- n-Butanol
- Octane

using a wide spectrum of panelists.

The development of these models required the design and construction of an odour generator which supplied a steady flow of gas with a constant odourant concentration.

II. LITERATURE SURVEY

Odourous emissions from stationary sources tend to be the most frequent sources of air pollution complaint [2,15]. To reduce odour complaints, a variety of control measures may be taken. However, in all cases some form of odour measurement is needed to establish the extent of the problem and to assess the degree of improvement achieved by the implementation of odour control systems.

The objectives common to most odour evaluations are

- to study the relative importance of various odourous discharges to determine the principal source of the odour problem
- to study the effectiveness of odour control systems
- to quantify the odourant levels in discharges
- to forecast odour levels at various distances from a source based on source concentration, stack height, effluent gas temperature, topography, and meteorology
- to predict the impact of the odourous emissions on the surrounding community.

None of the currently implemented procedures for the evaluation of odours provide an overall model of the impact of an odour pollution problem on a community because they are not designed to quantify the magnitude of the nuisance caused by the odour [15]. Although many methods exist for the evaluation of odour detection thresholds, these procedures fail to develop any information related to the impact of the odour on a neighborhood or panel of judges who have been exposed to the odour. Since their development these methods have been used to quantify the odourous emissions from industrial sources. Much work has been performed in the measurement of odour thresholds and the values corresponding to many pure chemical odourants are available in literature [4,18,22]. However, the literature values of thresholds for many compounds could vary by several orders of magnitude [18,22]. These variations may be explained, in part, as being due to differences in the sensitivity of panelists and differences in the method of presentation of the odour to the panelists for sensory evaluation [6,7,18]. This stresses the need for some form of standardization of the odour evaluation process.

Since one of the goals of any odour related studies is to predict the impact of an odourous emission on a community, odour measurements are needed to establish the relationship between the community's reaction to an odour and the dose to which it is exposed [2]. This goal may be achieved through the use of the University of Windsor Odour Impact Model which was developed and applied to industrial situations by Poostchi [15]. This model provides a practical procedure for the routine evaluation of essential odour dimensions including probabilities of detection, discrimination, complaint, and the degree of annoyance as functions of the dilutions (concentration) of the odour.

The results of any odour investigation requiring the use of sensory judges are dependant upon the method of odour presentation [18]. The recent use of dynamic olfactometry has produced odour detection thresholds of much lower concentrations (sometimes by several orders of magnitude) than previously reported values which were determined using static methods. There is a definite preference for dynamic dilution techniques as opposed to static methods because they are perceived generally to be more reproducible and to be better controlled in delivering the odour stimulus to a panelist [16]. The American Society for Testing and Materials (ASTM) has recently received much criticism concerning the "Standard Method for Measurement of Odor in Atmospheres (Dilution Method)" published in the "Annual Book of ASTM Standards" [19]. This criticism has set in motion a search for a better alternative to this standard method. This procedure employed syringes to present the odour to the panelist.

Consensus may have been reached about the superiority of using dynamic dilution techniques as opposed to a static method but there is still much difference of opinion concerning the flowrate at which the odour should be delivered to the panelist. A difference in flowrates causes odour sensory results to vary widely among panels exposed to the same odour stimulus [16]. For example, Duffee and Cha reported that a 100-fold variation in flowrate can produce more than a 1000-fold variation in the reported threshold by the same panel [7].

Dravnieks contended that while higher flowrates are preferable in odour testing, lower flowrates provide portability, to permit using sample sizes that may be conveniently transported, and allow the use of testing rooms with lower ventilation rates [6]. In addition, Duffee doesn't see the need for high flowrates since he believes that individuals adjust to the available sample flowrate [8]. One significant disadvantage of using a high flowrate relates to the olfactory fatigue which could occur due to the impingement of the odourous gas stream on the olfactory membrane [14]. As a result there could be a reduction in a panelist's ability to distinguish the odour from a clean air supply. Hesketh [6] believes that the flow supplied by a low flow olfactometer must lead to dilution errors even under the most ideal conditions. However, in response to Hesketh, Dravnieks [6] claimed that data produced by the low flow IITRI olfactometer are very similar to higher flow devices.

The low flow IITRI olfactometer was chosen because;

- the low background contamination requires lower ventilation rates than for high flow devices
- the odour samples from an industrial source are easily transported due to the small sample size requirements
- there is less chance of causing olfactory fatigue using the low flow olfactometer
- it eliminates the confusion often reported by panelists who must decide whether they sense an odour or are reacting to the odourous gas stream pressure on their noses [16].

The intention of this investigation was to examine parameters which could prove to be important in the odour evaluation process. Such factors include panel size, panelist characteristics, sessional variations, and certain model definitions which may not presently withstand the scrutiny of members of the legal profession. Once these parameters have been evaluated and the necessary refinements to the model have been made, the Odour Impact Model can be implemented as an effective tool for the regulation of odourous emissions from stationary sources.

III. THE ODOUR IMPACT MODEL

The Odour Impact Model is basically an extension of the currently used principle of ternary forced choice detection threshold determination with a six level dynamic olfactometer. In addition to identifying the ports which are perceived to be emitting odourous material, panelists are also required to specify the levels at which they are sure, beyond a doubt, about the presence of the odour. Furthermore, panel members are provided with a form on which they are asked to indicate at which dilutions (concentrations) they would complain if they were exposed to similar odourous stimuli for an average period of eight hours and to rate the degree of complaint at each dilution level [15]. The panelists are advised to rate their annoyance on a scale of 0 to 10 according to the categories in Table 3.1.

TABLE 3.1: Annoyance Categories

Annoyance Range	Descriptor
0-2	Tolerable
2-4	Unpleasant
4-6	Very Unpleasant
6-8	Terrible
8-10	Unbearable

The panelists are assisted in this evaluation by the pictorials shown in Figure 3.1 which provide a visual representation of the annoyance categories.

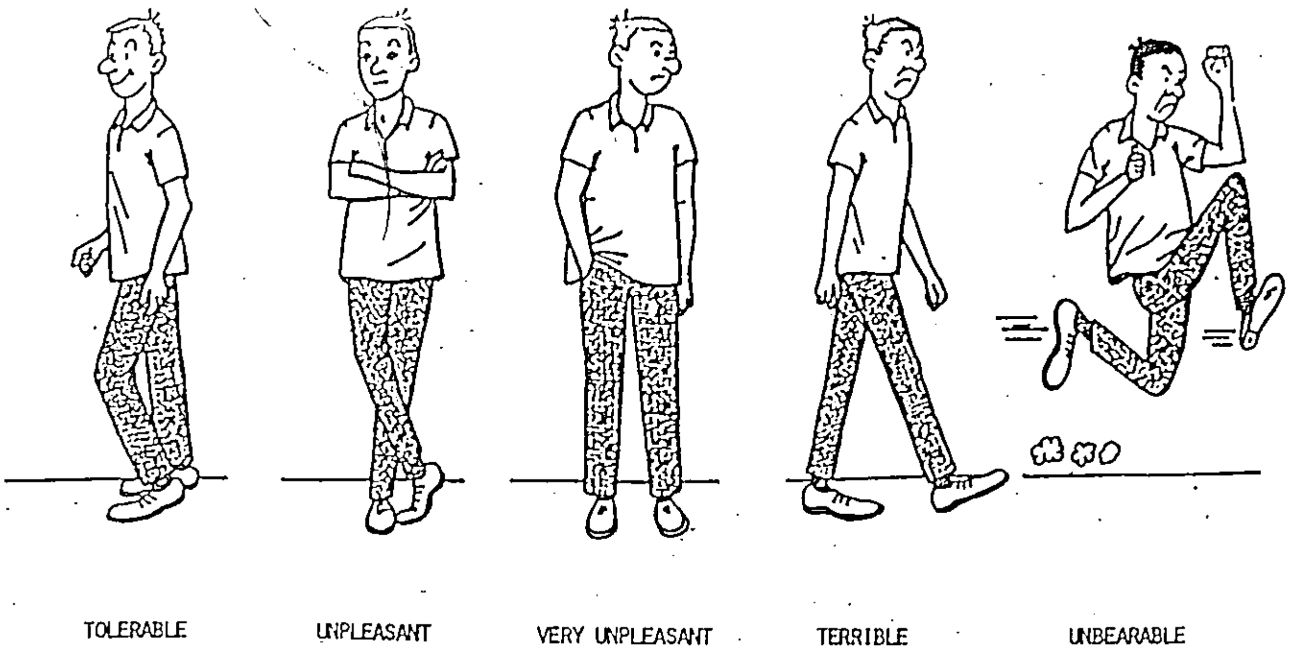


FIGURE 3.1: Visual Representation of Annoyance Levels.

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 (PD) to different odour levels as illustrated by curve I of Figure 3.2.

The odour 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 odour. Curve II of Figure 3.2 illustrates the location of a typical discrimination threshold (PDn) profile with respect to the detection threshold profile [15].

Similarly, the dilution levels (concentrations) at which panelists would complain (degree of annoyance greater than zero) and the magnitudes of annoyance provide data for the generation of probability of complaint (PC) and degree of annoyance (DA) profiles as shown by curves III and IV of Figure 3.2 [15].

The degree of offensiveness of an odour at a source is a function of the intensity and hedonic character of the odour and is defined by

$$DO = (MDL \ @ \ 100 \ PC)(DA_{100}) \qquad (3.1)$$

where DO = the degree of offensiveness of an odour at the source

MDL @ 100 PC = the maximum number of dilutions of the original sample for 100 percent probability of complaint

DA_{100} = the predicted degree of annoyance at MDL @ 100 PC on a scale of 0 to 10. [11]

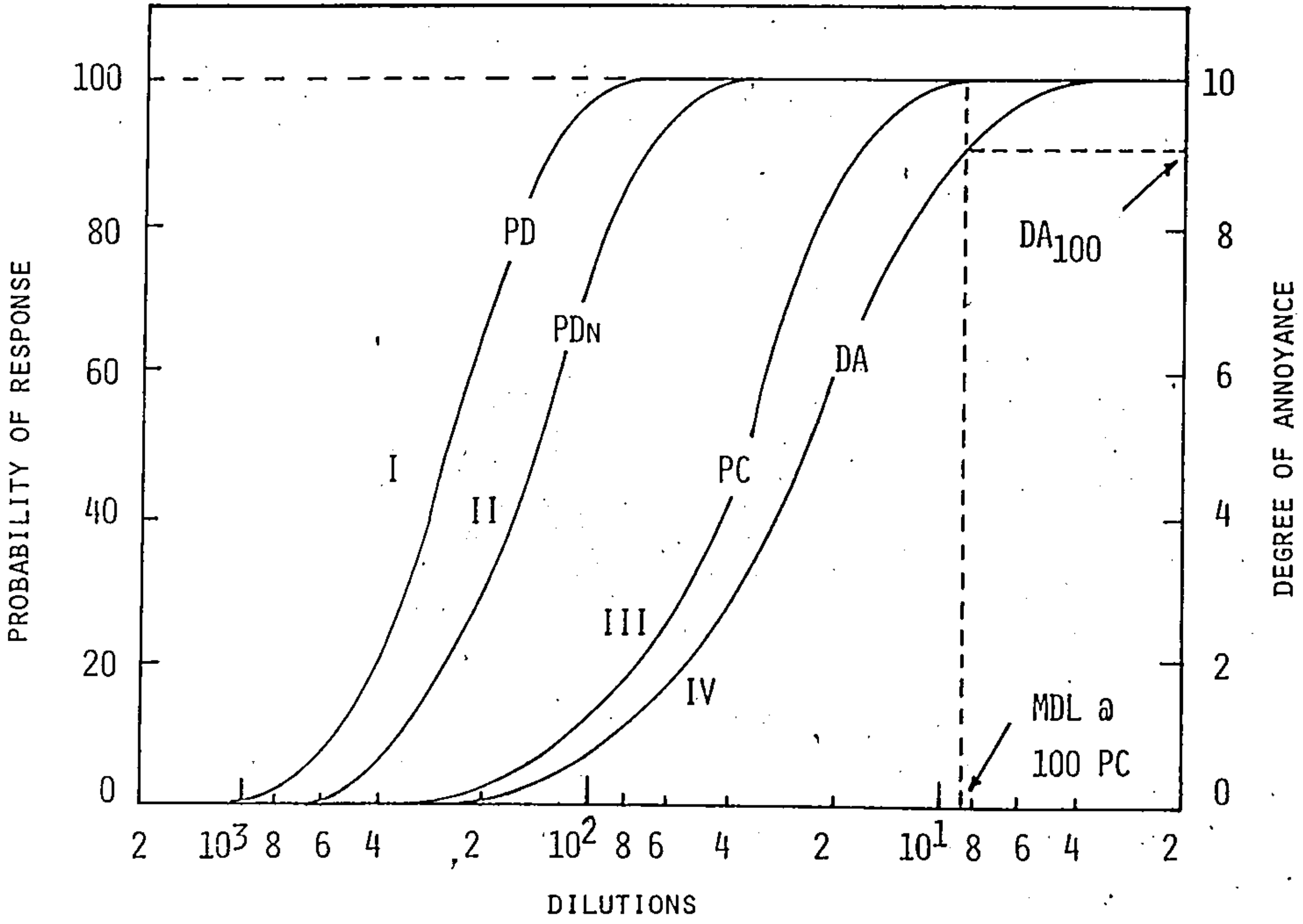


FIGURE 3.2: Idealized Odour Impact Model Profiles.

The MDL @ 100 PC is used since it is normally an experimentally determined level at which all members of an odour panel have complained and expressed their personal degree of annoyance on a scale of 0 to 10.

It should be apparent that the DO is not a true measure of the potential odour impact of any particular source on a community without consideration of the amounts of odours emitted per unit of time. A low emission rate of an odour with a high DO can be less serious than a high volumetric flowrate of an odour with a relatively lower DO. The odour impact model provides a means of estimating the potential level of source annoyance (SA) on the basis of the volumetric flow rate and degree of offensiveness according to

$$\begin{aligned} SA &= V_o\,(\text{MDL @ 100 PC})(DA_{100}) \\ &= V_o \cdot DO \end{aligned} \tag{3.2}$$

where SA = the potential level of source annoyance

V_o = the volumetric flowrate of odourous gas

DO = the degree of offensiveness. [11]

The SA provides ratings of different odourous sources at a specific facility in terms of their hedonic and volumetric flow parameters.

In order to quantify the impact of a particular source on its surrounding community, it is necessary to assess the ambient odour 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 Odour Impact Model. Estimates of the number of dilutions of the source emissions at different downwind distances provide measures of PC and the corresponding DA values from the Odour Impact Model profiles.

The potential odour impact (OI) in the community at various distances and elevations for a range of meteorological conditions can be expressed as

$$OI = (PC)(DA) \tag{3.3}$$

where OI = potential odour impact at any receptor location on a scale of 0 to 1000

PC = percent probability of complaint at any receptor location based on predicted dilutions from source to receptor

DA = predicted degree of annoyance corresponding to PC at any receptor location, on a scale of 0 to 10. [11]

For the purpose of this study it was necessary to plot the profiles of detection, discrimination, and complaint and the degree of annoyance curve versus concentration instead of dilutions. Consequently, it is possible to compare the response of panels who have been exposed to the same odour as a function of odourant concentration.

A common parameter used in many odour evaluation procedures is the detection threshold. This is the dilution at which 50% of the members of a sensory panel perceive the odour. It may be determined from data generated by an odour panel in two ways:

(i) The effective dosage at 50% probability of detection (ED_{50}) is calculated according to

$$ED_{50} = \left[\prod_{i=1}^{n} ED_{50_i} \right]^{1/n} \qquad (3.4)$$

where ED_{50} = the panel effective dosage at 50% probability of detection.

ED_{50_i} = the detection threshold of panelist "i"

n = the number of individuals on the panel.

This value represents the geometric mean of the individual panelist thresholds and is an estimate of the panel detection threshold.

(ii) The dilution at which 50% of the panel begin to detect the odour can be interpolated from the detection profile of the Odour Impact Model. This value, designated as Z @ 50 PD, differs from the ED_{50} in that it is a single measurement involving the full panel rather than the mean of individual panelist thresholds.

Similarly, there are two definitions of the discrimination threshold. One value, designated as D_{50}, is the geometric mean of the individual discrimination thresholds. Another value, designated as Z @ 50 PDn is the dilution corresponding to the 50% probability of discrimination as derived from the discrimination profile of the Odour Impact Model.

The values of ED_{50} and D_{50} will only be used to compare the sensitivities of individual panelists with the average sensitivity. Their counterparts, Z @ 50 PD and Z @ 50 PDn, are true measures of the panel detection and discrimination thresholds, respectively. That is, they are measures of the dilutions (concentration) at which 50% of the panel responds to the presence of the odour. Therefore, these are the actual panel thresholds, unlike the ED_{50} and D_{50} which are the geometric means of individual panelist thresholds.

When the panel thresholds are to be expressed in concentration units the detection threshold will be designated as C @ 50 PD and the discrimination threshold will be designated as C @ 50 PDn.

IV. EXPERIMENTAL DETAILS

The objectives of the experiments performed in this study were to

- validate the procedure normally used to calibrate the dynamic dilution olfactometer
- develop and validate an odour generator that can supply the olfactometer with a continuous flow of odourous gas at a constant odourant concentration
- generate the raw data necessary to produce odour impact models from a wide spectrum of panelists subjected to six chemical odourants
- generate enough data to detect variations in performance of panelists who differ in terms of age, sex and employment in odourous or non-odourous conditions.

A. Equipment Details

The equipment used in the odour evaluation experiments included an odour generator, an IITRI olfactometer, and an odour testing booth.

1. Odour Generation

Generation of a continuous flow of odourous gas with a constant odourant concentration required the design and construction of

- an air preparation system
- a system for the introduction of the odour into the clean air at a constant rate
- a predilution system
- a feed system for delivery of the odourous gas to the olfactometer.

These components were combined into the odour generator illustrated schematically in Figure 4.1.

Compressed air from the laboratory air line was passed through a filter where oil and dirt were removed. The flowrate was controlled by a valve connected to the air line and measured using a rotameter. The filtered air was brought to a constant temperature by passing through a 10-foot copper coil immersed in a constant temperature water bath. The air was then dehumidified and its temperature was measured in a chamber containing a bed of Drierite approximately 5 inches in depth. The volume of the prepared air was then measured with a dry test meter corrected to 25°C. Since the measured gas volume must be corrected for pressure in addition to temperature, a U-tube water manometer was connected in line at the exit from the dry test meter for pressure measurement. Subsequently, the air stream passed through an activated carbon bed, six inches in depth, to remove potentially odourous organic material from the air supply. A "T" fitting in the line split the flow between two sections of the odour generator. One line led to a regulating valve followed by a rotameter which directed the gas to a horizontal cylindrical tube containing the odourant. The air passed over the surface of the odourous material kept at a constant temperature. The head space above the odourant was continually flushed to produce an odourous gas stream. The air diverted from the odour generator passed through a rotameter before mixing with the odourous air exiting from the odour generating tube. This approach provides a

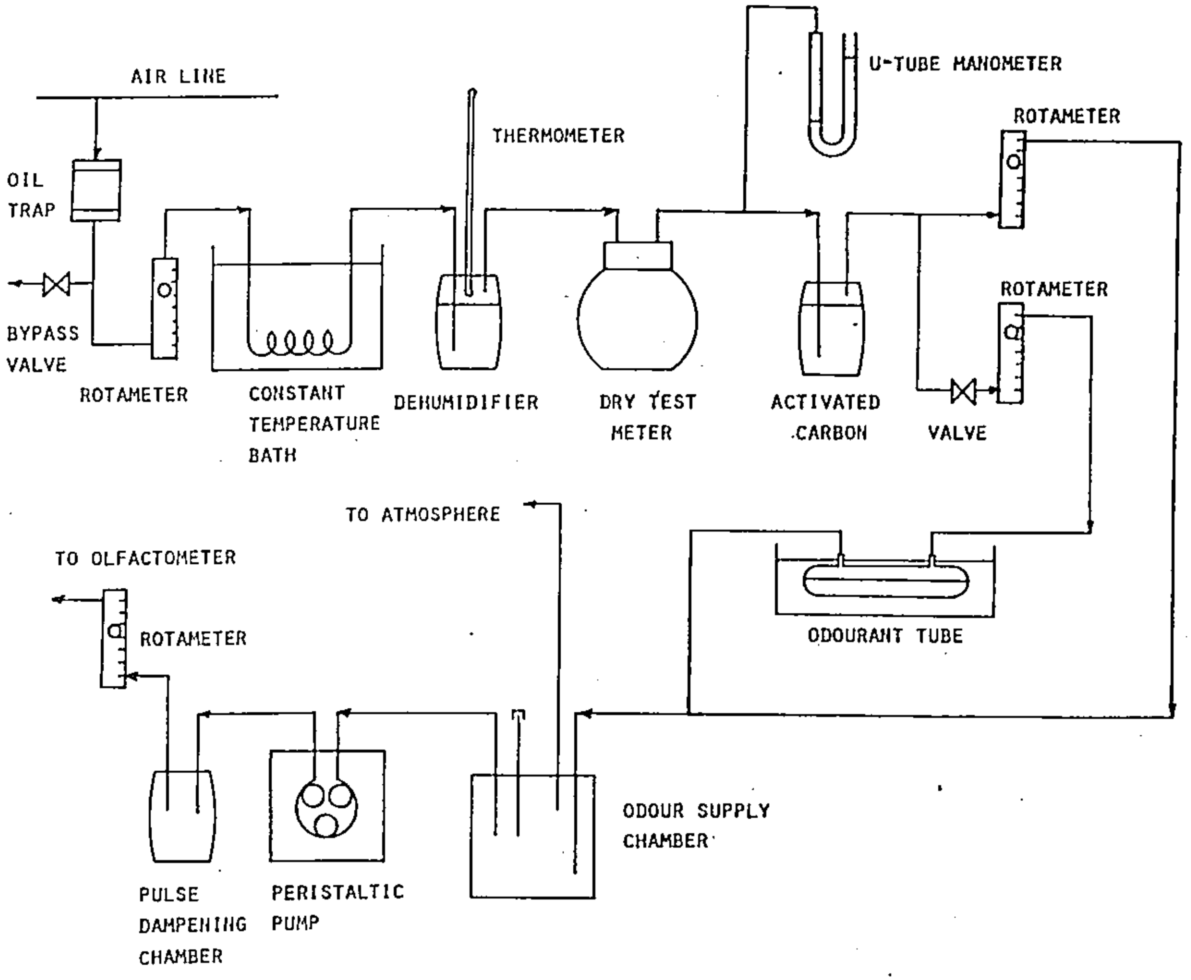


FIGURE 4.1: The Odour Generator.

level of predilution of the odour before it reaches the olfactometer. Without this dilution step, the odour delivered to the olfactometer could be excessively intense. The odourous gas was delivered to an odour chamber of approximately 3 litres capacity. There were three exit tubes from this vessel. One was a sampling port which was normally closed unless the gas was being sampled for analysis. A second tube delivered the gas to the olfactometer and the third tube allowed the unused portion of the gas to exit to the atmosphere, outside the building. Odourant was supplied to the olfactometer by means of a variable speed peristaltic pump with a range of 60 to 600 RPM. The odourous gas was removed from the supply chamber by the pump and passed through a small chamber which dampened the pulsating flow of the peristaltic pump. The smoothed flow from the dampening chamber then passed through a rotameter and into the olfactometer supply line.

The strength of the odour from the generator was adjusted by regulating the proportion of air which bypassed the odour tube. In addition, the amount of odour sent to the olfactometer was varied by changing the peristaltic pump flowrate. Care was taken to ensure that the flow being delivered to the olfactometer did not exceed the flow of odourous gas to the supply chamber. If this were to occur then clean atmospheric air would enter through the excess odour exit tube and cause an unpredictable additional dilution of the odour.

For any specific test, the odourant tube was connected to the system only after the desired flow had been established.

Before panelists began a test, the system was allowed to reach equilibrium for a one-half hour period. After the testing was completed the supply of air from the compressed air line was shut off and the change in weight of the odourant tube and the volume of air passed through the odour generator over the testing period were recorded. These values provided the basis for evaluating the concentration of the odourant in the gas stream entering the olfactometer.

A more detailed description of the odour generator and an explanation of the experimental method used to verify its capabilities are provided in Appendix I.

2. Odour Evaluation Equipment

The odour evaluation equipment consisted of a dynamic olfactometer housed in an odour-free test room.

a. The Dynamic Olfactometer

The olfactometer used in this study was purchased from the IIT Research Institute [15]. It consists of a dilution air pump, a peristaltic odour pump, a signal box, air rotameters, deodourizing chamber, six sets of sniffing ports, two manifolds, and Teflon sample lines. This instrument provides six dilution stations each equipped with a set of three glass sniffing ports. Two of the ports emit deodourized room air (blanks) while the third discharges the odourous gas diluted with deodourized air. The IITRI olfactometer is illustrated in Figure 4.2. The flow patterns associated with this apparatus are depicted in Figure 4.3.

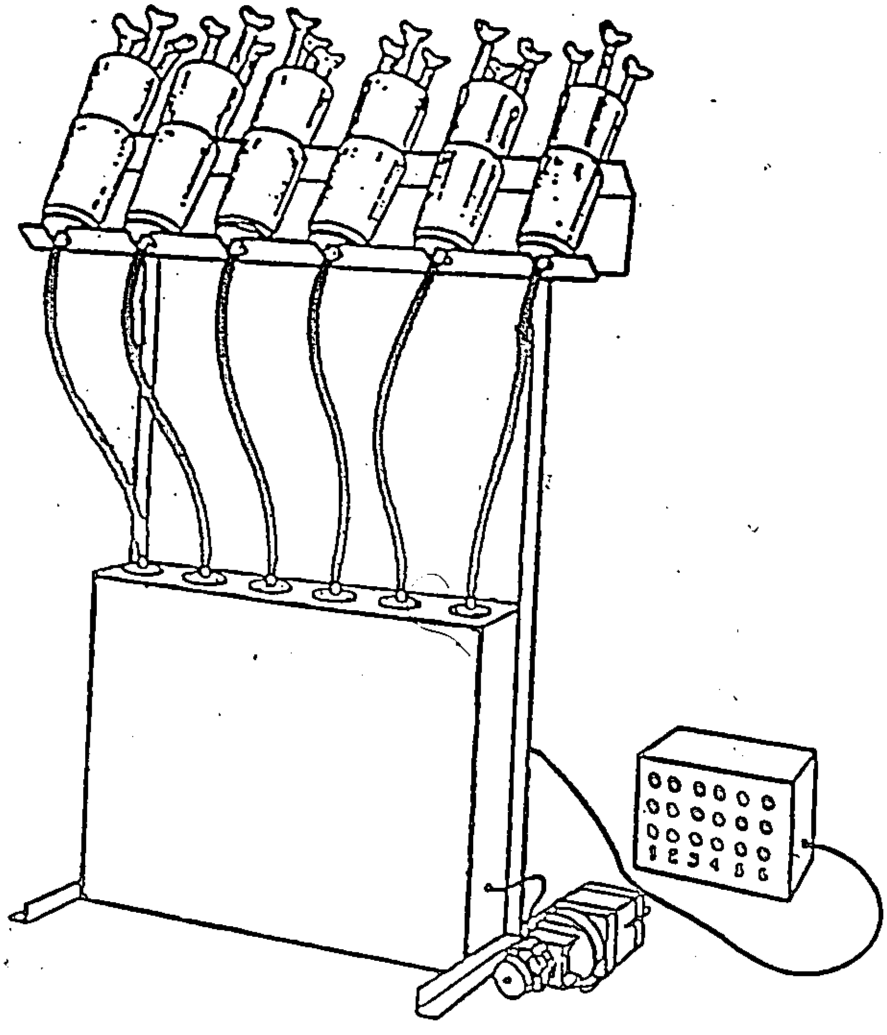


FIGURE 4.2: The IITRI Six-Level Dynamic Triangle Olfactometer.

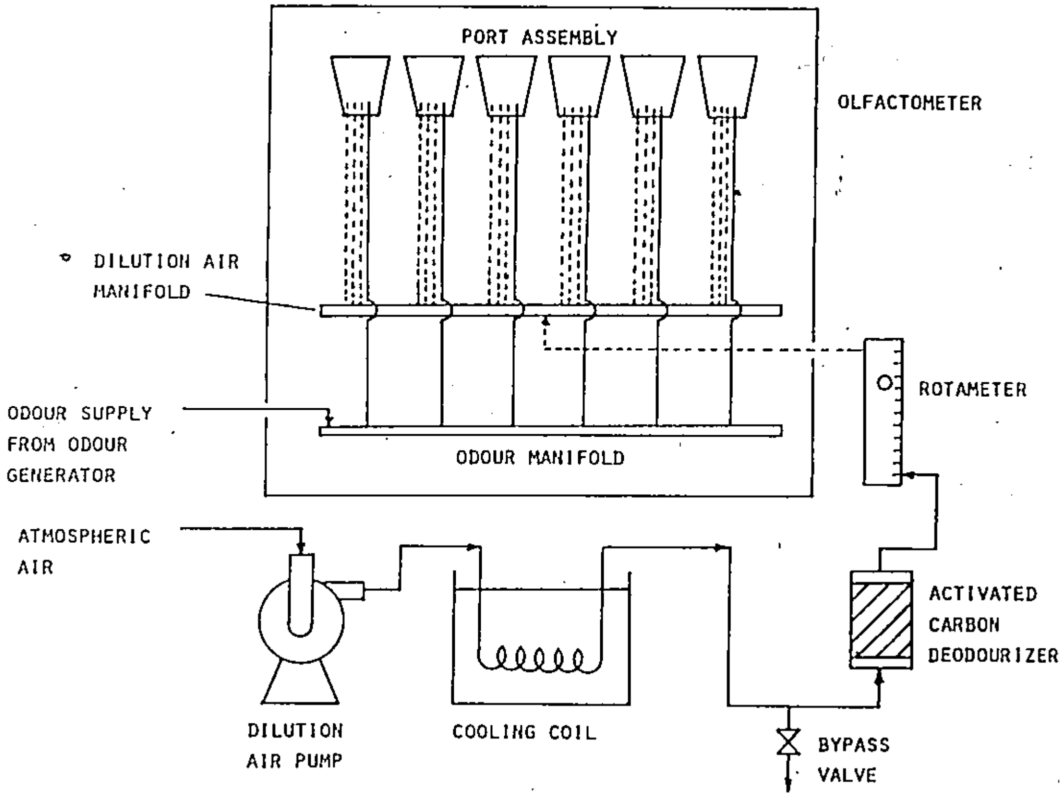


FIGURE 4.3: Flow Patterns of the IITRI Olfactometer.

The odourous gas is delivered to the olfactometer at a rate chosen by the panel leader depending on the required range of dilutions to be used in an odour evaluation. The deodorized dilution air is supplied at a rate of approximately 10 L/min. Two manifolds divide the odour and air flows among the odour stations in specific ratios. Each port delivers between 600 and 700 mL/min of air or odourous sample. Preliminary testing showed that panelists could not sense any gas pressure on their noses and, therefore, they were unable to detect variations in gas flowrates between ports. Consequently, the response of the panelists were not influenced by the small differences in total gas flowrates that occurred from port to port. The concentration of the odourant at each dilution level increased from left to right by a factor of approximately 3.0.

A signal box with six triple sets of lights provided panelists inside the odour free room with a means of communicating their responses to the panel leader.

The dilution level at each odour station was established using a volumetric flowrate calibration technique. Experiments were conducted to prove that this technique provided an accurate measure of the actual dilutions experienced at each olfactometer station. These procedures are described in detail in Appendix II.

Following each test, the olfactometer was purged overnight using a high flowrate of deodourized air. This cleaning process rendered the ports indistinguishable from each other after several hours.

A detailed equipment description is given in the Instruction Manual for Dynamic Triangle Olfactometer: 1977 Model [12].

b. The Odour Test Room

All odour tests were carried out in an odour-free environment maintained in a previously designed odour-free test room. This 4 ft wide by 4 ft long by 8 ft high chamber is a double walled room equipped with a door, a glass window, an interior light, an electric air cleaner and an exhaust fan for removal of odours introduced through the olfactometer. The inside walls are constructed of washable arborite [23].

The air cleaner delivers odour-free background air into the test room at a low flow of 100 ft^3/min or a high flow of 150 ft^3/min. It consists of a two stage electrostatic precipitator for particulate removal down to 0.03 μm (microns) with a disposable carbon filter for removal of odours. An outside lint screen removes larger dust particles [21].

The test room houses the olfactometer and a wooden stool used as a seat by the panelists during an odour evaluation. Precautions were taken in the design of the test room to maintain an atmosphere free from distractions or outside noise [21].

B. Panelist Selection and Training

Panel selection and the need for training procedures depend upon the tasks that a sensory panel is asked to perform. A panel to be used for making discriminating measurements such as measuring the quality and intensity characteristics of odours would be selected on a different basis than a panel used to measure annoyance or the threshold response of the general population [13].

While odour intensity and threshold measurements require only a few trained experts, the evaluation of the impact that an odour would have on a community requires a panel representative of the entire population. Also, since no discriminating selection of panelists is to be performed, a large number of panelists is necessary to achieve reproducible odour evaluations. Consequently, in this study a large number of panelists was used to create each odour impact model. The number of panelists varied between 22 and 28 for each model. Five panels of ten members each were formed from the group participating in each test to allow a statistical comparison between smaller panels. In addition, panelists were chosen from different age groups representing both sexes to produce panels that are truly representative of the population. This variety also provided enough data to compare the sensitivities of panelists who differ in terms of age, sex, and the presence or lack of odour in their working environment. A list of panelists and the data pertinent to this investigation about each individual is included in Appendix III.

For tests involving the determination of odour thresholds and odour character from which the population response is to be estimated, the only training needed is how to proceed with smelling and responding to the specific odour [14].

C. Experimental Procedure

Each chemical odourant was examined over a period of one day. During this time five panels of 10 people were subjected to the odour under investigation. Each panelist evaluated an odourant an average of two times during the testing period but not more than three times.

Two of the chemicals were tested using seven 10-member panels. These panels functioned on two different days with five panels the first day and two panels a week later. This testing protocol facilitated the comparison of panel responses between different testing sessions.

The evaluation of each chemical was preceeded by a preliminary test which did not require the use of a full sized panel.

1. Preliminary Test

The purpose of the preliminary test was to adjust the settings of the odour generator until an odour concentration was achieved which

- could be detected by 3 panelists (who have exhibited average sensitivity to odours in the past) consistently near the middle of the dilution levels available on the olfactometer.
- did not exceed the maximum short term exposure limits published in industrial hygiene guidelines [20].

The first objective was accomplished by beginning with a low odour concentration which was slowly increased until three panelists who were not overly sensitive or insensitive to most odours detected the odour consistently at, or near, the fourth dilution level. By centering the detection point near the middle of the dilution range available on the olfactometer it was possible to develop odour impact models which extended both below and above the average point of detection.

After all the appropriate settings of the odour generator had been determined (including rotameter readings, generator internal pressure, and gas and bath temperatures) the system was shut down by opening the bypass valve illustrated in Figure 4.1. This valve is used since it is the only one that provides an on/off capability. When the bypass valve is opened the generator stops producing an odour. Once this valve is reclosed all rotameter settings return to their original positions. This design makes it very easy to maintain consistent operating conditions between tests. After shut down of the odour generator is accomplished, the initial mass of the odourant tube and its contents is measured. In addition, the dial reading on the dry test gas meter is recorded. Following this, the valve is closed and the odour generator begins to operate at its previous setting.

Once the odour generator and all other equipment used during a normal testing session are operating they are allowed to function for a period of 30 to 45 minutes. During this time no panelists are required to evaluate the odour. This period is used to equilibrate the olfactometer tubing with the odourous gas stream. This is a necessary step in order to minimize adsorption of the odourant from the gas stream onto the tubing of the olfactometer during panel evaluation of the odour.

After this period was completed, the final mass of the odourant tube and contents was measured and the volume of air passed through the system was recorded from the dry test meter. Calculation of the odourant concentration was performed as described in Appendix I.

The expected odourant concentration in the stream coming from the olfactometer station with the lowest number of dilutions was determined for comparison with maximum short term exposure limits published in the most recent industrial hygiene guidelines [20]. While this comparison may appear to be an excessively cautious step due to the extremely small chemical doses given to the panelist during the testing period, it was found to be a great reassurance to all panelists, many of whom worried about the risks associated with their participation in the odour study. Despite verbal reassurances about the negligible risks associated with their exposure, the only satisfactory way to reduce their apprehensions was to present the panelists with actual measurements from the preliminary test and to compare them with short term exposure criteria.

If the calculated concentration were to exceed the published guidelines then the odourant concentration must be reduced and the preliminary test repeated. Fortunately, this situation did not arise during this investigation.

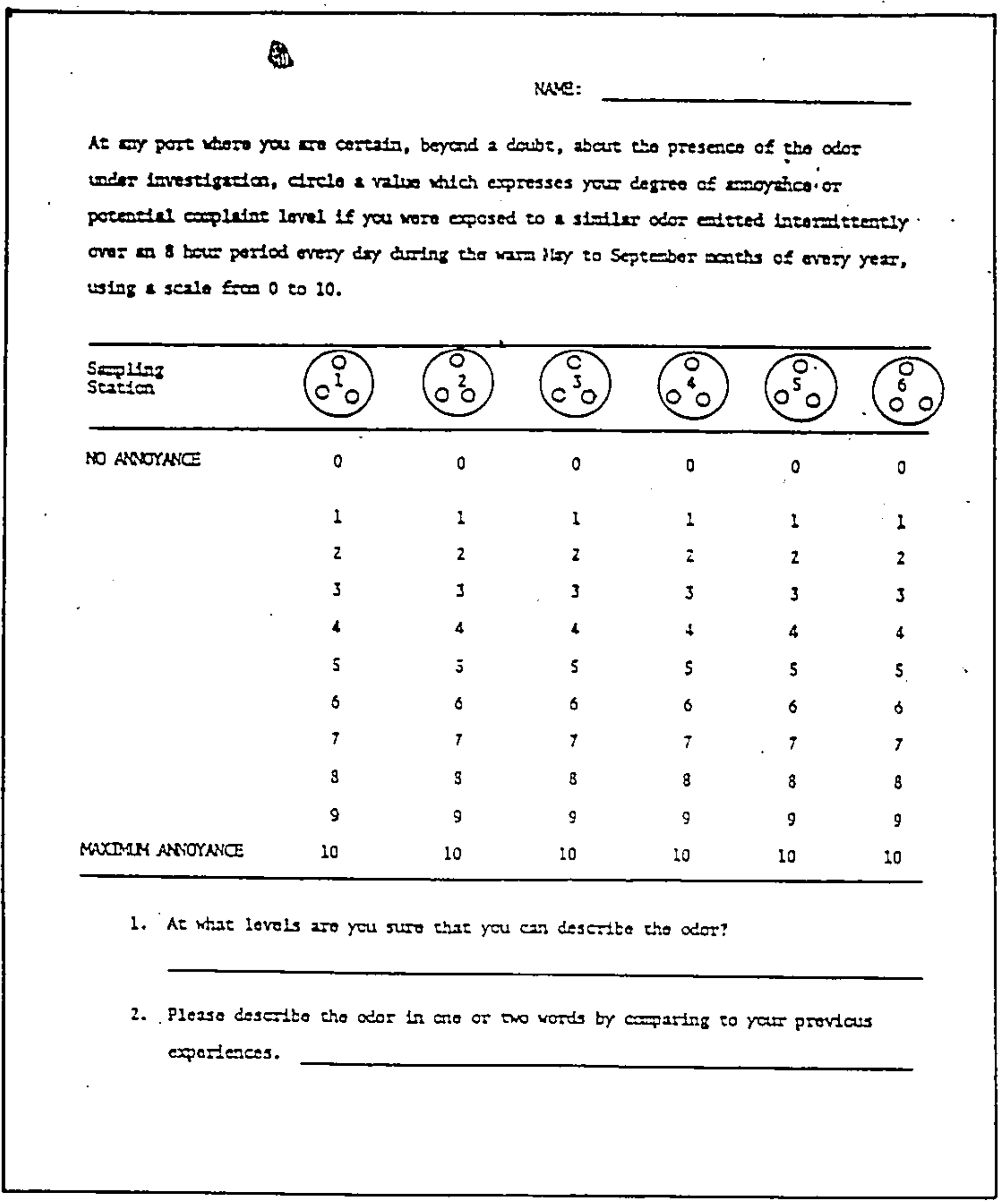
2. Panel Evaluation of the Odours

Inside the odour booth each panelist was provided with a form for recording the individually perceived complaint level associated with each dilution level. This form is illustrated in Figure 4.4. 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, located to the right and behind the panelist, between dilution levels especially when the panelist experienced a loss of sensitivity due to fatigue
- press the button corresponding to the port at which they could perceive the odour. If unable to detect the odour, the panelist was requested to make a guess (forced-choice olfactometry)
- identify the dilution level at which they are sure, beyond any doubt, about the presence of the odour
- identify, using the preprinted form, the dilutions at which they would complain if they were exposed to similar odourous stimuli for an average period of eight hours and rate their degree of annoyance at each level on a scale of 0 to 10 [15].

The panelists' selections of the ports at which they perceived the odour were recorded from the signal box responses on a panel record sheet shown in Figure 4.5. The operating parameters associated with each test were recorded on a Test Data Sheet form illustrated in Figure 4.6.

The information contained on these forms provide all the data necessary to evaluate the percent probabilities of detection, discrimination, and complaint as well as the degree of annoyance as functions of odourant concentration. The methods used to reduce this raw data to the odour impact model are described in Appendix IV.



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.

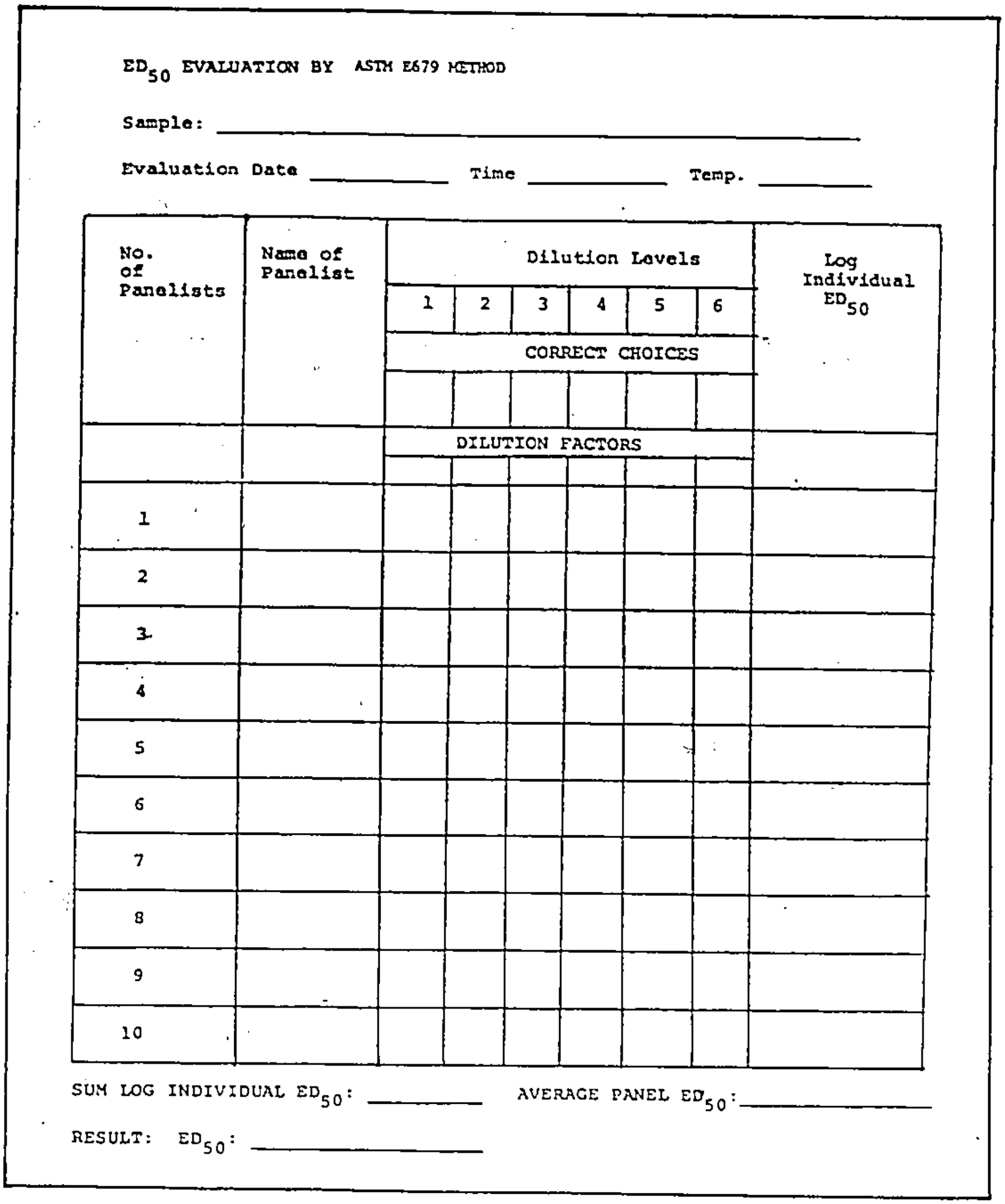
Sampling Station	1	2	3	4	5	6
NO ANNOYANCE	0	0	0	0	0	0
	1	1	1	1	1	1
	2	2	2	2	2	2
	3	3	3	3	3	3
	4	4	4	4	4	4
	5	5	5	5	5	5
	6	6	6	6	6	6
	7	7	7	7	7	7
	8	8	8	8	8	8
	9	9	9	9	9	9
MAXIMUM ANNOYANCE	10	10	10	10	10	10

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 4.4: Panelist Response Sheet.



ED_{50} EVALUATION BY ASTM E679 METHOD

Sample: ______________________

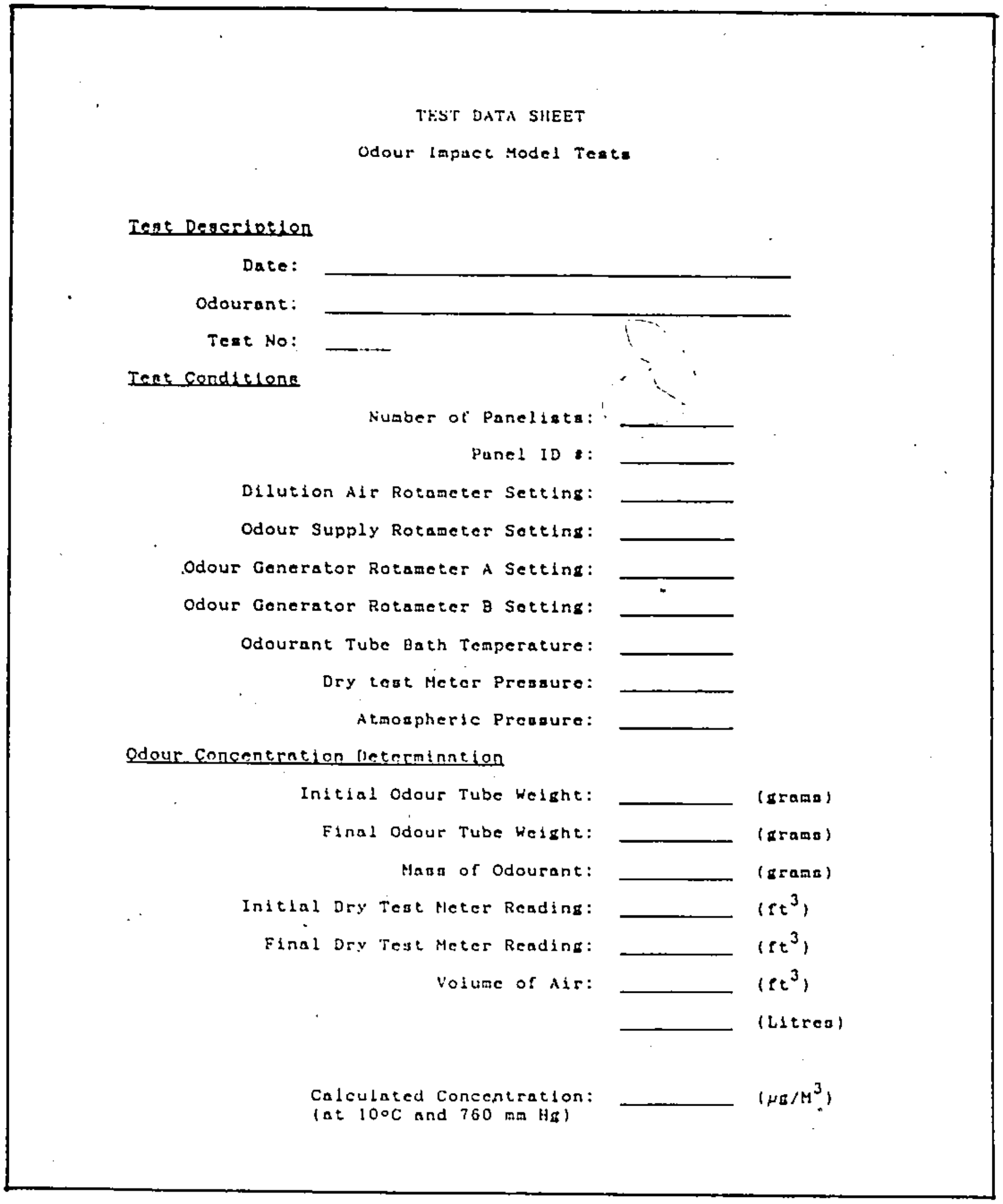
Evaluation Date __________ Time __________ Temp. __________

No. of Panelists	Name of Panelist	Dilution Levels						Log Individual ED_{50}
		1	2	3	4	5	6	
		CORRECT CHOICES						
		DILUTION FACTORS						
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

SUM LOG INDIVIDUAL ED_{50}: __________ AVERAGE PANEL ED_{50}: __________

RESULT: ED_{50}: __________

FIGURE 4.5: Panel Record Sheet.



TEST DATA SHEET

Odour Impact Model Tests

Test Description

Date: ______________________

Odourant: ______________________

Test No: ____

Test Conditions

Number of Panelists: ________

Panel ID #: ________

Dilution Air Rotameter Setting: ________

Odour Supply Rotameter Setting: ________

Odour Generator Rotameter A Setting: ________

Odour Generator Rotameter B Setting: ________

Odourant Tube Bath Temperature: ________

Dry test Meter Pressure: ________

Atmospheric Pressure: ________

Odour Concentration Determination

Initial Odour Tube Weight: ________ (grams)

Final Odour Tube Weight: ________ (grams)

Mass of Odourant: ________ (grams)

Initial Dry Test Meter Reading: ________ (ft^3)

Final Dry Test Meter Reading: ________ (ft^3)

Volume of Air: ________ (ft^3)

________ (Litres)

Calculated Concentration: ________ ($\mu g/M^3$)
(at 10°C and 760 mm Hg)

FIGURE 4.6: Test Data Sheet.

V. RESULTS AND DISCUSSION

Odour impact models (OIM's) have been developed for the six chemicals listed in Table 5.1. The data for each of the tests were analyzed to identify parameters which are important in the OIM development process.

For convenience, the names of each of the six chemicals will be shortened to the designations shown in Table 5.1.

TABLE 5.1: Chemical Odourants Investigated.

No.	Chemical Name	Designation
1	n-Butyl Acetate	Acetate
2	Propylene Glycol Monomethyl Ether	Glycol
3	Methyl Isoamylketone (5-Methyl-2-Hexanone)	Hexanone
4	Isobutanol	Isobutanol
5	n-Butanol	Butanol
6	Octane	Octane

The six odour impact models were developed using five panels consisting of 10 members each. The overall OIM for each odourant is developed by combining each of the five panels into one large panel consisting of 50 responses. Note that these responses come from between 22 and 28 panelists; since, each panelist evaluated the odour more than once. The final odour impact models for the six chemicals under investigation are illustrated in Figures 5.1

through 5.6. Although only six dilution levels were examined by each panel, Figures 5.1 to 5.6 show twelve points corresponding to each curve of an OIM. This difference is the result of the data from each of the five panels being interpolated at 12 points to produce a smoother curve.

A. Verification of the Olfactometer Calibration Technique

The dilution factor at each of the olfactometer stations must be established if the responses of an odour panel are to be expressed on a quantitative basis. The factors can be evaluated by measuring the odour and dilution air flowrates delivered to each port or by measuring the concentration of a known odourant at each port and comparing them with the original odour sample concentration.

The dilution factors determined at each port using the volumetric calibration technique are calculated from

$$Z_i = \frac{Q_{a,i} + Q_{o,i}}{Q_{o,i}}$$

where Z_i = the dilution factor at dilution level "i"

$Q_{a,i}$ = the dilution air flowrate at level "i" (mL/min)

$Q_{o,i}$ = the odour flowrate at level "i" (mL/min)

If the concentration based calibration technique is used then the dilution factor at each port is calculated according to

$$Z_i = \frac{C_o}{C_i}$$

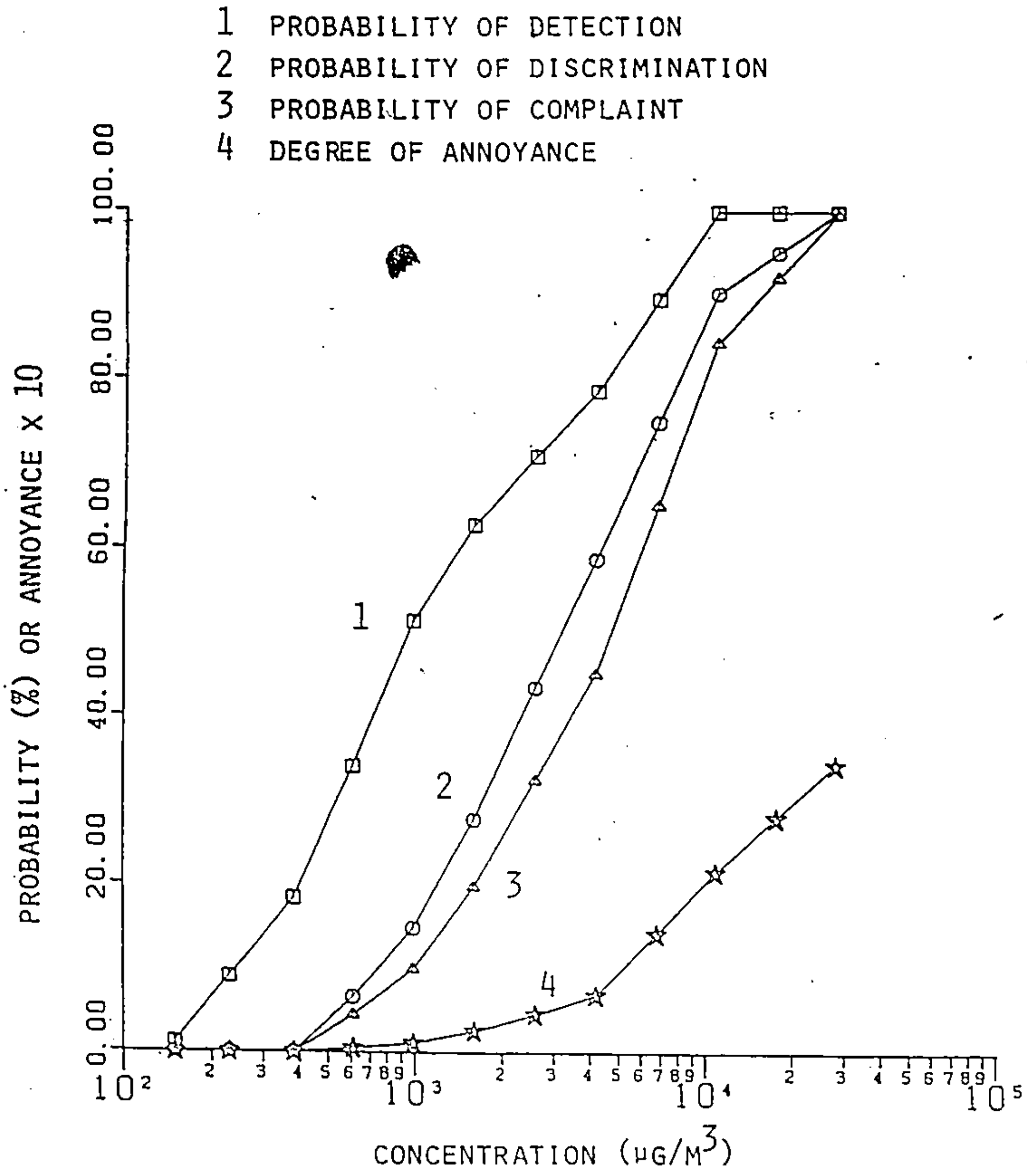


FIGURE 5.1: Odour Impact Model for n-Butyl Acetate.

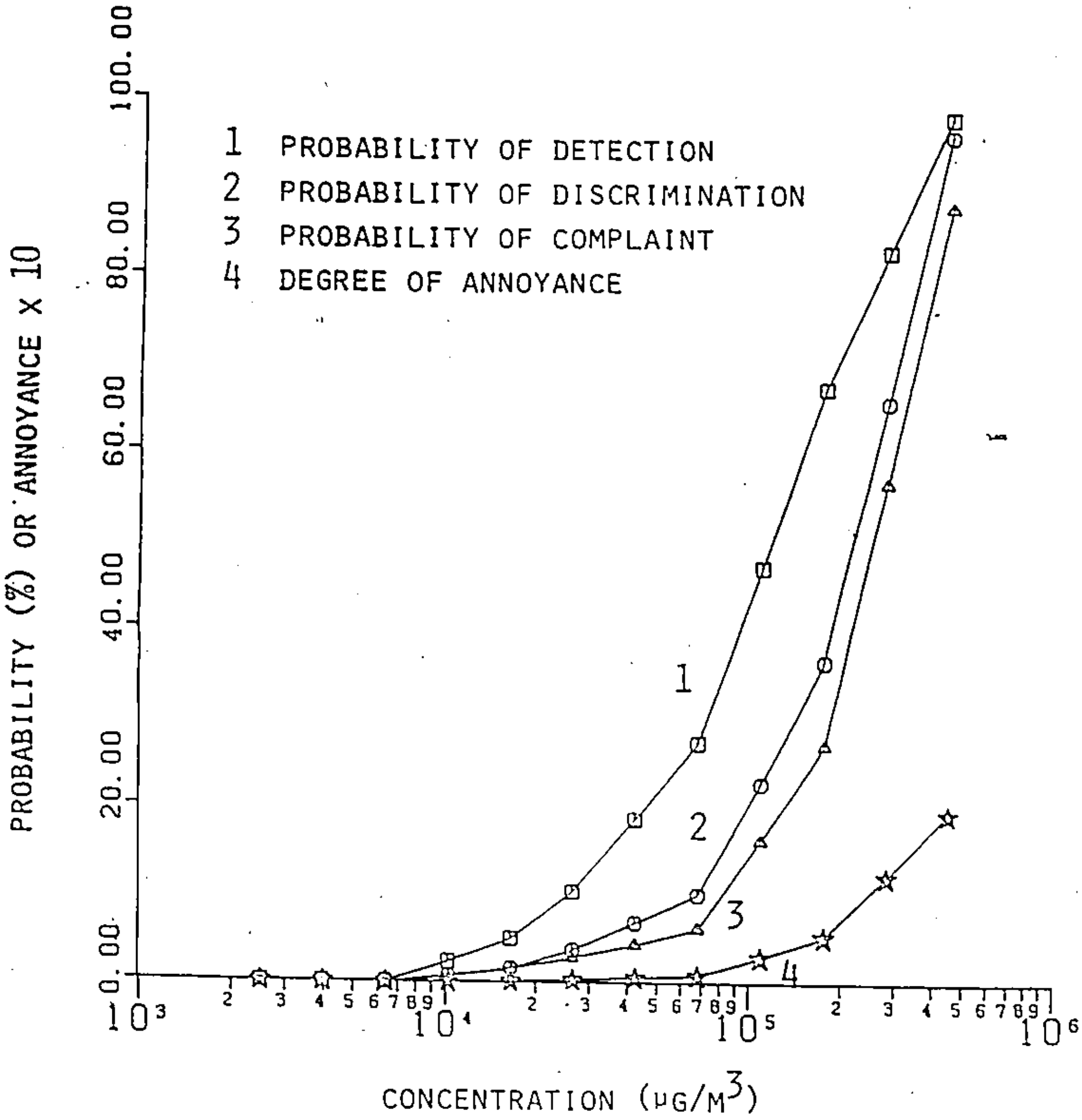


FIGURE 5.2: Odour Impact Model for Propylene Glycol Monomethyl Ether.

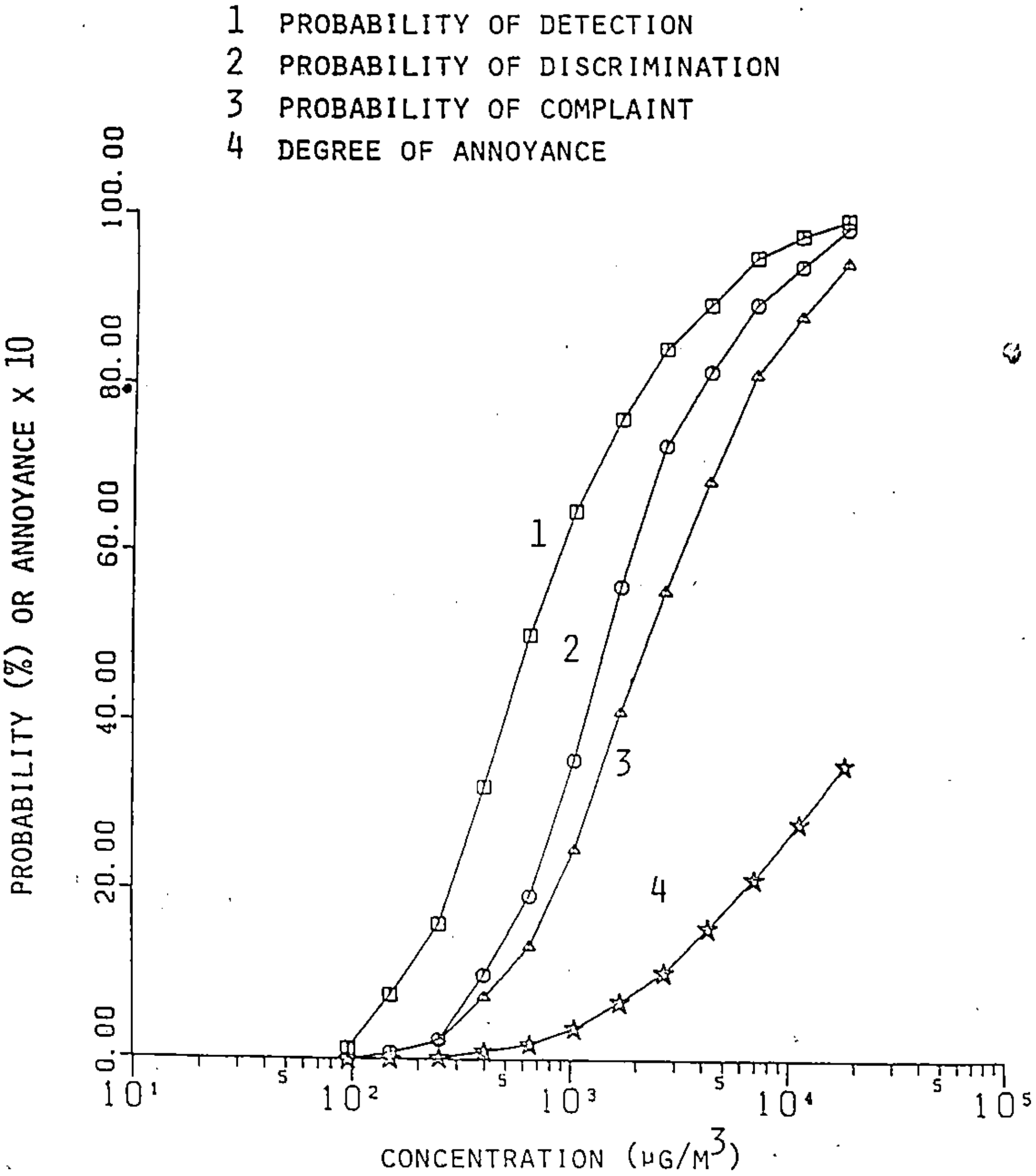


FIGURE 5.3: Odour Impact Model for Methyl Isoamylketone.

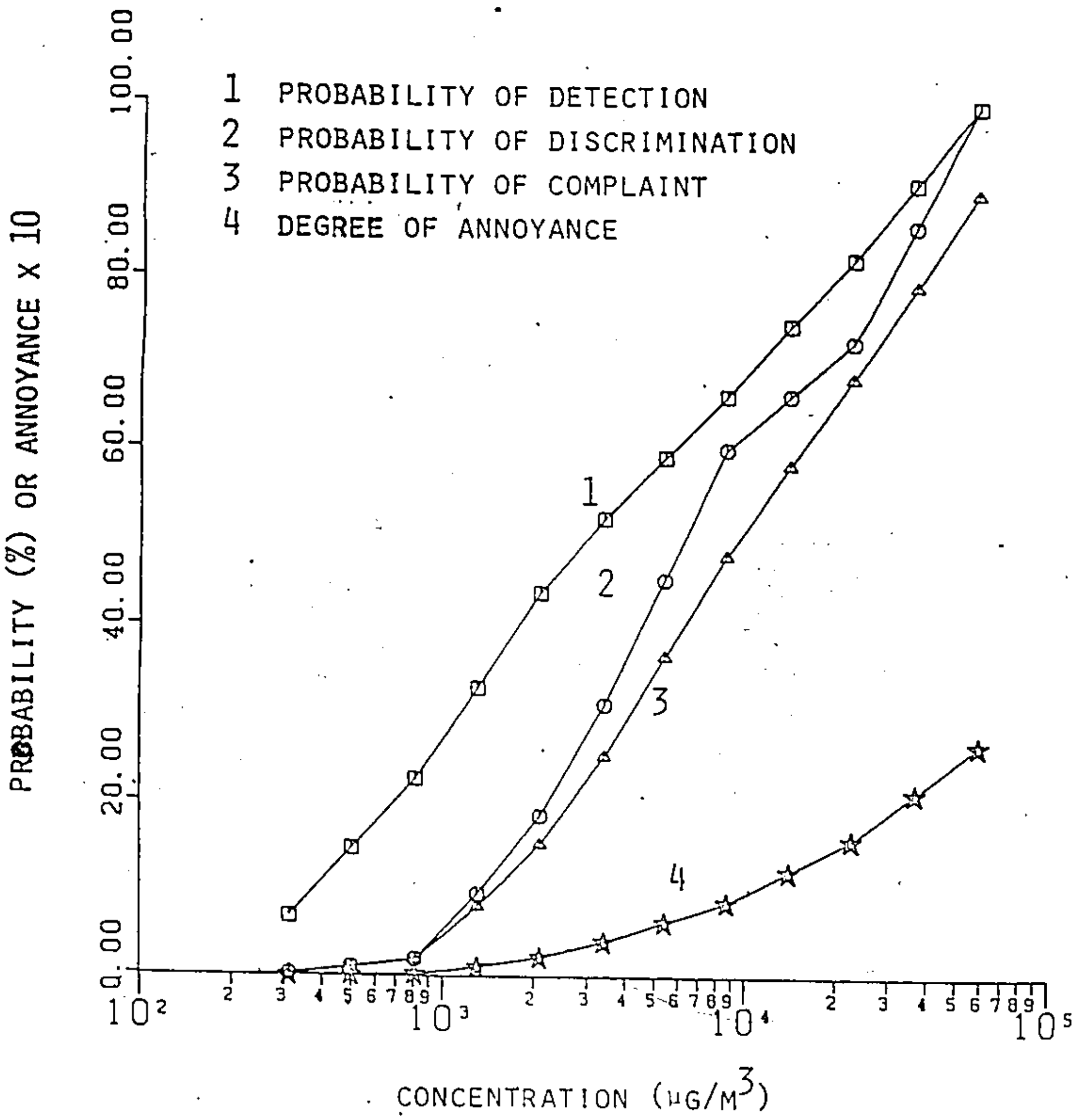


FIGURE 5.4: Odour Impact Model for Isobutanol.

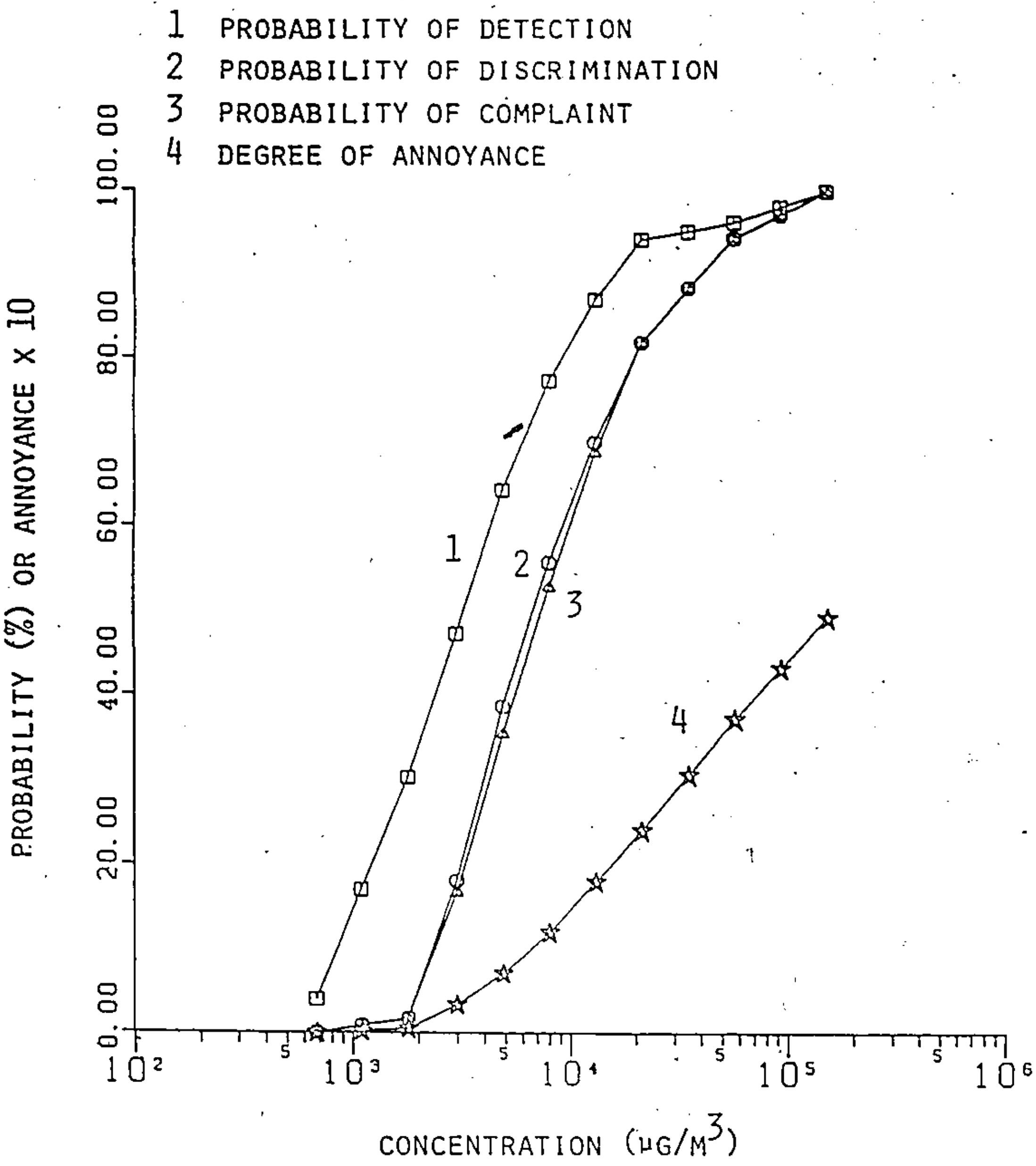


FIGURE 5.5: Odour Impact Model for n-Butanol.

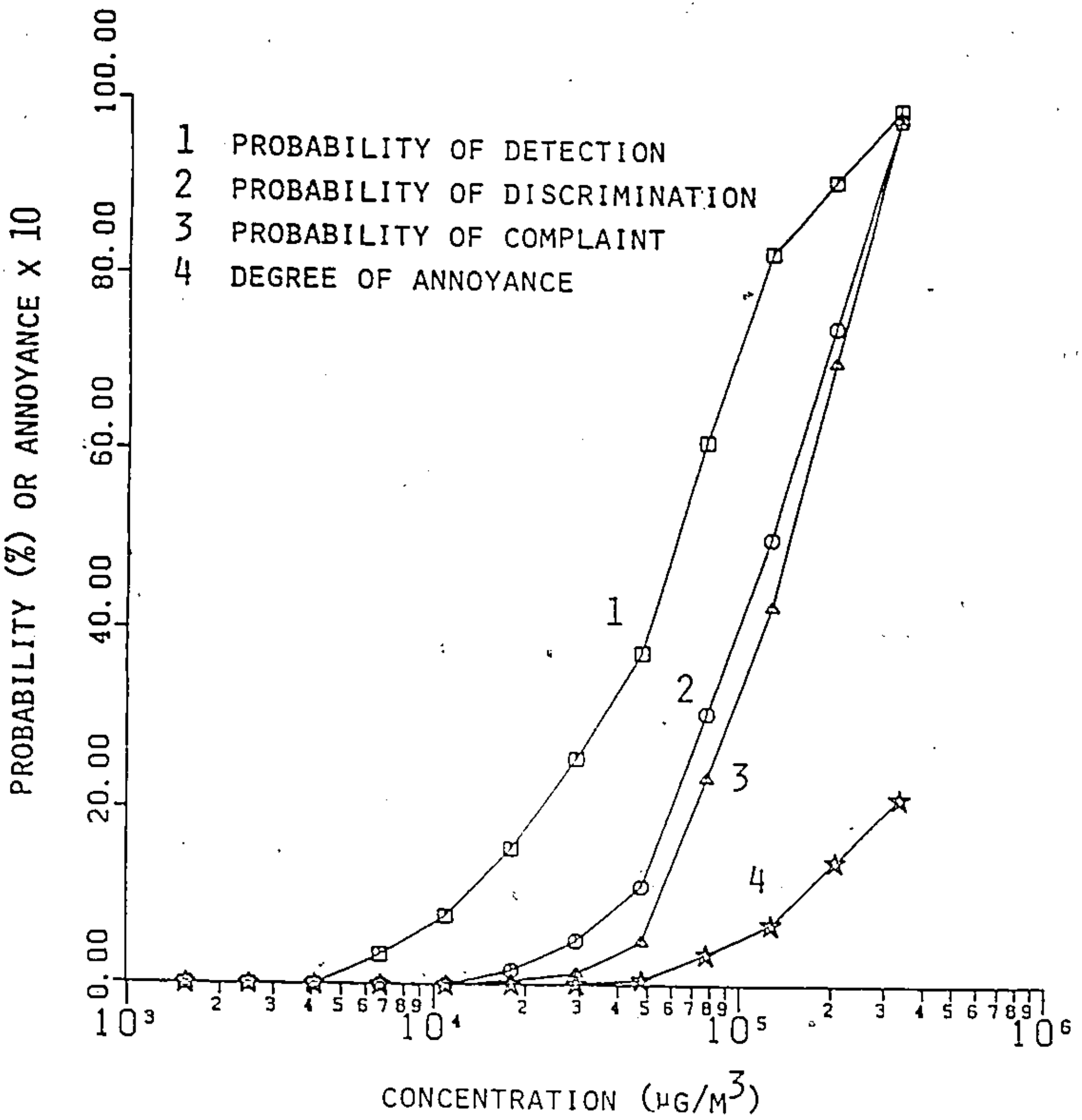


FIGURE 5.6: Odour Impact Model for Octane.

where Z_i = the dilution factor at dilution level "i"

C_o = the odour supply concentration

C_i = the odourant concentration at level "i"

The volumetric technique is normally used to calibrate the olfactometer since it is very quick and requires no complicated or expensive instrumentation. The concentration technique is not as simple since it requires a sample collection apparatus and an instrument which is capable of accurately measuring a large range of chemical concentrations.

In past work involving the IITRI olfactometer, it has been assumed that the volumetric technique provides accurate measures of the dilution factors at each olfactometer station. However, this assumption had never been verified Therefore, before odour impact models for specific chemicals could be developed with confidence, it was necessary to confirm the results of the volumetric calibration procedure using a concentration based technique.

An odourous gas stream of n-butanol in air was generated and introduced into the olfactometer. The concentration of the odour supply and of the diluted streams emitted from the olfactometer ports were measured using an Organic Vapour Analyzer (OVA). These values were then used to determine the dilution factor corresponding to each olfactometer station. During the same testing period, the volumetric flowrates of dilution air and odourous sample at each station were also measured and used to determine the dilution factors.

A comparison of the two techniques demonstrated that the methods produced results which differed by less than 3%. The good correlation between the two calibration techniques indicates that the volumetric calibration procedure produces accurate measures of the dilution factors at each of the olfactometer ports.

The experimental procedure and the results are presented in detail in Appendix II.

B. Panelist Characteristics

The effect of sex, age and odourous working conditions on the panelists' abilities to detect odours were examined. Each panelist was requested to complete a questionnaire which asked the sex and age of the panelist and whether or not the individual worked under odourous or non-odourous conditions.

1. Sex

The detection thresholds of male and female panelists between 18 and 27 years of age were calculated for the six chemicals. Subsequently, the average value for these male and female panelists, grouped separately, were determined and compared using the Student's t-Test for the comparison of two means [9]. This test had to be performed in terms of the average logarithm of the detection threshold instead of the actual threshold value because the detection thresholds are log-normally distributed [5]. The results of the calculations are shown in Table 5.2.

When the calculated values of the t-statistic are

TABLE 5.2: Comparison of the Mean Detection Thresholds of Male and Female Panelists.

Odour No.	Logarithms of Thresholds				t	df
	Male		Female			
	Mean	σ	Mean	σ		
1	0.000	0.226	0.130	0.348	0.691	40
2	2.052	0.137	2.070	0.287	0.111	40
3	-.189	0.263	0.070	0.267	1.133	37
4	0.395	0.336	0.451	1.020	0.199	38
5	0.533	0.170	0.548	0.475	0.089	44
6	1.617	0.220	1.812	0.024	1.216	36

df = no. of degrees of freedom   t = t-statistic
σ = standard deviation

compared to the tabulated values [15] at the 5% level of significance, the results demonstrate that there is no significant difference between the male and female panelists between 18 and 27 years of age.

An additional comparison was performed using two panels to develop two odour impact models for each of three odourants; glycol, butanol, and octane. The first panel in each case consisted entirely of males and the second consisted of females; all being between 18 and 27 years of age. The results of these odour impact models were compared using the one-way Analysis of Variance (ANOVA) technique explained in Appendix V. The ANOVA test was applied at four evenly spaced concentration values along the degree of annoyance curve and at the average detection threshold (ED_{50}). The results are tabulated in Table 5.3.

TABLE 5.3: ANOVA Comparison of OIM's Generated by Male and Female Panelists.

Odourant	Calculated F-statistic at Point				
	1	2	3	4	ED_{50}
Glycol	0.871	0.042	0.110	0.514	0.319
Butanol	1.199	1.738	2.656	3.086	0.558
Octane	0.528	0.558	1.350	1.478	1.096

The critical value of F from statistical tables for the comparison of two groups with 10 members each is 4.41 at the 5% level of significance. This value is not exceeded at any of the points of comparison along the DA curve nor at the detection threshold. Therefore, it can be concluded that there is no significant difference between male and female panelists between 18 and 27 years old.

A full distribution of ages representing both sexes was not available and, therefore, a complete comparison between the two genders could not be performed. However, the results for this age group suggest that differences in sex are not largely responsible for the differences in panelists' abilities to perceive odours.

2. Odourous Working Atmosphere

The detection thresholds of panelists between 18 and 27 years old who are employed under odourous or non-odourous working conditions were grouped separately and their averages were compared using the Student's t-test for significant differences. The results of this comparison are shown in Table 5.4.

The values of the t-statistic do not exceed critical values tabulated in the literature [9] for the 5% level of significance. Therefore, people between 18 and 27 years of age who claim to be employed in odourous working conditions do not exhibit any significant differences in their ability to detect odours.

TABLE 5.4: The Effect of Odourous and Non-Odourous Working Conditions on Detection Thresholds.

Odour No.	Logarithms of Thresholds				t	df
	Odourous		Non-Odourous			
	Mean	σ	Mean	σ		
1	0.024	0.223	-.149	0.236	0.942	33
2	2.081	0.147	2.032	0.186	0.388	40
3	-.284	0.212	-.260	0.112	0.158	32
4	0.383	0.306	0.457	0.779	0.326	38
5	0.589	0.225	0.633	0.288	0.281	40
6	1.679	0.186	1.651	0.182	0.203	36

A full distribution of ages for both groups was not available and, therefore, insufficient data was generated to measure the effect of odourous and non-odourous working conditions for all people. However, the results of this experiment indicate that young people who are employed in an odourous atmosphere retain their ability to perceive odours as least as well as those who are not employed in odourous working conditions. Therefore, an odourous working atmosphere is not a major contributing factor to the differences in panelists' sensitivities to odours.

3. Age

The detection threshold (ED_{50}) of panelists over the age of 30 years and over the age of 50 years were grouped separately for comparison with the overall mean panel threshold. The results of these two tests are shown in Tables 5.5 and 5.6.

The value of t from statistical tables for 50 or more degrees of freedom is approximately 1.65 for a 5% level of significance, 1.96 for 2.5% significance, and 2.34 for 1% significance [9]. The values in Table 5.5 reveal that in many cases the threshold of the over 30 age group is significantly different from the mean panel threshold. The over 50 age group exhibits the same characteristics. Therefore, the age of the panelist is an important factor in the odour evaluation procedure.

There were not enough panelists available to make a

TABLE 5.5: Comparison of Panelists over the Age of 30 with the Overall Group.

Odour No.	Logarithms of Thresholds				t	df
	Group		Older than 30			
	Mean	σ	Mean	σ		
1	0.068	0.258	0.278	0.295	1.027	56
2	2.027	0.164	1.892	0.164	0.926	58
3	-.119	0.252	0.168	0.297	1.855	62
4	0.528	0.519	1.022	0.610	1.951	58
5	0.549	0.257	0.620	0.058	0.470	52
6	1.739	0.172	2.006	0.086	2.179	61

TABLE 5.6: Comparison of Panelists over the Age of 50 with the Overall Group.

Odour No.	Logarithms of Thresholds				t	df
	Group		Older than 50			
	Mean	σ	Mean	σ		
1	0.068	0.258	0.258	0.411	0.842	54
2	2.027	0.164	2.140	0.036	0.611	54
3	-.119	0.252	0.209	0.376	1.577	55
4	0.528	0.519	1.247	0.261	2.541	55
5	0.549	0.257	0.790	0.115	0.663	50
6	1.739	0.172	2.037	0.056	1.972	56

full statistical analysis of the range of ages between 18 and 63. However, if the thresholds for age groups are normalized with respect to the group average threshold, it can be seen that as age increases there is a trend demonstrating a loss of olfactory sensitivity. This trend is demonstrated in Table 5.7.

TABLE 5.7: Normalized Age Group Detection Thresholds (ED_{50} expressed in concentration units)

Age (years)	Normalized Threshold (ED_{50})
All (18-63)	1.00
30-39	1.33
40-49	2.19
50+	2.31

Since age appears to be an important parameter in the sensory evaluation of odours, all odour panels should be composed of people of a variety of ages to reflect the sensitivity and response of the general population to an odour stimulus.

C. Panel Size

The human nose is the ultimate judge of the sensory characteristics of an odour. However, the responses of odour judges, even those that are highy trained, are extremely variable. This means that more than one panelist is required to obtain reliable odour data [21].

The objective of the odour impact model is to determine the relationships between odour levels and annoyance thresholds in the community [11]. Any evaluation of community odour nuisance would require a panel representative of the entire population. In a random selection of panelists, the panel reflects the distribution of sensitivities of the population. Panelists chosen for their closely similar sensitivities provide more reproducible values but do not give an insight into the population response [16]. Therefore, the panelists used in the development of an odour impact model should be randomly picked in order to adequately represent the population. This means that a high range of variability is to be expected in the model results. For this reason, experiments are required to determine the optimum number of panelists needed to produce results that are acceptable in terms of their reproducibility and their measurement costs.

It has been shown that the age of the panelist is an important factor in the selection of odour judges. A large random selection of panelists from the population would reflect the distribution of ages in the population. However, since the panel sizes used in this study were not large enough to achieve an adequate age distribution, this distribution had to be forced onto the panels. That is, every panel of 10 members were required to have between 2 and 3 panelists who were over the age of 30. Panelists below the age of 18 could not be used since they are considered to be minors under the laws of Ontario.

Each odour impact model was developed from five panels consisting of 10 members each. Individual panelists were usually members of more than one panel but never more than three. Ten panel members was considered to be a minimum number of panelists for an odour evaluation because past work has revealed that this number is required to produce consistent and reproducible odour threshold measurements [14,21]. The odour impact models developed from each 10-member panel are shown in the Appendices corresponding to each odourant.

An analysis of variance statistical test was performed for each odourant to compare the results of the 10-member panels. This test was performed at six equally spaced points along the degree of annoyance curve and at the mean detection threshold (ED_{50}) for each panel. The calculated F-ratio for the test points corresponding to each odourant are shown in Table 5.8. This table also includes the value of "g" calculated for Cochran's Test for the Homogeneity of Variances. This test may be used to increase the confidence about conclusions reached from the ANOVA test. Explanations of these tests are contained in Appendix V.

The critical value of the F-ratio from statistical tables for 45 degrees of freedom between panelists and 4 degrees of freedom between panels is 2.57 at the 5% level of significance. Since none of the calculated values of F exceed the table value the conclusion can be made that there is no significant difference among the 10-member panels and that each panel derives from the same population. The latter conclusion is critical in odour evaluations since it is necessary to produce odour impact

TABLE 5.8: ANOVA and Cochran Test Results for 10-Member Panels.

Odourant	Test	Comparison Point						
		1	2	3	4	5	6	ED_{50}
Acetate	F	2.4	1.9	1.4	0.7	0.6	0.1	0.2
	g	0.8	0.7	0.3	0.3	0.3	0.3	0.3
Glycol	F	0.8	0.6	0.9	1.5	1.6	1.2	0.3
	g	0.9	0.5	0.6	0.4	0.4	0.4	0.3
Hexanone	F	1.0	1.4	1.7	1.4	1.3	1.5	0.8
	g	0.7	0.8	0.5	0.5	0.5	0.4	0.3
Isobutanol	F	0.8	0.7	1.0	0.9	1.4	1.4	0.5
	g	0.9	0.4	0.3	0.3	0.3	0.3	0.3
Butanol	F	1.0	1.0	1.0	0.9	0.8	1.0	1.3
	g	0.0	1.0	0.4	0.3	0.3	0.3	0.4
Octane	F	2.3	1.9	1.7	1.1	0.3	0.1	0.8
	g	0.8	0.4	0.3	0.3	0.3	0.3	0.3

$F_{.05}(45,4) = 2.57$ $g_{.05}(10,6) = 0.3682$

models which represent the response of the overall population.

The results of the ANOVA test do not prove, however, that the 10-member panels produce the same set of curves. Rather, the test results indicate that the individual panels produce essentially the same variability in their responses and that these variations overlap each other around some common value. In general, there are three possible conclusions which can be made from an ANOVA test:

(1) If the calculated value of F exceeds the critical value then there is a significant difference between groups.

(2) If the calculated value of F is less than 1.0 and if the value of g is less than its critical value, then the means of the compared groups are essentially the same.

(3) If the calculated value of F is greater than 1.0 but less than the critical value then no valid conclusion may be drawn about the equality of the means.

Before a conclusion may be made about the optimum panel size for an odour evaluation, consideration must be given to the intended use of the OIM.

1. Measuring the Impact of an Odour on the Community

The results presented in Table 5.8 indicate that the 10 member panels produce no significantly different results at the 5% level of significance. Despite this, it is apparent that many of the calculated values of the F-ratio are between 1.0 and the critical value. This would leave some doubt about the 10-member panel being a true representation of the general population even though it shows close to the same variations as other 10-member panels. This result leads to the conclusion that a single panel of this size would not provide a satisfactory measure of the impact of an odour on the community.

In any analytical measurement, a certain minimum degree of accuracy must be achieved. In the case of the Odour Impact

Model it is not easy to achieve a high degree of accuracy without using an unrealistically large number of panelists. Usually, a compromise must be made between the required minimum degree of accuracy and a practical number of panelists.

The accuracy of a series of measurements may be judged by the confidence limits associated with the measurements. These confidence limits are determined using

$$C_L = \bar{X} - t_\alpha \cdot \frac{\sigma}{n^{1/2}}$$

$$C_U = \bar{X} + t_\alpha \cdot \frac{\sigma}{n^{1/2}}$$

where C_L = the lower confidence limit

C_U = the upper confidence limit

$\bar{X}$ = the mean value of the measured variable

[illegible] = the standard deviation of the measured variable

n = the number of measurements of the variable

t_α = the Student's t-value at n-1 degrees of freedom and a confidence level of $1-\alpha$

As the number of measurements increase, the upper and lower values of the confidence limits converge toward each other. This produces a smaller confidence interval associated with the mean. The smaller a confidence interval must be, the greater the number of measurements required.

If a single panel of 10-members evaluates an odour, confidence limits may be determined for the degree of annoyance at any dilution and the average panelist threshold (ED_{50}). Confidence limits may only be calculated for these points since they are the only measurements in the Odour Impact Model which depend on the single panelist. Limits cannot be determined for any points along the probability of detection, discrimination, or complaint curves because these curves are not dependant on the individual panelist but on the panel as a whole. For example, the dilutions at which 75% of the panelists complain about the odour cannot be assigned confidence limits from a single panel since each panelist does not provide a measure of this value. On the other hand, each panelist has his own detection threshold and a degree of annoyance at all dilutions of an odour; therefore, it is possible to calculate a confidence interval for these values based on the mean and the variations of the values between panelists.

In order to determine confidence limits for the probability of detection, discrimination, and complaint curves it is necessary to evaluate the odour using more than one panel. The more panels that are used, the smaller the range of confidence will become.

Therefore, when measuring the impact of an odour on the community it is necessary to

- use panel sizes of no less than ten members, with at least 2 panelists over the age of 30, so that the panel exhibits the same variations as the overall population.
- perform multiple panel evaluations of the odour to permit the calculation of confidence limits. The number of

panels that are required depends on the maximum acceptable size of the confidence limits associated with the odour impact model curves.

2. Generating a Standard OIM for a Chemical

Normally the odour impact model describes community reaction to an odour as a function of the dilutions of the odour from the odour source. An alternative use is to create standard reference odour impact models which reflect the attitude of the general population as a function of odourant concentration. These curves may then be used to set guidelines for maximum concentrations of odourous chemicals in ambient air based on the annoyance potential of the odourant. For certain chemicals guidelines such as these are necessary even though the chemicals do not cause any immediately obvious health problems. For example, it is possible for an odourant to be present in a working atmosphere at a concentration which is not considered to adversely effect the health of the worker but it may still be detected by the sense of smell. If the exposed person finds this odour to be offensive it may have an effect which is not as readily obvious as symptoms of most work related diseases. Research has shown that prolonged exposure to annoying odours can generate undesireable reactions in people which may include unease, discomfort, irritation, anger, depression, headaches, nausea and vomitting [15]. To avoid these consequences of exposure to odours an odour impact model may be consulted to determine a concentration that is acceptable in terms of its annoyance potential.

The values in Table 5.8 indicate that while the 10-member panels do not demonstrate any significant difference between panels there are still large variations in the responses. This degree of variability is more obvious when the curves are placed on the same graph for comparison. For example, Figures 5.7, 5.8, 5.9 and 5.10 are the superimposed curves for the 10-member panels evaluating n-butanol over a range of concentrations.

It is immediately apparent that any values read from these curves would vary considerably. As an illustration, consider the calculations necessary to determine the degree of offensiveness of an odour. The degree of offensiveness is defined by

$$DO = (MDL \ @ \ 100 \ PC)(DA_{100})$$

where MDL @ 100 PC = the maximum dilution level at 100% probability of complaint.

DA_{100} = the predicted degree of annoyance at 100% probability of complaint.

DO = the degree of offensiveness

This calculation requires two values to be determined from the odour impact model curves. Unfortunately, the values corresponding to the 100% probability of complaint were not always available since the odours examined were not particularly offensive. In addition, the probabilities of complaint were measured as a function of concentration and not dilutions.

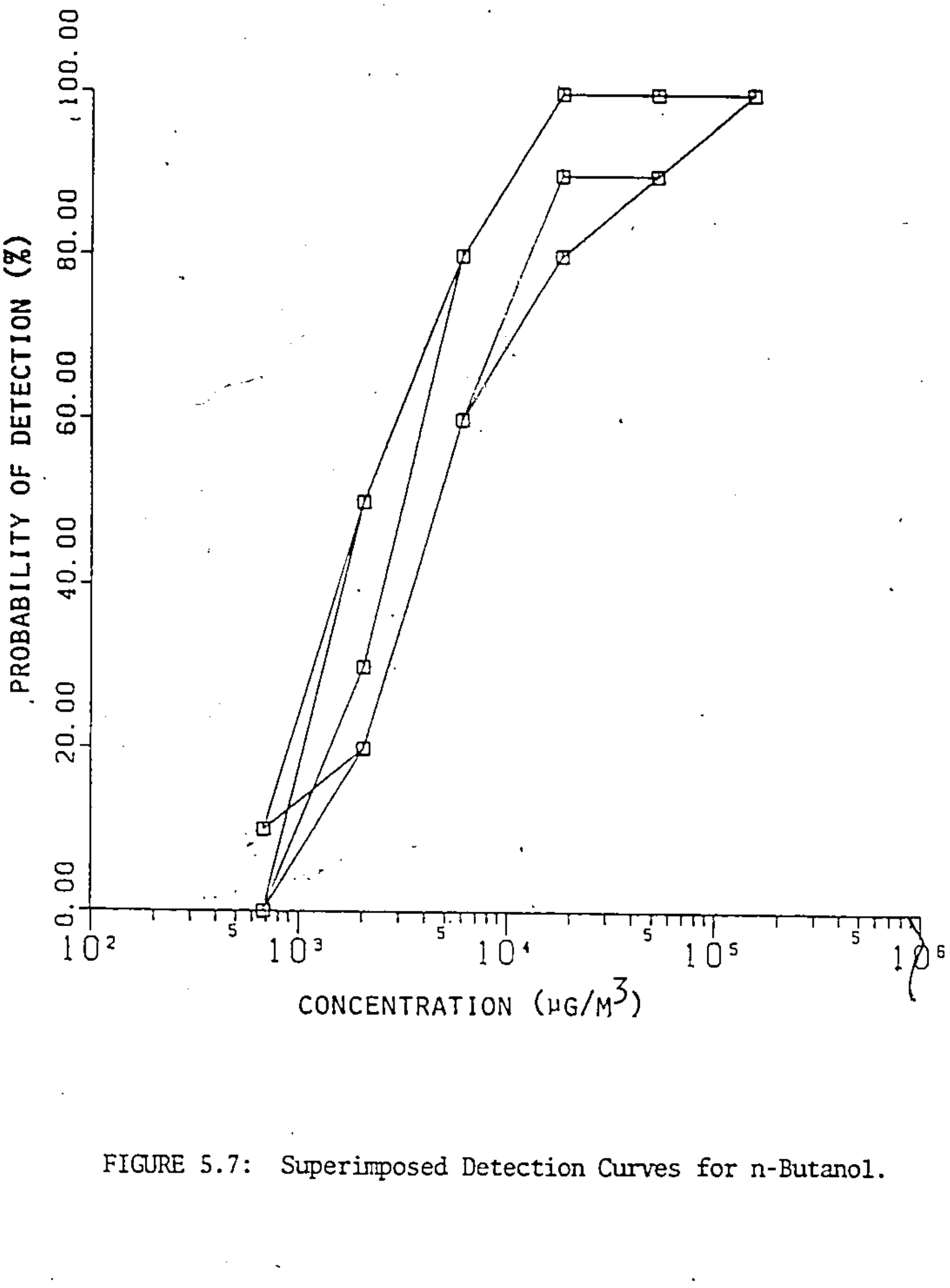


FIGURE 5.7: Superimposed Detection Curves for n-Butanol.

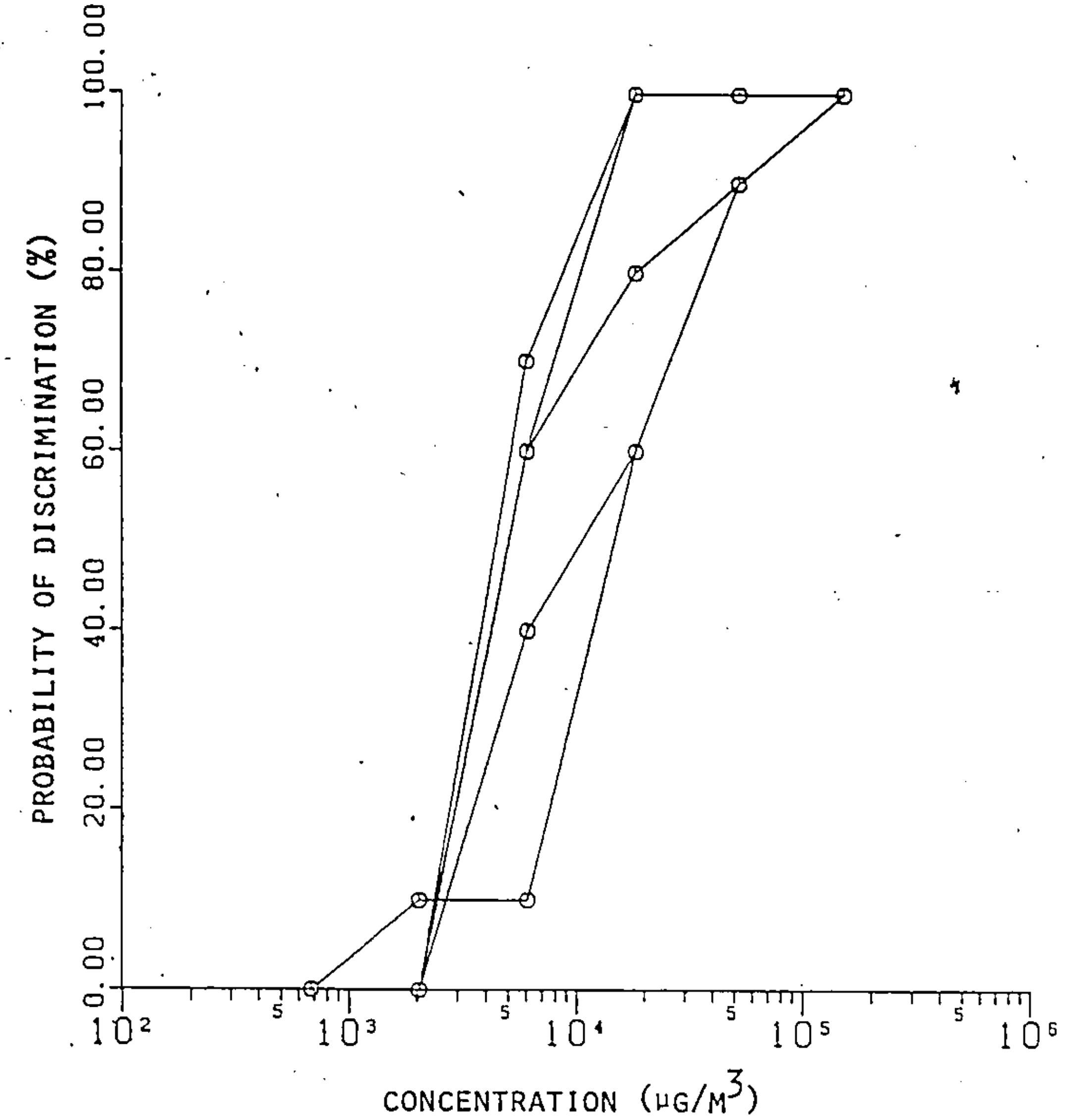


FIGURE 5.8: Superimposed Discrimination Curves for n-Butanol.

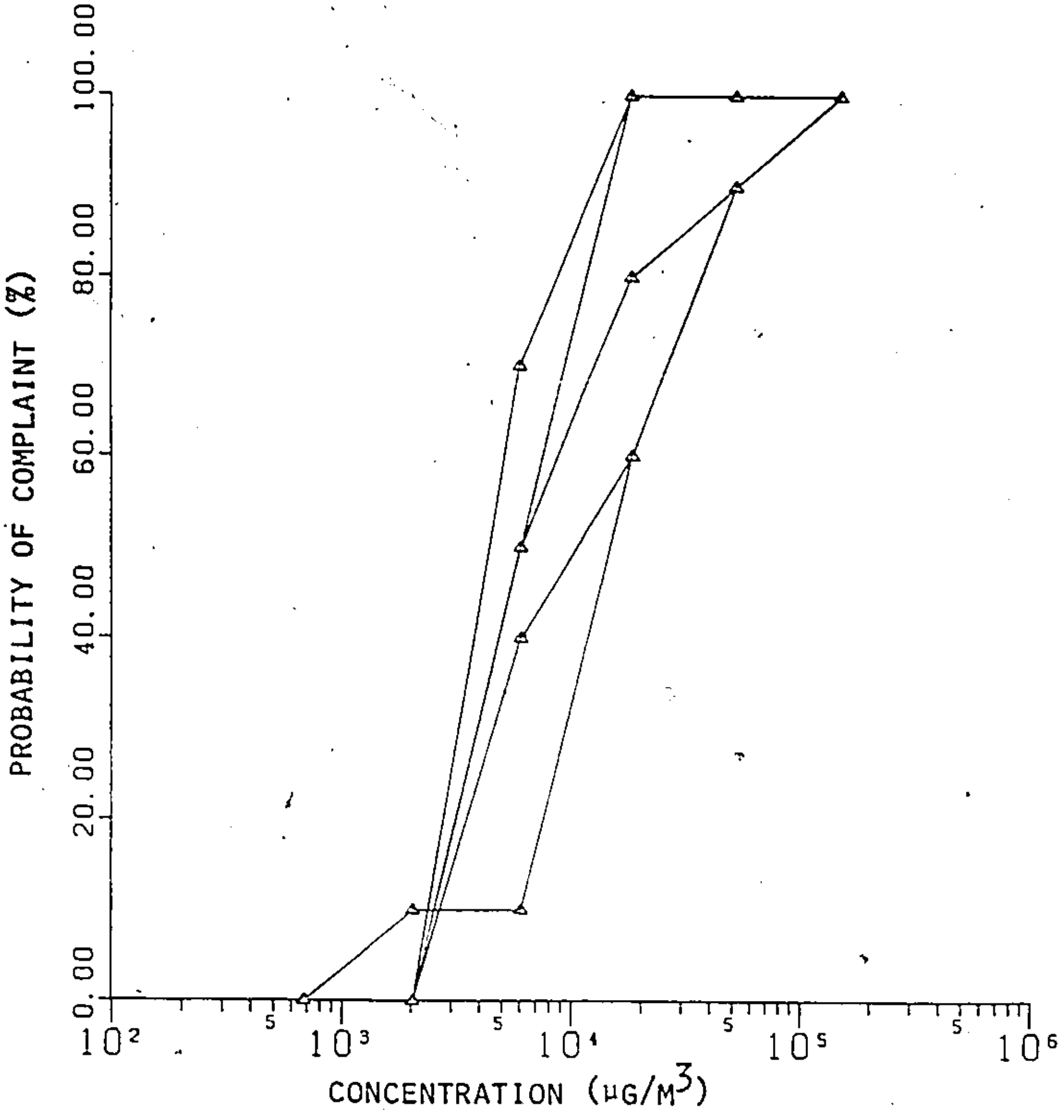


FIGURE 5.9: Superimposed Complaint Curves for n-Butanol.

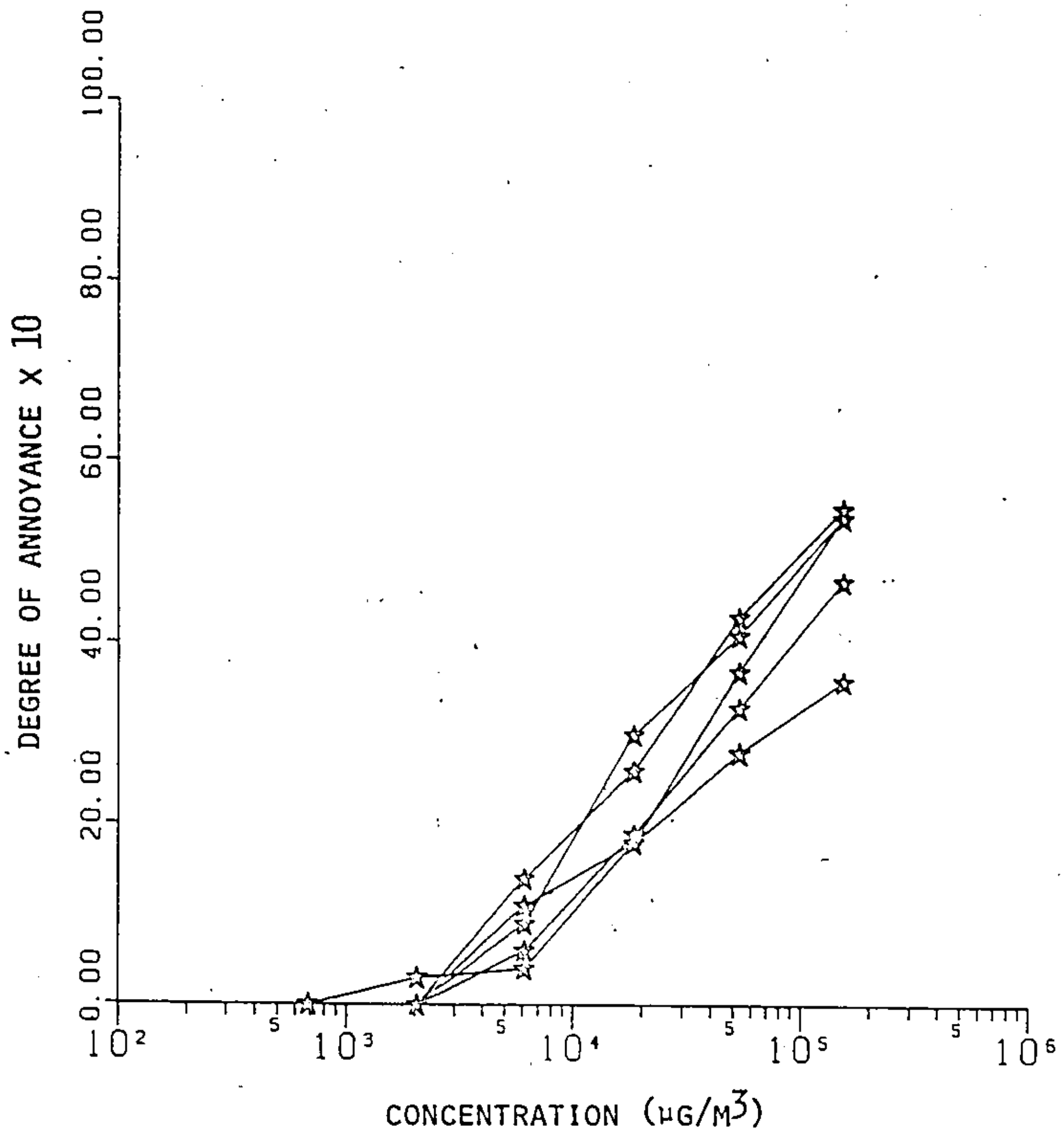


FIGURE 5.10: Superimposed Annoyance Curves for n-Butanol.

Therefore, another definition of the degree of offensiveness is required before the calculations may be carried out. One such definition which parallels the normally used definition of the degree of offensiveness is

$$\text{MDO} = \frac{\text{DA}_{50}}{\text{C @ 50 PDn}} \times 1 \times 10^{6}$$

where C @ 50 PDn = the concentration at 50% probability of discrimination ($\mu g/m^3$)

DA_{50} = the predicted degree of annoyance at 50% probability of discrimination

MDO = the modified degree of offensiveness.

This definition of the degree of offensiveness cannot be used in practice because it depends on the odourant. However, it can be used to show the variations which would be encountered in the evaluation of the degree of offensiveness according to the unmodified definition. MDO is a parallel definition to DO since it is of the same form and because concentration is inversely proportional to the dilution factor.

The values of the concentration at which 50% of the panelists discriminated the odour and the corresponding degree of annoyance were interpolated and recorded from each odour impact model. The standard deviation of these values were calculated and then expressed as a percentage of the mean. These values are presented in Table 5.9.

The standard deviation values in Table 5.9 vary between approximately 10 and 60 percent for the concentration values and

TABLE 5.9: Standard Deviations of Interpolated Data from 10-Member Panels.

Odourant	Standard % Error in C @ 50 PDn	Standard % Error in DA_{50}	Standard % Error in MDO
Acetate	42	10	50
Glycol	10	32	40
Hexanone	36	37	31
Isobutanol	39	29	26
Butanol	56	39	36
Octane	34	15	20

TABLE 5.10: High and Low Values of MDO from 10-Member Panels.

Odourant	Degree of Offensiveness (MDO)		
	Low Value	High Value	Ratio of High To Low Value
Acetate	120	352	2.9
Glycol	1.8	5.8	3.2
Hexanone	200	500	2.5
Isobutanol	32.	180	5.6
Butanol	100	220	2.2
Octane	4.7	7.8	1.7

between 10 and 40 percent for the degree of annoyance. In odour evaluations, large deviations are a commonplace occurrence, however, these deviations are excessive. If the high and low values of the calculated degree of offensiveness (MDO) are compared, it is immediately apparent that the 10-member panels do not provide consistent results. This may be seen in Table 5.10.

Therefore, a single 10-member panel is not large enough to reflect the annoyance potentials of the general population. However, since 10-member panels produce odour impact models which show the same variations in responses, it is possible to generate standard reference OIM's by evaluating the odour using a multiple number of panels. The number of 10-member panels required depends on the maximum acceptable size of the confidence limits associated with each of the OIM curves. The odour must be evaluated by independant panels until the confidence interval is reduced to an acceptable size. It is beyond the scope of this study to determine the optimum size of confidence intervals for standard reference odour impact model curves.

D. Variations in Thresholds Between 10-Member Panels

The panel detection threshold, C O 50 PD, and the panel discrimination threshold, C O 50 PDn, were interpolated from each odour impact model produced by the 10-member panels. The values corresponding to each odourant are presented in Table 5.11 through 5.16 with the computed values of the geometric mean and the standard deviation of the logarithm of the thresholds.

TABLE 5.11: Thresholds for n-Butyl Acetate

Panel No.	Threshold (mg/M^3)	
	Detection	Discrimination
1	1.21	4.0
2	1.21	5.0
3	0.96	4.0
4	0.91	1.7
5	0.77	2.1
Geometric Mean	1.00	3.1
Log(Mean)	0.00	0.49
Standard Deviation of Log(Mean)	0.08	0.20

TABLE 5.12: Thresholds for Propylene Glycol Monomethyl Ether.

Panel No.	Threshold (mg/M^3)	
	Detection	Discrimination
1	106	210
2	137	220
3	145	250
4	114	190
5	106	210
Geometric Mean	121	215
Log(Mean)	2.08	2.33
Standard Deviation of Log(Mean)	0.06	0.04

TABLE 5.13: Thresholds for Methyl Isoamylketone

Panel No.	Threshold (mg/M^3)	
	Detection	Discrimination
1	0.96	2.0
2	0.58	1.4
3	0.54	1.3
4	0.43	0.8
5	0.74	2.2
Geometric Mean	0.63	1.4
Log(Mean)	-0.204	0.161
Standard Deviation of Log(Mean)	0.13	0.17

TABLE 5.14: Thresholds for n-Butanol

Panel No.	Threshold (mg/M^3)	
	Detection	Discrimination
1	4.65	14.0
2	4.65	11.0
3	2.05	5.0
4	3.17	5.0
5	2.05	4.0
Geometric Mean	3.10	6.9
Log(Mean)	0.491	0.838
Standard Deviation of Log(Mean)	0.18	0.24

TABLE 5.15: Thresholds for Isobutanol

Panel No.	Threshold (mg/M^3)	
	Detection	Discrimination
1	3.9	6.0
2	1.8	4.9
3	5.6	11.0
4	1.2	4.7
5	4.6	9.0
Geometric Mean [1-5]	2.95	6.7
Log(Mean) [1-5]	0.470	0.827
Standard Deviation of Log(Mean) [1-5]	0.28	0.16
* 6	2.7	9.0
* 7	1.6	5.0
Geometric Mean [1-7]	2.64	6.7
Log(Mean) [1-7]	0.422	0.827
Standard Deviation of Log(Mean) [1-7]	0.25	0.15

* second session

TABLE 5.16: Thresholds for Octane

Panel No.	Threshold (mg/M^3)	
	Detection	Discrimination
1	86.0	120
2	63.0	190
3	74.5	100
4	42.8	90
5	52.3	100
Geometric Mean [1-5]	61.8	116
Log(Mean) [1-5]	1.791	2.062
Standard Deviation of Log(Mean) [1-5]	0.12	0.13
* 6	51.0	190
* 7	75.0	150
Geometric Mean [1-7]	61.8	129
Log(Mean) [1-7]	1.791	2.110
Standard Deviation of Log(Mean) [1-7]	0.11	0.14

* second session

Based on the information in Tables 5.11 to 5.16, confidence limits for the thresholds were determined according to procedures discussed in Appendix V. These confidence limits are shown in Table 5.17 and 5.18 for the detection and discrimination thresholds, respectively.

The mean standard deviation between thresholds for 10-member panels is approximately 0.14 logarithmic units. This is consistent with the observations of Dravnieks [4] who performed a detection threshold study using 9-member panels and reported a mean standard deviation of 0.2 logarithmic units. The mean value of the standard deviation for the discrimination threshold was determined to be 0.16 logarithmic units.

The threshold value determined by a sensory panel depends on the olfactometer used. Consequently, the results of this study cannot be compared with others unless they were performed with an IITRI olfactometer. The only chemical odourant of the six examined in this investigation that was studied by other researchers using the IITRI olfactometer was n-butanol. Dravnieks [4] reported a mean detection threshold of 1.7 mg/M^3 for n-butanol with a low value of 0.59 mg/M^3 and a high value of 4.7 mg/M^3. His standard deviation was 0.37 logarithmic units. The current study produced a mean detection threshold value of 3.1 mg/M^3 with a low value of 2.05 mg/M^3 and a high value of 4.7 mg/M^3 and a standard deviation of 0.18 logarithmic units. Unlike most reported thresholds which often differ by orders of magnitude, these two latest studies have produced very similar

TABLE 5.17: Confidence Limits of Detection Thresholds Using 10-Member Panels.

Odourant	No. of Panels	Detection Threshold (mg/M^3)		
		Mean	95% Confidence Limits	
			Low	High
Acetate	5	1.00	0.85	1.18
Glycol	5	121.	107	137.
Hexanone	5	0.63	0.48	0.82
Isobutanol	5	2.95	1.65	5.27
	7	2.64	1.73	4.03
Butanol	5	3.10	2.10	4.50
Octane	5	61.8	48.2	79.3
	7	61.8	51.3	74.4

TABLE 5.18: Confidence Limits of Discrimination Thresholds Using 10-Member Panels.

Odourant	No. of Panels	Discrimination Threshold (mg/M^3)		
		Mean	95% Confidence Limits	
			Low	High
Acetate	5	3.10	2.10	4.70
Glycol	5	215.	197	235.
Hexanone	5	1.40	1.02	2.06
Isobutanol	5	6.70	4.80	9.40
	7	6.70	5.20	8.70
Butanol	5	6.90	4.20	11.3
Octane	5	116.	88.1	151.
	7	129.	91.0	146.

results. Some of the variations may be due to the method which Dravnieks used to determine the concentration of his odour supply. His concentration value was determined from vapour pressure - temperature relationships rather than by performing actual concentration measurements [4].

E. Sessional Variations in Measurements

Two chemicals, octane and isobutanol, were evaluated during two separate sessions to detect any differences that might occur as a result of temporal variations. An Analysis of Variance test (ANOVA) was performed to compare the results of the two sessions scheduled approximately one week apart. The ANOVA test results are shown in Table 5.19.

TABLE 5.19: ANOVA Test Applied to OIM's Developed During Two Sessions a Week Apart.

Odourant	F-statistic at Point						
	1	2	3	4	5	6	ED_{50}
Isobutanol	0.8	0.8	1.2	1.6	3.6	3.4	0.7
Octane	2.3	1.8	1.4	1.1	0.6	0.4	0.7
$F_{.05}(63,6) = 2.25$ $F_{.01}(63,6) = 3.12$							

This comparison reveals that at most points the panels exhibited no significant difference at the 5% and 1% levels of significance. However, in the second session evaluation of isobutanol one of the panels rated the annoyance of the odour abnormally high over the full range of concentrations. This high rating causes significant differences to be noted between panels at certain points along the DA curve. This variation stresses the need for some form of panelist training to reduce the variability of the degree of annoyance curve.

No additional variation was observed in the measurement of the mean detection (ED_{50}) and discrimination (D_{50}) threshold values between sessions. That is, the threshold values determined during the second session were between the maximum and minimum values from the first session. This may be seen in Tables 5.20 and 5.21.

The comparisons between sessions show that no additional variations are measured between sessions except on the degree of annoyance curve. This is most likely due to the fact that this curve depends on subjective responses of panelists. An attempt should be made to reduce this variability through the development of training procedures to make responses less subjective.

TABLE 5.20: Comparison of ED_{50} Between Sessions

Odourant	Session No. 1 (5 Panels)			Session No. 2 (2 Panels)		
	Low	High	Mean[‡]	Low	High	Mean[‡]
Isobutanol	1.23	4.58	2.95	1.57	2.66	2.05
Octane	42.8	86.0	61.8	51.0	75.0	61.8

[‡] geometric mean (thresholds are log-normally distributed)

TABLE 5.21: Comparison of D_{50} Between Sessions

Odourant	Session No. 1 (5 Panels)			Session No. 2 (2 Panels)		
	Low	High	Mean*	Low	High	Mean*
Isobutanol	4.70	11.0	6.72	5.00	9.00	6.71
Octane	90.0	190.	116.	150.	190.	169.

* geometric mean (thresholds are log-normally distributed)

VI. MATHEMATICAL ANALYSIS OF THRESHOLD DETERMINATIONS

Three mathematical relationships have been developed to demonstrate how an individual panelist affects the thresholds predicted by a panel evaluation technique. The results of this investigation provide

- an expression relating a panel's detection and discrimination thresholds
- an expression showing the potential effect of replacing one panelist with another panelist having a different threshold
- a method for calculating the number of panelists required to reduce the effect of a single panelist on the panel threshold value to an acceptable tolerance.

A. Detection and Discrimination Thresholds

Most odour control regulations and/or guidelines rely on a panel evaluation technique to determine the detection thresholds of odourous emissions. The odour threshold value is commonly referred to as the effective dosage at 50% probability of detection (ED_{50}).

Although odour threshold data do not characterize the odour intensity of an undiluted sample, they are nevertheless useful in pollution control. At dilutions corresponding to the detection threshold the presence of the odour is sensed but the character of the odour cannot be recognized. To recognize the odour character a higher odour concentration is required. Most odour control regulations are based on detection thresholds, however, many odour measurement practitioners contend that as long as the odour character is not recognizeable, the odour is not likely to be annoying [16]. As a result, the discrimination threshold may be a better benchmark for odour control. A panelist discrimination threshold is defined as the dilution (concentration) at which a panelist is sure ,beyond a doubt, about the presence of the odour. The discrimination threshold of a panel is often expressed as the geometric mean of the discrimination thresholds of all the members of the sensory panel (D_{50}). The panel detection threshold is the dilution at which 50% of the odour judges correctly identify the presence of the odour consistently at this and lower dilutions. This value is usually approximated as the geometric mean of the panel members' individual detection thresholds (ED_{50}).

An attempt has been made to relate the discrimination threshold, D_{50}, with the detection threshold, ED_{50}, using probability theory.

If a panelist "i" evaluates an odour using a procedure with "N" different dilution levels, and he begins to correctly differentiate between the odourous sample and the blank(s) at dilution level "j" then his detection threshold is calculated as

$$X_i = (Z_{j-1} \cdot Z_j)^{1/2} \qquad (6.1)$$

where X_i = the i'th panelist's detection threshold

Z_j = the dilution at station (dilution level) j.

The overall panel detection threshold is calculated by

$$\bar{X} = \left[\prod_{i=1}^{n} X_i\right]^{1/n} \qquad (6.2)$$

or

$$\text{Log } \bar{X} = \frac{1}{n} \cdot \sum_{i=1}^{n} \text{Log } X_i \qquad (6.3)$$

where $\bar{X}$ = the panel detection threshold (ED_{50})

n = the number of panelist on the panel

If a panelist begins to correctly identify the presence of the odour at dilution level j he may not really be sure about the odour until the j+1, j+2, or even lower dilution levels. His consistently correct identification of the odourous port at higher dilution levels may be entirely due to chance since the forced-choice method requires a guess from the panelist about which tube is emitting the odour if the choice is not obvious. Therefore, this panelist's detection threshold will be calculated according to

$$X_i = (Z_{j-1} \cdot Z_j)^{1/2} \qquad (6.1)$$

and the discrimination threshold will be defined by

$$Y_i = (Z_{j+a-1} \cdot Z_{j+a})^{1/2} \qquad (6.4)$$

where Y_i = the i'th panelist's discrimination threshold

a = the number of ports correctly identified before the panelist begins to discriminate the odour.

Mathematical manipulation of equations 6.1 and 6.4 show that the relationship between the two thresholds may be expressed as

$$X_i = Y_i \cdot F^a \qquad (6.5)$$

where F = the multiplication factor relating consecutive dilution levels (ie: $Z_j = F \cdot Z_{j+1}$, $j=0,1,\ldots,N$)

The value of "a" cannot be predicted for a single panelist. However, for a large number of panelists the number of individuals who have a particular value of "a" may be predicted using probability theory provided that "a" depends entirely on chance. Assuming that "a" depends entirely on chance, a number of relationships can be developed. The validity of this assumption will be checked using data from the odour impact models developed in this study.

For example, if "M" panelists guess "a" consecutive ports correctly before they begin to discriminate the odour, the value of $\bar{X}$ can be modified to remove these guesses. This modification is accomplished by removing the "M" panelists detection thresholds and replacing them with their discrimination thresholds. This adjustment to the mean detection threshold can be expressed as

$$\text{Log } \bar{X}_m = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i - \sum_{j=1}^{M} \text{Log } X_j + \sum_{j=1}^{M} \text{Log } Y_j\right] \qquad (6.6)$$

where $\bar{X}_m$ = the modified panel threshold

X_j = the j'th individual's detection threshold

Y_j = the j'th individual's discrimination threshold

M = the number of people whose detection and discrimination thresholds are related by a particular value of "a"

This expression can be simplified to:

$$\text{Log } \bar{X}_m = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i + \text{Log}\left[\frac{\prod_{j=1}^{M} Y_j}{\prod_{j=1}^{M} X_j}\right]\right] \qquad (6.7)$$

or

$$\text{Log } \bar{X}_m = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i + \text{Log}\left[\prod_{j=1}^{M} \frac{Y_j}{X_j}\right]\right] \qquad (6.8)$$

Since

$$X_j = Y_j \cdot F^a \qquad \text{or} \qquad \frac{Y_j}{X_j} = F^{-a} \qquad (6.5)$$

substitution of equation 6.5 into 6.8 yields

$$\text{Log } \bar{X}_m = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i + \text{Log}\left[\prod_{j=1}^{M} F^{-a}\right]\right] \qquad (6.9)$$

$$= \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i + M \text{ Log } F^{-a}\right] \qquad (6.10)$$

The number of panelists, "M", who guess "a" ports correctly before they begin to discriminate can be calculated by evaluating the probability of guessing "a" ports correctly in a row given "C" choices at each dilution level. This is represented by

$$P = \left[\frac{1}{C}\right]^a \qquad (6.11)$$

where P = the probability of guessing "a" consecutive ports correctly

C = the number of choices available at each dilution level (1 odourous port, C-1 blank ports)

The number of people who guess "a" ports in a row correctly is then determined by

$$M = P \cdot n$$

$$= \frac{n}{C^a} \qquad (6.12)$$

where n = the total number of panelists on the panel. Substituting equation 6.12 into 6.10 produces

$$\text{Log } \bar{X}_m = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i + \frac{n}{C^a} \cdot \text{Log } F^{-a}\right]$$

which reduces to

$$\text{Log } \bar{X}_m = \frac{1}{n} \sum_{i=1}^{n} X_i + \text{Log } (F^{\frac{-a}{C^a}}) \qquad (6.13)$$

Solving for $\bar{X}_m$ gives

$$\bar{X}_m = 10^{\frac{1}{n}\sum_{i=1}^{n} \text{Log } X_i} \times F^{\frac{-a}{C^a}}$$

$$= \bar{X} \cdot F^{\frac{-a}{C^a}} \qquad (6.14)$$

Equation 6.14 defines a modified value of the detection threshold for panelists who have a particular value of "a". However, "a" can vary between 0 and the number of dilution levels (N) presented to the panelist. Therefore, $\bar{X}$ must also be corrected for values of "a" between 0 and N. The fully modified value of the threshold may be expressed as

$$\bar{X}_M = \bar{X} \times F^{\frac{0}{C^0}} \times F^{\frac{-1}{C^1}} \ldots \times F^{\frac{-N}{C^N}}$$

$$= \bar{X} \cdot \prod_{a=1}^{N} F^{\frac{-a}{C^a}}$$

$$= \bar{X} \cdot F^{-\sum_{a=1}^{N} \frac{a}{C^a}} \qquad (6.15)$$

Since the value of $\bar{X}$ in equation 6.15 has been modified to exclude all correct guesses from the threshold, the resulting value should be an estimate of the discrimination threshold provided that the detection and discrimination thresholds differ only due to the effects of chance (as assumed earlier). Therefore, the two thresholds may be related by

$$D_{50} = ED_{50} \cdot F^{-\sum_{a=1}^{N} \frac{a}{C^a}} \qquad (6.16)$$

where D_{50} = the panel discrimination threshold

ED_{50} = the panel detection threshold

N = the total number of dilution levels

C = the number of port choices at each dilution level

F = the constant factor relating dilution levels
(ie: $Z_j = Z_{j+1} \cdot F$, j = 0, 1, ..., N)

The following parameters describe the IITRI olfactometer:

$F = 3.0$ (the value of F according to design)
$C = 3$ (3 ports at each dilution level)
$N = 6$ (6 odour stations)

Therefore, the factor relating D_{50} and ED_{50} according to

$$D_{50} = K \cdot ED_{50} \tag{6.17}$$

where

$$K = F^{-\sum_{a=1}^{N} \frac{a}{C^{a}}} \tag{6.18}$$

will be

$$K = 3.0^{-\sum_{a=1}^{6} \frac{a}{3^{a}}}$$

$$= 0.4412$$

An empirical value of K was determined using the data collected from the six odour impact models discussed previously. Experimental values were determined using the expression

$$K = \frac{D_{50}}{ED_{50}} \tag{6.19}$$

but in a slightly different form. Since equation 6.17 was developed in terms of dilutions, the equivalent expression in terms of thresholds expressed in concentration units is

$$K = \frac{ED_{50}}{D_{50}} \tag{6.20}$$

due to the inverse relation between concentration and the number of dilutions. The values of K from each 10-member panel corresponding to each odourant are presented in Table 6.1.

TABLE 6.1: Values of K from the Six Odour Impact Models.

Odourant	Values of K from Panel No.					Mean
	1	2	3	4	5	
Acetate	0.42	0.33	0.27	0.43	0.46	0.37
Glycol	0.54	0.59	0.61	0.74	0.47	0.58
Hexanone	0.46	0.45	0.51	0.57	0.41	0.48
Isobutanol	0.52	0.46	0.47	0.41	0.48	0.47
Butanol	0.37	0.46	0.30	0.58	0.52	0.44
Octane	0.72	0.28	0.58	0.43	0.48	0.47
Overall Mean Value of K						0.46

The mean of the values of K is not calculated as an arithmetic mean but rather as a geometric mean because the mean detection threshold of all panels is calculated according to

$$\overline{ED}_{50} = \left[\prod_{i=1}^{m} ED_{50_i} \right]^{1/m} \qquad (6.21)$$

where $\overline{ED}_{50}$ = the mean detection threshold of all panels

ED_{50_i} = the mean detection threshold of panel "i"

m = the total number of panels

and the mean discrimination threshold is calculated from

$$\overline{D}_{50} = \left[\prod_{i=1}^{m} D_{50_i} \right]^{1/m} \qquad (6.22)$$

where $\bar{D}_{50}$ = the mean discrimination threshold of all panels

D_{50_i} = the mean discrimination threshold of panel "i"

m = the total number of panels

The mean values are calculated as a geometric mean because the thresholds are log-normally distributed [5].

The mean value of K is the ratio of the mean discrimination threshold to the mean detection threshold, each being expressed in dilutions. Therefore,

$$\bar{K} = \frac{\bar{D}_{50}}{\overline{ED}_{50}} = \frac{\left[\prod_{i=1}^{m} D_{50_i} \right]^{1/m}}{\left[\prod_{i=1}^{m} ED_{50_i} \right]^{1/m}}$$

$$= \left[\prod_{i=1}^{m} \frac{D_{50_i}}{ED_{50_i}} \right]^{1/m}$$

$$= \left[\prod_{i=1}^{m} K_i \right]^{1/m} \qquad (6.23)$$

which is the geometric mean of the m values of K.

The value of F for the IITRI olfactometer used in this study is 2.88 which is only a slight deviation from the design value of 3.0. For this value of F, the predicted value of K using equation 6.18 becomes

$$K = 2.88^{-\sum_{a=1}^{6} \frac{a}{3^a}} = 0.455 \simeq 0.46$$

The overall mean value of K from all six odourants was calculated to be 0.46. This extremely good correlation between the calculated and predicted values of K supports the assumption that the detection threshold (ED_{50}) and the discrimination threshold (D_{50}) differ only because of chance. Therefore, the value of D_{50} may be predicted if a large number of panelists have been used to determine the value of ED_{50}.

The Odour Impact Model does not use the values of ED_{50} and D_{50} as a measure of the detection and discrimination thresholds. Instead these thresholds are derived from the detection and discrimination profiles at the probability level of 50%. These values are designated Z @ 50 PD (detection) and Z @ 50 PDn (discrimination). Fortunately, the values of the two definitions of the detection and discrimination thresholds are usually very close. The exact value of K cannot be predicted mathematically for the profile method of determining the thresholds, however, it was found that equation 6.18 produces a good approximation of the value. This is demonstrated in Table 6.2.

Therefore, the discrimination threshold of the Odour Impact Model may be predicted if a detection threshold has been measured using a large number of panelists. This is important because the discrimination threshold may be a better representation of a panels' ability to perceive an odour. Therefore, through use of equation 6.17 and 6.18, past evaluations of specific detection thresholds could be used to determine the corresponding discrimination thresholds.

TABLE 6.2: K Values from Odour Impact Models Using Two Threshold Definitions.

Odourant	$K = \dfrac{Z @ 50\ PDn}{Z @ 50\ PD}$	$K = \dfrac{D_{50}}{ED_{50}}$
Acetate	0.33	0.37
Glycol	0.73	0.58
Hexanone	0.48	0.48
Isobutanol	0.48	0.47
Butanol	0.44	0.44
Octane	0.49	0.47
Mean	0.48	0.46
Value of K by Equation 6.18		0.46

B. Effect of a Single Panelist

One of the major problems with any odour evaluation technique is the high variability in the sensitivities of the individual panelists. For example, when a detection threshold is measured by a panel of 10 people it is possible that if one of those panelists were replaced by another person the same detection threshold would not be obtained, despite the fact that the panels were nearly identical. The same variations would be expected for measurements of the discrimination threshold.

The effect of exchanging one panelist for another may be measured mathematically using similar expressions to those that were developed in the previous section.

A panel of "n" members would produce a threshold evaluated from

$$\text{Log } \bar{X} = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i\right] \qquad (6.2)$$

where $\bar{X}$ = the panel threshold (detection or discrimination)

X_i = the i'th individual's threshold

n = the number of panelists on the odour panel

If the same test were performed using all but one member of the original panel who is replaced by another panelist with a threshold that occurs "a" dilutions later, the resulting threshold would differ from the original by

$$\text{Log } \bar{X}_N = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i - \text{Log } X_j + \text{Log } X_{j+a}\right] \qquad (6.24)$$

where $\bar{X}_N$ = the new threshold resulting from the replacement of one panelist

X_j = the threshold of the original panelist who began to detect/discriminate at dilution level j

X_{j+a} = the threshold of the replacement panelist who begins to detect/discriminate the odour "a" dilution levels later than the original panelist

Equation 6.24 may be simplified to

$$\text{Log } \bar{X}_N = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i + \text{Log}\left[\frac{X_{j+a}}{X_j}\right]\right] \qquad (6.25)$$

Since

$$\frac{X_{j+a}}{X_j} = F^{-a} \qquad (6.5)$$

Substitution of equation 6.5 into 6.25 produces

$$\text{Log } \bar{X}_N = \frac{1}{n}\left[\sum_{i=1}^{n} \text{Log } X_i + \text{Log } F^{-a}\right] \tag{6.26}$$

Solving equation 6.26 for $\bar{X}_N$ and using 6.2 to simplify gives

$$\bar{X}_N = \bar{X} \cdot F^{-a/n} \tag{6.27}$$

It is necessary to define

- a factor, "f", which is a measure of how an individual panelist affects the panel threshold, according to

$$f = \frac{\bar{X}_N}{\bar{X}} = F^{-a/n} \tag{6.28}$$

- a range, "R", which is a measure of the range of control that the new panelist has upon the old panel threshold by correctly identifying the odour "a" dilution levels away from the original panelist, according to

$$R = \frac{\left[\frac{\bar{X}}{f} - f \cdot \bar{X}\right]}{\bar{X}} \times 100\%$$

$$= \left[\frac{1}{f} - f\right] \times 100\% \tag{6.29}$$

Accordingly, if the replacement panelist on a panel of 10 members detects the odour 2 ports earlier or later (a=2) than the replaced panelist (using the IITRI olfactometer with F (= 3.0), the range, "R", is determined for

$$f = F^{-a/n} = 3.0^{-2/10} = 0.8027$$

to be $$R = \left[\frac{1}{0.8027} - 0.8027 \right] \times 100\% = 44.3\%$$

Therefore, the replacement panelist would change the original detection threshold to a value over a range that is as wide as 44.3% of the original threshold value. The range is defined by

$$\bar{X} \cdot 0.8027 \leq \bar{X}_N \leq \frac{\bar{X}}{0.8027}$$

This range is a measure of the effect that a single panelist would have on the threshold of a panel of "n" members when the replacement panelist has a personal threshold which differs from the replaced panelist by "a" dilution levels.

C. The Minimum Number of Panelists for a Given Tolerance

The analysis applied in the previous section may be used to determine the number of panelists required to reduce the effect of a specific panelist to an acceptable range, "R". Equation 6.29 may be solved to provide "f" in terms of "R".

Since $$R = \left[\frac{1}{f} - f \right] \times 100 \qquad (6.29)$$

it follows that $$\frac{fR}{100} = 1 - f^2$$

and $$f^2 + \frac{fR}{100} - 1 = 0$$

Solving the quadratic expression gives

$$f = \frac{-R}{200} + 0.5\sqrt{\frac{R^2}{10000} + 4} \qquad (6.30)$$

From $$f = F^{-a/n} \qquad (6.28)$$

$$\text{Log } f = -\frac{a}{n} \cdot \text{Log } F$$

and $$n = \frac{-a \text{ Log } F}{\text{Log } f} \qquad (6.31)$$

Accordingly, the number of panelists, "n", who are required to reduce the effect of a replacement panelist whose threshold differs from the replaced panelist by "a" dilution levels to a range, "R", may be calculated from

$$n = \frac{-a \cdot \text{Log } F}{\text{Log}\left[\frac{-R}{200} + 0.5\sqrt{\frac{R^2}{10000} + 4}\right]} \qquad (6.32)$$

If a tolerance, "T", is defined as the allowable range of control that a panelist is allowed to exercise by detecting or discriminating the odour at one higher or lower dilution level (a=1) it follows that

$$t = F^{-1/n} \qquad (6.33)$$

and
$$T = \left[\frac{1}{t} - t \right] \times 100\% \qquad (6.34)$$

and
$$n = \frac{-\operatorname{Log} F}{\operatorname{Log}\left[\frac{-T}{200} + 0.5 \sqrt{\frac{T^2}{10000} + 4} \right]} \qquad (6.35)$$

where T = the tolerable range of control with a=1 (%)

F = the factor relating consecutive dilution levels

t = the value of "f" when a=1

n = the minimum number of panelists required to meet the tolerance value, "T"

For example, if the effect of the single panelist is to be reduced to a 10% tolerance level when using the IITRI olfactometer (F = 3.0), the minimum number of required panelists would be

$$n = \frac{-\operatorname{Log}(3.0)}{\operatorname{Log}\left[\frac{-10}{200} + 0.5 \sqrt{\frac{10^2}{10000} + 4} \right]}$$

$$\simeq 22$$

It must be appreciated that 22 is the number of panelists required to reduce the effect of only one dilution level difference between the thresholds of replaced and replacement panelists. If there were a greater difference between the two panelists (a > 1), the number of panelists required to accomplish the same tolerance would be

$$n_a = a \cdot n \qquad (6.36)$$

where n = the number of panelists required to reduce the effect of a one dilution level difference between the replaced and replacement panelists

a = the actual number of dilution levels between the two panelists' thresholds

n_a = the number of panelists required to reduce the effect of a replacement panelist whose threshold differs from the replaced panelist by "a" dilution levels.

The optimum value of the tolerance, "T", must be defined in terms of the maximum allowable panelist effect in the threshold evaluation. The determination of this value is beyond the scope of this study but is recommended for further consideration.

VII. RECOMMENDATIONS

Several features of the Odour Impact Model must be modified and others must undergo further study if the model is to form the basis of odour regulations.

A. Recommended Refinements to the Odour Impact Model

There are a number of refinements which must be made to the Odour Impact Model (OIM) to make it representative of the reactions of the general population to any odour.

1. The Degree of Annoyance Curve

Two alternatives have been proposed for the method by which points along the Degree of Annoyance curve are to be calculated.

The first option was used by Poostchi [15] in his development of the model in its present form. This method involves calculation of the annoyance at a given dilution level from

$$DA_i = \frac{1}{N_c} \cdot \sum_{j=1}^{n} A_{ij} \qquad (7.1)$$

where DA_i = the degree of annoyance at dilution level "i"

A_{ij} = the annoyance of panelist "j" expressed at dilution level "i"

N_c = the number of panelists who express a non-zero annoyance at dilution level "i"

n = the total number of people who evaluated the odour.

According to Poostchi [15], only those panelists who are sensitive to the odour and complain about it (annoyance greater than zero) are taken into account at each point along the DA curve. The advantage of this approach is that people who are very sensitive to the odour are given a greater weighting in the evaluation of the hedonics of the odour.

The alternative to equation 7.1 is expressed as

$$DA_i = \frac{1}{n} \cdot \sum_{j=1}^{n} A_{ij} \qquad (7.2)$$

with all variables being the same as in equation 7.1. This expression evaluates the annoyance at a given dilution level from a calculation of the average annoyance expressed by all panelists; whether they are zero or non-zero. The result is an expression of annoyance of the general population to an odourous stimulus.

Equation 7.2 is conside[illegible] to be the better of the two alternatives for assessing the annoyance at any given dilution level. The advantage of the second approach over the first may be shown through a specific example.

For illustrative purposes, consider 25 people who are asked to evaluate a particular odour at six dilution levels. After the test, the raw data are reduced and the resulting information is summarized in Table 7.1.

As expected, with increasing concentrations the number of panelists who detect, discriminate, and complain about the

TABLE 7.1: Example Odour Evaluation

Number of Panelists Who...	Port No.					
	(High Dilution) ⟷ (Low Dilution)					
	1	2	3	4	5	6
Detect	0	0	0	18	22	25
Discriminate	0	0	1	17	22	25
Complain	0	0	1	15	21	25
Annoyance Level	No. of Complaints at each Annoyance					
1	0	0	0	14	2	3
2	0	0	0	0	13	3
3	0	0	1	0	3	12
4	0	0	0	1	2	3
5	0	0	0	0	1	3
6	0	0	0	0	0	1
7-10	0	0	0	0	0	0
Equation No.	Calculated Degree of Annoyance					
7.1	0	0	3.0	1.2	2.4	3.1
7.2	0	0	0.1	0.7	2.0	3.1

odour increases. Despite the expected trends, an inconsistency may be noted by examining the annoyance levels calculated at each dilution. At ports 1 and 2 no complaints are registered. As a result, the degree of annoyance is zero. At port 3 one person complains. In this example the person has expressed a personal annoyance of 3. Therefore, by equation 7.1, the degree of annoyance for the panel is recorded as the average of those who complained resulting in a panel annoyance of 3.0. Equation 7.2 averages this non-zero value with the zero values to provide a panel annoyance of 0.10. At the fourth port a greater number of people express complaints. The PDA value determined by equation 7.1 is 1.2 while the value calculated by equation 7.2 is 0.7. This is the point of inconsistency. Despite the fact that more people have complained about the odour at the fourth dilution level, equation 7.1 evaluates the annoyance at this level to be less than the previous level. Even if the person who complained with an annoyance of 3 at the third dilution level had complained with an annoyance of 10 at the fourth dilution level, the panel annoyance would still be only be 1.6. Therefore, this inconsistency causes the degree of annoyance curve to oscillate when, in fact, it should rise with increasing odourant concentration. For this reason, equation 7.2 should be used to evaluate the annoyance potential of a panel.

The situation described above is a fictitious example that does not necessarily occur all the time. However, during the testing performed in this study it did occur several times.

For example, such a situation arose for one of the 10-member panels who evaluated n-butanol. The odour impact model for this panel is shown in Figure 7.1. The dotted curve corresponds to the DA curve calculated using equation 7.1 and the solid DA curve was calculated using equation 7.2.

A statistical comparison was performed on the five panels using both methods of evaluating the panel annoyance. The results of the ANOVA test for the third dilution level are shown in Table 7.2.

TABLE 7.2: Comparison of DA Curves at the Third Dilution Level for n-Butanol.

PDA Evaluated By Equation	F-ratio at 3rd Point		Conclusion
	Calculated	Critical	
7.1	18.24	2.98	Significant Difference
7.2	0.37	2.59	No Significant Difference

This table suggests that there is a significant difference among panels when equation 7.1 is used to evaluate the annoyance but there is no significant difference if equation 7.2 is used. To demonstrate the approach of using the first equation in the development of odour impact models, examine Figure 7.2. The dotted line represents the use of equation 7.1 and the solid line results from the use of equation 7.2 to compute the degree of annoyance curves. The consequences of using equation 7.1 show up as oscillations, or irregularities, in the final odour impact model unlike the use of equation 7.2.

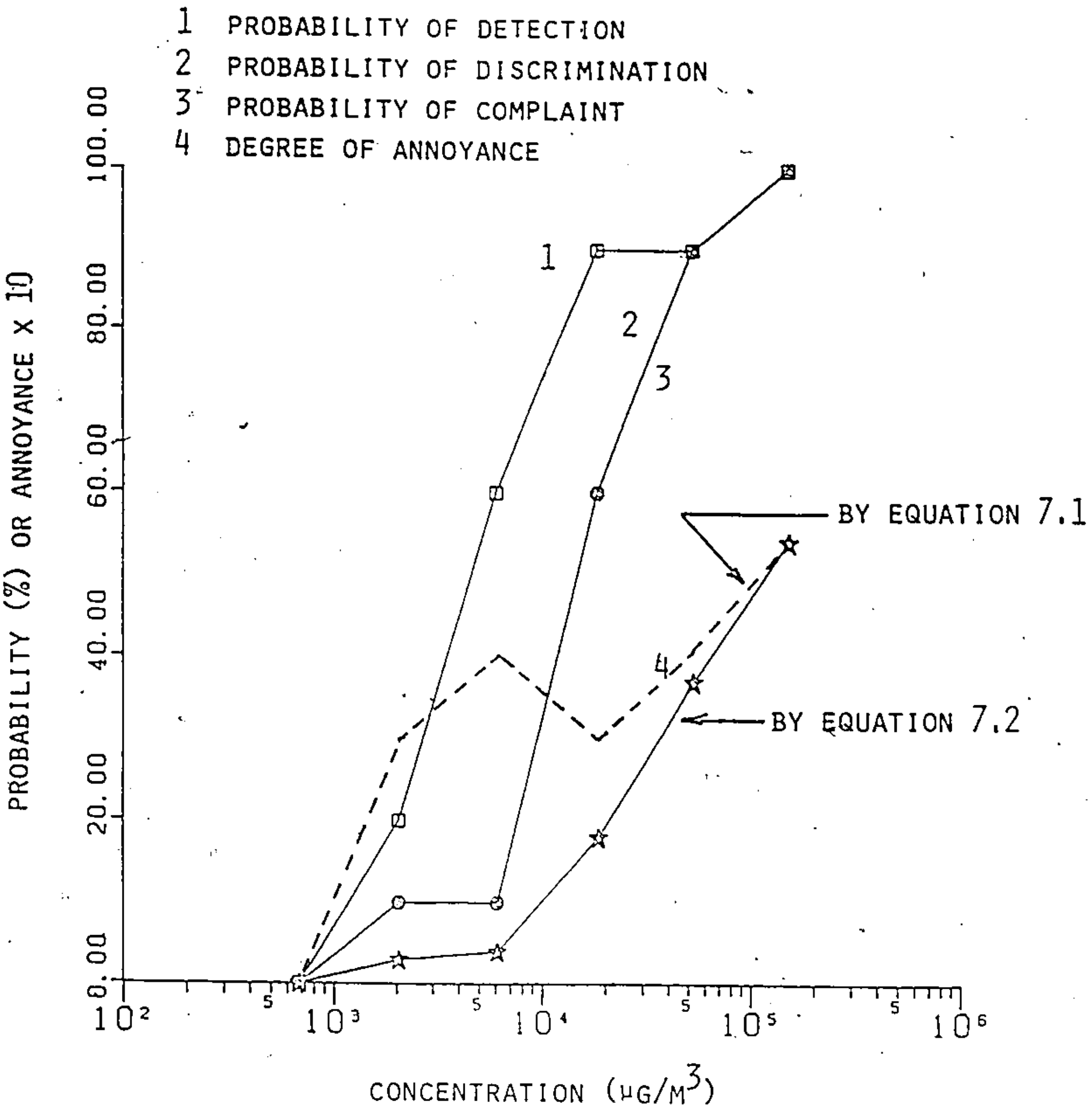


FIGURE 7.1: Comparison of Methods for the Calculation of Annoyance Using a Single Panel.

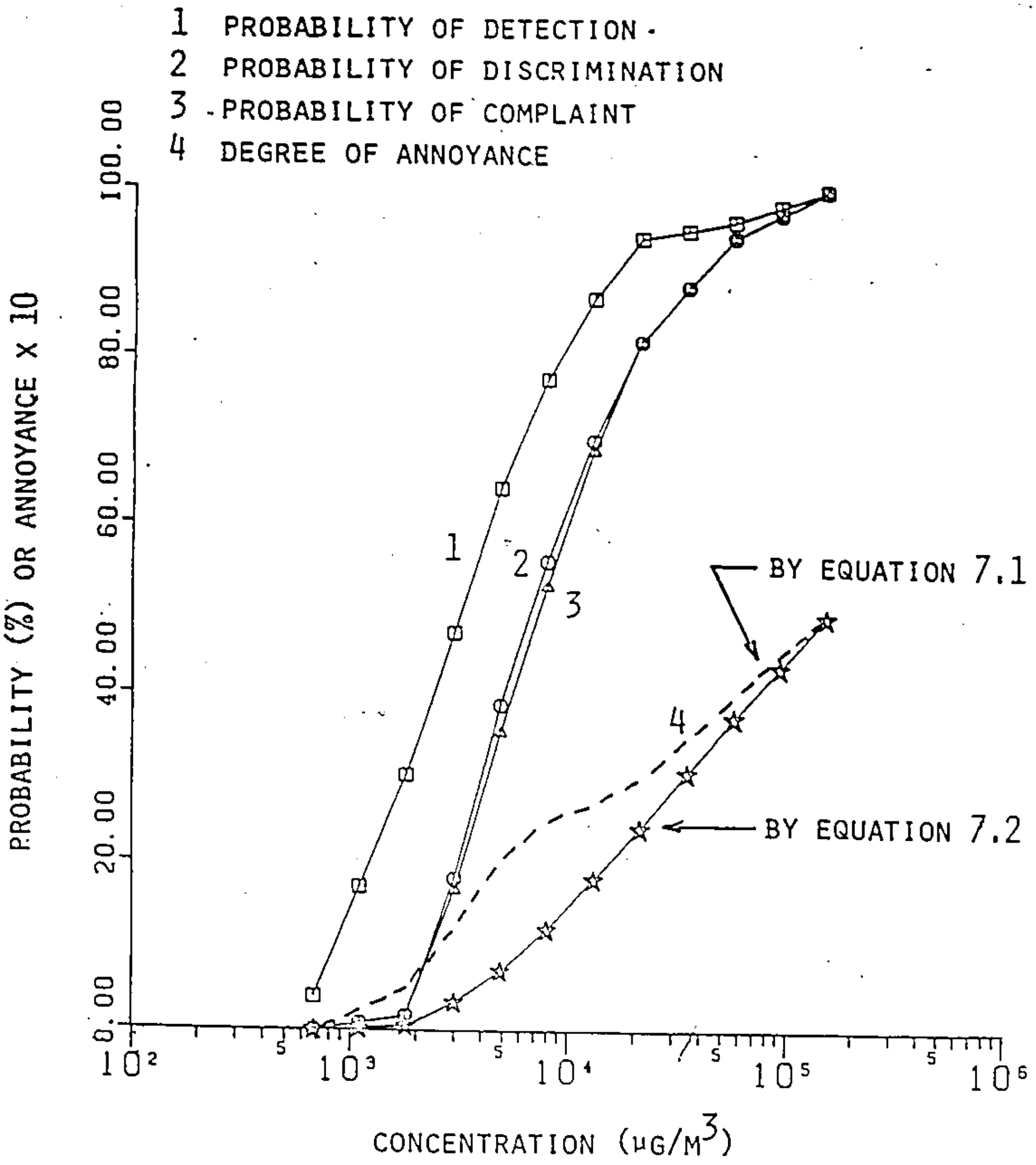


FIGURE 7.2: Comparison of n-Butanol Odour Impact Model Using Both Methods for the Calculation of Panel Annoyance.

Therefore, the predicted degree of annoyance curve should be plotted using annoyance values at each dilution level that are calculated according to

$$DA_i = \frac{1}{n} \sum_{j=1}^{n} A_{ij} \qquad (7.2)$$

where n = the total number of people who evaluated the odour

DA_i = the degree of annoyance at dilution level "i"

A_{ij} = the annoyance of panelist "j" expressed at dilution level "i"

2. The PC and PDn Curves of the Odour Impact Model

Figures 5.1, 5.2, 5.3, 5.4, 5.5, and 5.6 demonstrate that the probability of discrimination (PDn) and the probability of complaint (PC) curves are very similar and in some cases are coincidental. Such agreement occurs because panelists that are able to discriminate an odour often have a tendency to express some degree of annoyance (whether it be very small or large).

Poostchi [15] suggested that for practical purposes the Odour Impact Model should be simplified to exclude one of these curves since they are usually redundant. He argued that the probability of discrimination curve should be eliminated from the model leaving the probability of complaint curve for the evaluation of the potential Odour Impact (OI) at any dilution as defined by

$$OI = PC \times DA \qquad (7.3)$$

where OI = the potential odour impact at any receptor location on a scale of 0 to 1000

PC = the percent probability of complaint at any receptor location based on predicted dilutions from source to receptor.

DA = the predicted degree of annoyance corresponding to the PC at any receptor location, on a scale of 0 to 10.

A more suitable alternative would be to eliminate the PC curve instead of the PDn curve so that OI values would be calculated according to

$$OI = PDn \times DA \qquad (7.4)$$

where PDn = the percent probability of discrimination at any receptor location based on predicted dilutions from source to receptor.

The reason for this change is simple. A person is considered to have complained if he expresses an annoyance due to an odour at a level greater than zero. This is a completely arbitrary definition of complaint. It is possible to argue that if a person complains about the odour with an annoyance ranging between 0 and 2 he is not really complaining at all because such an annoyance value is still in the "tolerable range" as defined in Table 3.1. Therefore, the complaint profile does not provide a real measure of complaint potential.

It is possible to arbitrarily choose any value on the annoyance scale as the point where a person may be considered to have complained; but, to avoid any arbitrariness, the probability of discrimination curve could be used. Since, the PDn curve is based on the panelists' abilities to perceive the odour, the OI values calculated from this curve provide a measure of the reaction of the entire population and not just the reaction of those people who complain beyond some arbitrarily chosen annoyance value.

3. Detection Versus Discrimination Thresholds

At present the concentration of an odour is expressed in terms of odour units (o.u.) per unit volume of gas. This value is determined by calculating the detection threshold of a panel exposed to the odour over a range of dilutions. The number of dilutions required to reduce the original odour concentration to the detection threshold value corresponds to the number of odour units per volume of gas.

It has been shown that the detection threshold and the discrimination threshold may be related by the expression

$$D_{50} = K \cdot ED_{50} \qquad (6.17)$$

where

$$K = F^{-\sum_{a=1}^{N} \frac{a}{C^{a}}} \qquad (6.18)$$

The value of K represents the elimination of correct guesses from the detection threshold value. The excellent correlation between the predicted and measured values of K suggests that the detection threshold differs from the discrimination threshold only by chance. Therefore, the detection threshold is not a meaningful measure of a panel's ability to perceive an odour.

An additional numerical simulation was performed to confirm this concept. If a detection threshold is affected by chance then its reproducibility should be less than the reproducibility of the discrimination threshold. Such a difference was confirmed for all six chemicals when a comparison was made between their mean detection and discrimination thresholds. Table 7.3 shows that the variation among individuals' is consistently less for the discrimination threshold than for the detection threshold.

TABLE 7.3: Comparison of Variations in Detection and Discrimination Thresholds.

Odourant	Mean of Log (ED_{50})	Variance	Mean of Log (D_{50})	Variance
Acetate	0.068	0.258	0.497	0.178
Glycol	2.027	0.164	2.263	0.107
Hexanone	-0.118	0.252	0.203	0.200
Isobutanol	0.528	0.519	0.858	0.289
Butanol	0.549	0.257	0.910	0.197
Octane	1.739	0.172	2.063	0.087

The comparison in Table 7.3 was made between the means of the logarithm of the threshold values because the thresholds are log-normally distributed [5].

These results lead to the conclusion that the discrimination threshold is a more reliable measurement of a panel's ability to perceive an odour. Consequently, the concentration of an odour in odour units (o.u.) should be based on the dilutions required to reduce the odour concentration to the discrimination threshold value. If the discrimination threshold has not been determined, its value may be estimated using the the relationship between the discrimination and detection thresholds expressed by equations 6.17 and 6.18.

4. The Degree of Offensiveness

The present Odour Impact Model defines the degree of offensiveness of an odour in terms of

$$DO = (MDL \,@\, 100\ PC)(DA_{100}) \qquad (3.1)$$

where DO = the degree of offensiveness of an odour at the source.

MDL @ 100 PC = the maximum number of dilutions of the original odour sample for 100 percent probability of complaint

DA_{100} = the predicted degree of annoyance at MDL @ 100 PC on a scale of 0 to 10.

This definition is not appropriate for several reasons. First, it has already been shown that the use of the probability of complaint (PC) curve should be replaced by the probability of discrimination (PDn) curve. Secondly, it is not always possible to measure a dilution at 100% probability of complaint or discrimination if the hedonics of the odour are not sufficiently offensive. Thirdly, the dilution level at 100% probability of complaint or discrimination should not be used because these values depend too heavily on the response of the final panelist to discriminate or complain about the odour. Fourthly, equation 3.2, which depends on the value of DO, cannot be used reliably to rank odours in terms of their offensiveness no matter what percentage of complaint or discrimination is used as a point of reference. This will be demonstrated through the use of an example.

Consider the situation presented in Figures 7.3 and 7.4. Two hypothetical odour impact models are shown for odours with different hedonic characteristics, as demonstrated by the differences in the degree of annoyance curves. If the degree of offensiveness is calculated for each odour using the 50% and 90% levels of probability as a point of reference, the values listed in Table 7.4 are produced.

TABLE 7.4: Degree of Offensiveness of Two Odours Evaluated at the 50% and 90% Probability Levels (either PC or PDn).

Odour	Dilutions @ 50% Level	DA @ 50% Level	DO	Rank
A	20.0	2.0	40.0	2
B	40.0	1.5	60.0	1
Odour	@ 90% Level	@ 90% Level	DO	Rank
A	3.0	6.0	18.0	1
B	4.3	3.1	13.3	2

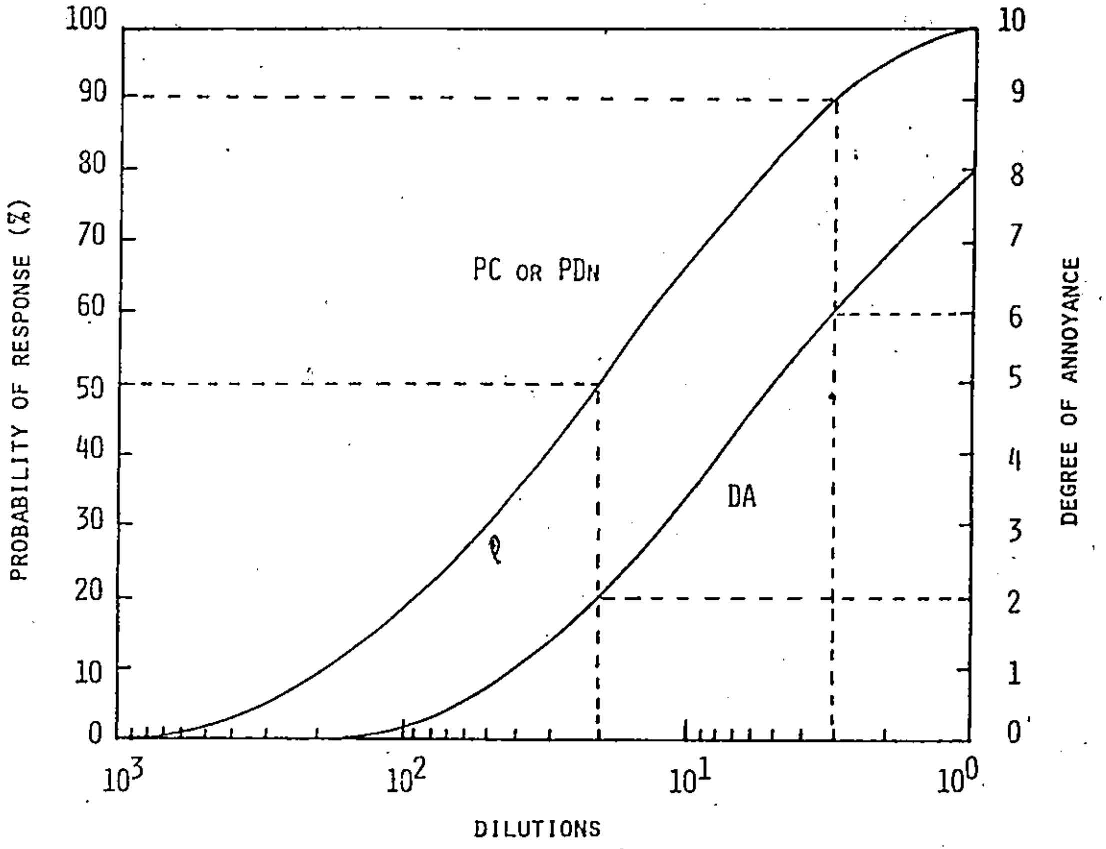


FIGURE 7.3: Hypothetical Odour Impact Model for Odour A.

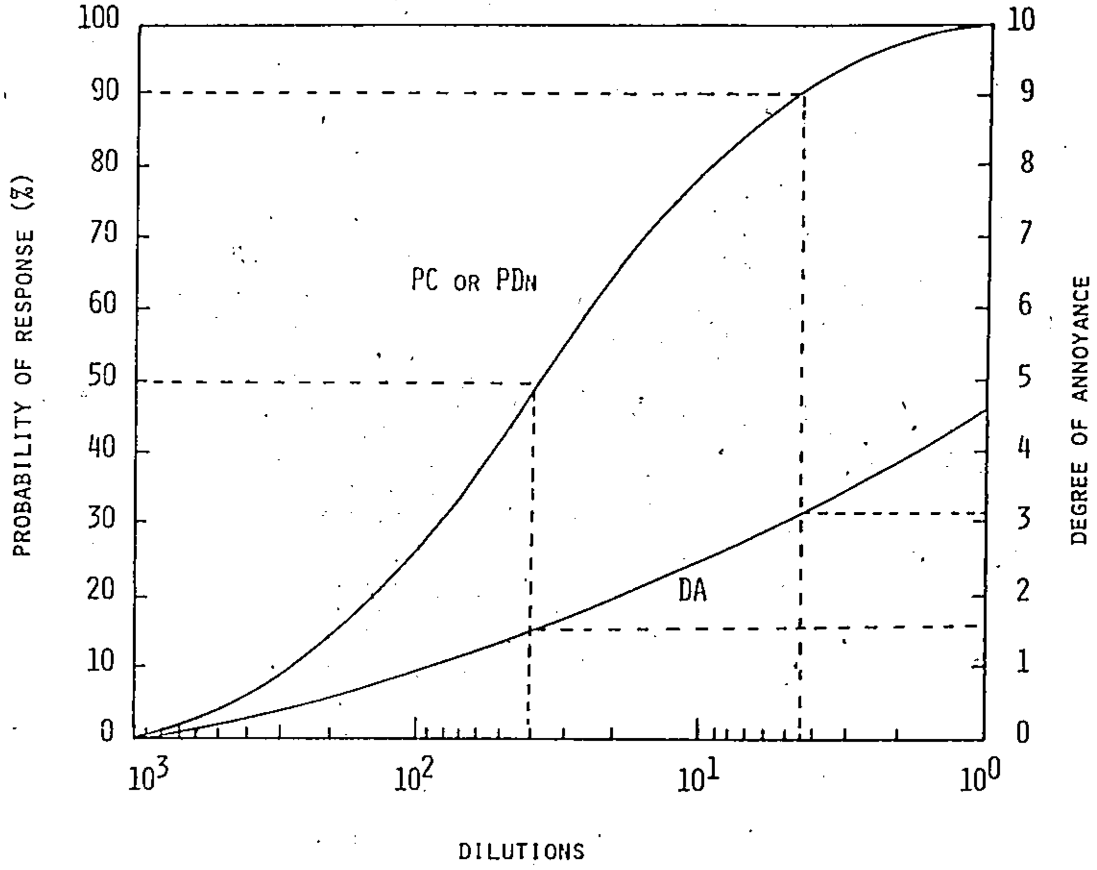


FIGURE 7.4: Hypothetical Odour Impact Model for Odour B.

Using the first definition of the degree of offensiveness,

$$DO = (Z @ 50\ PDn)(DA_{50})$$

or

$$= (Z @ 50\ PC)(DA_{50})$$

the ranking of the offensiveness of the two odours is

DO(odour B) > DO(odour A).

If the second definition of the degree of offensiveness,

$$DO = (Z @ 90\ PDn)(DA_{90})$$

or

$$= (Z @ 90\ PC)(DA_{90})$$

is used then the ranking of the offensiveness of the odours is

DO(odour A) > DO(odour B).

Since the ranking of the offensiveness of the odours could depend on the arbitrary choice of a base value for the percent probability of discrimination or complaint it is reasonable to conclude that this definition of the degree of offensiveness does not meet the needs of the Odour Impact Model.

An alternate method of evaluating the degree of offensiveness is to consider

$$DO = \int_{Z=1}^{Z\ @\ DA=0} DA(Z)\ dZ \qquad (7.5)$$

where Z = the dilution factor

Z @ DA=0 = the dilutions of the odour to achieve no annoyance.

DA(Z) = the degree of annoyance at dilution Z.

This definition is fundamentally of the same form as the original definition of the degree of offensiveness in that it involves the multiplication of the predicted degree of annoyance by the corresponding dilutions. However, this definition differs in that it involves all values of the degree of annoyance between the original source concentration and the concentration at which no annoyance is registered by the panel (Z @ DA=0). This definition takes into account the annoyance experienced by the population at all dilutions of the odour rather than one dilution corresponding to an arbitrarily chosen probability of complaint or discrimination. It could provide a truer estimate of the potential offensiveness of the odour.

Equation 7.5 cannot be tested using the information collected during this study. In future work, odours must be examined using the usual Odour Impact Model but with one additional measurement; each panelist must evaluate the odour at its original concentration (Z=1). This additional information will allow the calculation of the area under the DA curve between the source concentration and the concentration at which no complaint is recorded (equation 7.5).

The calculation of the potential level of Source Annoyance (SA) should still be calculated using

$$SA = (V_o)(DO) \tag{3.2}$$

where V_o = the volumetric flowrate of odourous gas

DO = the degree of offensiveness

B. Recommendations for Further Research

There are several features of the Odour Impact Model that require further research.

1. Evaluating the Annoyance of an Odour

When a panelist evaluates an odour he is asked to assign annoyance values corresponding to the categories listed in Table 3.1. Observations of panelists who are evaluating an odour for the first time have generated the suspicion that some panelists do not actually respond with an annoyance level which describes the hedonic character of the odour. Instead, if the odour is not particularly offensive the panelists may tend to respond with an annoyance value which is a measure of their confidence in their ability to detect the odour at that dilution level.

A study must be performed to determine if panelists who respond in this way have a significant effect on the annoyance curve. In addition, methods should be developed to help train the inexperienced panelists to respond with an actual measure of their annoyance when exposed to an odour.

2. Maximum Panelist Effect

Equations 6.28 and 6.29 define the extent of the effect of a single member of an odour panel in determining detection or discrimination thresholds. A statistically valid study should be performed to determine how large an effect one panelist should be allowed to have in the odour evaluation process. This number could then be used in conjunction with equation 6.35 to determine the minimum number of panelists required to evaluate an odour for legal purposes.

3. Reference Odour Impact Models

The accuracy of a particular odour impact model would be measured according to the size of the confidence intervals associated with the detection, discrimination, complaint, and degree of annoyance profiles. Odour impact models which describe the effect of an odour on the general population with a high degree of accuracy require a large number of panelist evaluations. A study must be performed to determine how accurate a reference odour impact model must be in order to make it a useful tool in the management of odourous emissions.

4. The Degree of Offensiveness

The revised definition of the degree of offensiveness, as expressed equation 7.5, should be applied to an industrial situation to determine its validity. This study would require the evaluation of the undiluted odour by each panelist in addition to the normal evaluation procedure.

VIII. CONCLUSIONS

Odour impact models have been developed for

- n-Butyl Acetate
- Propylene Glycol Monomethyl Ether
- Methyl Isoamylketone
- Isobutanol
- n-Butanol
- Octane

On the basis of the results of these odour impact models, a number of conclusions regarding the sensory evaluation of odours can be made.

A. Panelist Characteristics

Statistical analysis of the variations in individual panelist thresholds indicate that factors such as panelist gender and employment in odourous or non-odourous conditions do not contribute heavily to the differences in olfactory sensitivity among panelists. However, trends indicate that there is a loss of sensitivity to odours with increasing age. Therefore, sensory panels should be composed of a variety of panelists who reflect the distribution of ages in the population.

B. Panel Size

The odour impact models were developed using panels consisting of ten members each with at least 2 members being over the age of 30. Statistical analysis of the models produced by each 10-member panel suggests that no significant differences will be noted between panels of this size. That is, each 10-member panel reflects the response and variations in response of the general population.

A single 10-member panel would produce an odour impact model which is a measure of the panelists' reaction to the odour but which may not provide an accurate description of the response of the population. The accuracy of an odour impact model may be measured by the size of the confidence interval associated with the model parameters. In order to determine the confidence limits associated with a given model, more than one 10-member panel is required to evaluate the odour. The number of panels appropriate to a specific odour study depends on the maximum allowable size of the confidence intervals for the measurements of interest.

C. Sessional Variations

The evaluation of odours during sessions separated by a period of one week demonstrates that no significant variations occur in the Odour Impact Model except for the Degree of Annoyance (DA) profile. Therefore, future research should concentrate on the development of a panelist training/educating procedure that would make individual expressions of annoyance more consistent.

D. Mathematical Expressions

Expressions have been developed to

- provide a measure of the effect of a single panelist on the evaluation of panel thresholds

- predict the number of panelists required to reduce the effect of a single panelist to a given tolerance
- relate the mean panel discrimination threshold to the mean detection threshold through the application of probability theory

The first two relationships may be used to establish the minimum number of panelists that are required to evaluate an odour when a maximum allowable panelist effect has been defined. The third expression may be used to predict discrimination thresholds from a detection threshold that has been determined using a forced-choice procedure.

E. Refinements of the Odour Impact Model

Several refinements must be made in the Odour Impact Model before it can be implemented as an odour testing procedure.

The degree of annoyance at any dilution level must be calculated by averaging all zero and non-zero annoyance levels registered by panelists. Evaluation of these magnitudes using only non-zero values can create oscillations of the Degree of Annoyance (DA) profile and can cause statistically significant differences among 10-member panels.

The Probability of Complaint curve should be eliminated from the Odour Impact Model since it is based on an arbitrarily chosen degree of annoyance level as the point where a panelist is considered to have complained. The Probability of Discrimination (PDn) curve should be used instead because this curve depends only upon panelists' ability to perceive the odour and not on any arbitrarily chosen parameters.

The good agreement of the expression relating the detection and discrimination thresholds of a panel with empirical data demonstrates that the detection threshold is significantly affected by chance. Therefore, any use of the detection threshold for legal purposes should be replaced with the discrimination threshold since this parameter is a true measure of a panel's ability to perceive an odour. As a consequence, the detection profile should be eliminated from the Odour Impact Model.

F. Odour Evaluation Equipment

The odour generator developed for this study facilitates the development of odour impact models for pure chemicals. This unit provides a steady flow of odourous gas with a constant odourant concentration. The concentration of the generated odour can be varied between levels ranging from the undetectable up to a level limited only by the vapour pressure of the odourant.

The magnitude of the dilution levels supplied at each station of the IITRI olfactometer are usually determined using a technique involving the measurement of volumetric flowrates of odour and dilution air at each station. This calibration technique produced the same dilution measurements as those obtained using a concentration based calibration technique. On the basis of this good agreement, the number of dilutions of the odour at each station of the olfactometer can be assessed accurately using the volumetric calibration procedure described in Appendix II.

References

1. Caulott, E., Significance Tests, Routledge and Kegan Paul Ltd., Boston, Mass. (1973).

2. Cheremisinoff, P., Young, R.A., Industrial Odor Technology Assessment, Ann Arbor Science Publishers Inc., Ann Arbor, Mich. (1975).

3. Cowden, D.J., Croxton, F.E., Applied General Statistics, Sir Isaac Pitman and Sons Ltd., N.J. (1955).

4. Dravnieks, A., Odor Thresholds by Forced Choice Dynamic Triangle Olfactometry: Reproducibility and Methods of Calculation, Journal of the Air Pollution Control Association, Vol. 36, No. 8 (August 1986).

5. Dravnieks, A., Jarke, F., Odor Threshold Measurment by Dynamic Olfactometry: Significant Operational Variables, Journal of the Air Pollution Control Association, Vol. 30, No. 12 (December 1980).

6. Dravnieks, A., Prokop, W., Source Emission Odor Measurement by a Dynamic Forced-Choice Triangle Olfactometer, Journal of the Air Pollution Control Association, Vol. 25, No. 1 (January 1975).

7. Duffee, R.A., Cha, S.S., Consideration of Physical Factors in Dynamic Olfactometry, Journal of the Air Pollution Control Association, Vol. 30, No. 12 (December 1980).

8. Duffee, R.A., Wahl, J.P., Defining and Measuring Objectionable Odors, International Pollution Engineering Congress, Philadelphia (1973).

9. Freund, J., Miller, J., Probability and Statistics for Engineers, Second Ed., Prentice-Hall Inc., N.J. (1977).

10. Gatchalian, M.M., Sensory Evaluation Methods with Statistical Analysis, University of the Philippines, Quezon City, Philippines (1981).

11. Gnyp, A., St. Pierre, C., Poostchi, E., Assessing the Impact of Odorous Emissions from Municipal Waste Landfill Sites on the Surrounding Community, Presented at the 78'th Annual Meeting of the Air Pollution Control Association, Detroit, Mich. (1985).

12. IIT Research Institute, Instructions for Dynamic Triangle Olfactometer: 1977 Model, Chicago, Ill. (1976).

13. Leonardos, G., Selection of Panelists, Journal of the Air Pollution Control Association, Vol. 30, No. 12 (December 1980).

14. Odors from Stationary and Mobile Sources, Board on Toxicology and Environmental Hazards, Assembly of Life Sciences, National Research Council, National Academy of Sciences, Washington, D.C. (1979).

15. Poostchi, E.B.M., Development of a Strategy for Quantifying the Impact of Odorous Emissions from Stationary Sources on the Surrounding Communities, Ph.D. Dissertation, University of Windsor, Windsor, Ont. (1985).

16. Prokop, W., Franz, J., Odour Measurement by Dynamic Olfactometry, Journal of the Air Pollution Control Association, Vol. 30, No. 12 (December 1980).

17. Robb, G.P., Turney, B.L., Statistical Methods for Behavioral Science, Intext Educational Publishers, N.Y. (1973).

18. Ruth, J.H., Odor Thresholds and Irritation Levels of Several Chemical Substances: A Review, American Industrial Hygiene Association Journal, Vol. 47 (March 1986).

19. Standard Method for Measurement of Odor in Atmospheres (Dilution Method), Annual Book of ASTM Standards, Part 23, ASTM-01391-57, American Society for Testing and Materials, Philadelphia, P.A. (1972).

20. Threshold Limit Values~~, and Bi~~ological Exposure Indices for 1985-86, American Conference of Governmental Industrial Hygienists, 2nd Printing (1985).

21. Varshney, S.C., Development of Procedures for Determining Industrial Odour Thresholds, M.A.Sc. Thesis, University of Windsor, Windsor, Ont. (1979).

22. Verschueren, K., Handbook of Environmental Data on Organic Chemicals, Van Nostrand Reinhold Co., New York, N.Y. (1977).

23. Viswanathan, S., Evaluation of Intensities, Hedonics and Complaint Potentials of Aliphatic Alcohols and Acetates Using n-Butanol as Standard, M.A.Sc. Thesis, University of Windsor, Windsor, Ont. (1979).

Appendix I

The Odour Generator

The Odour Generator

An odourous gas stream is delivered to the olfactometer by means of the apparatus illustrated in Figure 4.1. The description of its components has already been provided in a previous section.

A. Operation

The concentration of the odourant in the gas stream supplied to the olfactometer can be varied by adjusting the proportion of air that bypasses the odourant tube and the total flow of air into the odour generator. The system has demonstrated the capability of providing an odour which varies in concentration between levels that cannot be detected by the human sense of smell up to concentrations limited only by the vapour pressure of the odourant.

Once a satisfactory odour strength has been selected, the concentration of the odourant is determined by measuring the total volume of air that has passed through the system and the mass of odourant that has been vapourized from the odour tube over a specific period of time. The gas volume is determined by evaluating the difference between the initial and final readings of the dry test meter. The mass of odourant that has been vapourized into the air stream is assessed by weighing the odourant tube before and after the known volume of air has passed through the odour generator. This method of determining odourant concentration will be designated as the Change in Mass and Volume (CMV) procedure for later reference.

The concentration of the odour in milligrams per litre can be calculated from

$$\Delta m = (m_i - m_f) \times 1000 \text{ mg/g}$$

and

$$\Delta V = (V_f - V_i) \times 28.32 \text{ L/ft}^3$$

according to

$$C_o = \frac{\Delta m}{\Delta V} \times \frac{T_m + 273}{T_r + 273} \times \frac{P_r}{P_a + P_g}$$

where Δm = change in amount of odourant in tube (mg)

m_i = initial mass of odourant tube (g)

m_f = final mass of odourant tube (g)

ΔV = air volume passed through the odour generator (L)

V_i = initial reading of the dry test meter (ft^3)

V_f = final reading of the dry test meter (ft^3)

T_m = temperature at which volume of gas is measured (°C)

T_r = temperature at which odour concentration is to be reported (°C)

P_a = atmospheric pressure (inches of H_2O)

P_g = the gauge pressure at the exit of the dry test meter (inches of H_2O)

P_r = pressure at which odour concentration is to be reported (inches of H_2O)

C_o = odourant concentration at P_r and T_r

B. Evaluation of the Odour Generator

The purpose of the odour generator is to deliver a constant flowrate of odourous air to the olfactometer at a constant odourant concentration. Before the odour generator was used its capabilities were verified in a series of experiments.

The reproducibility of odour levels supplied by the odour generator were assessed through the repeated measurement of odourant concentration over a period of six hours. The concentration of the odourant, n-butanol, was determined using the CMV method described earlier. The results of this study are presented in Table I.1.

TABLE I.1: Concentration Variations of n-Butanol over a Six Hour Period.

Test	m_i	m_f	V_i	V_f	C_o
1	39.12160	38.95179	710.409	716.455	0.992
2	38.95179	38.81586	716.695	721.495	1.000
3	38.81586	38.65524	721.642	727.245	1.012
4	38.65524	38.51744	727.365	732.146	1.018
5	38.51744	38.36439	732.295	737.550	1.028
6	38.36439	38.22509	737.660	742.430	1.031
7	38.22509	38.04930	742.560	748.595	1.029
8	38.0493	37.90683	748.722	753.642	1.023

m_i, m_f - g V_i, V_f - ft^3 @ 448.8 in. H_2O, 25°C

C_o - mg/L @ 1 Atm, 10°C

According to the data in Table I.1 the concentration of the odourant from the odour generator did not vary significantly over time. The small variations that are evident (slow increase to a peak value and then slow decrease) may be explained by the changing area of the odourant surface exposed to the air stream. Initially the area increases as the volume of the odourant in the tube decreases due to the cylindrical (oriented horizontally) shape of the odourant tube. When the odourant depth corresponds to the axis of the cylinder, the concentration of the resulting gas is a maximum due to a maximum exposure of surface area. As the depth decreases further, the geometry of the cylinder causes the liquid surface area to decrease with a resulting decrease in the odourant concentration. As shown in Table I.1, the change in concentration due to the fluctuation in surface area was minimal and therefore was not considered to be a significant source of error. In future experiments involving very volatile liquids (resulting in large changes in area over the testing period) the horizontal cylinder could be replaced with an odourant tube with a box-like geometry.

During the period of this test the flowrate of air into the odour generator from the compressed air line was monitored by means of a rotameter. No measureable variations in the flow were noticed over the full testing period.

The CMV method of determining the odourant concentration was verified by passing a known volume of the odourous gas being produced by the odour generator through a tube containing activated carbon. The odourant collected on the charcoal was desorbed from the carbon into a known volume of carbon disulfide. The concentration of the resulting solution was measured using a gas chromatograph. This value was then used to calculate the concentration of the original gas sample. The results of two test samples in which concentrations were measured using both methods are shown in Table I.2.

TABLE I.2: Comparison of Two Methods Used to Determine the Odourant (n-Butanol) Concentration.

Sample No.	Odourant Concentration		Deviation from the Mean (%)
	GC Method (mg/M^3)	CMV Method (mg/M^3)	
1	0.965	0.951	0.73
2	0.978	0.970	0.41
Concentrations reported at 10°C and 1 Atmosphere			

The very good agreement between the two methods used to determine the odourant concentration indicates that the CMV procedure is accurate and will serve the needs of the odour impact model experiments very well.

These experiments have shown that the odour generator meets its objectives of providing

(1) a constant flow of odourous gas

(2) a constant concentration of the odourant in the gas stream

(3) an odour concentration which can be varied by the operator.

Therefore, the odour generator can be used confidently as the source of an odour for panel evaluation.

Appendix II

Olfactometer Calibration Procedures and Verification

Olfactometer Calibration

The dilution factor at each of the six olfactometer stations must be established reliably if the responses of an odour panel are to be expressed on a quantitative basis. These dilution factors can be evaluated by measuring the odour and dilution air flowrates delivered to each port or by measuring the concentration of a known odourant at each port and comparing them with the original odour sample concentration. The former method is simpler and is used on a regular basis because of this simplicity. The latter method can be used to verify the results of the first approach.

A. Volumetric Calibration Procedure

The volumetric calibration procedure depends on the measurement of the odour and dilution air flowrates at each port of the olfactometer.

The calibration procedure begins with the setting of the odour and dilution air pump flowrates to a predetermined level. This level may be set and monitored for any changes in flow by connecting rotameters to the air and delivery lines before they enter the olfactometer. Before flowrate measurements at each of the ports can be initiated, the pumps must be allowed to run until the rotameter readings stabilize to steady values.

Flowrate measurements are performed by pulling off the glass ports, removing the upper plastic ring from the cups carrying the ports to expose the ends of the Teflon lines, and measuring the flow from those lines with a soap film flowmeter (bubble meter). The low flows from the odour delivery lines are measured using a 10 millilitre graduated tube with a soap film solution reservoir. The comparitively higher flowrates of the dilution air lines are measured using a 1.0 litre soap film flowmeter. The time for a bubble to pass from the lower to the upper markings on the tube is measured and recorded. This step is repeated until a set of three reproducible figures is produced for each port.

The gas flowrates through each of the lines is calculated using

$$Q = \frac{V_b}{t} \times 60$$

where Q = the gas flowrate (mL/min)

V_b = the volume of the soap film flowmeter (mL)

t = the time for a soap bubble to pass between flowmeter markings (sec).

The dilution factor at each port is calculated from

$$Z_i = \frac{Q_{a,i} + Q_{o,i}}{Q_{o,i}}$$

where Z_i = the dilution factor at dilution level "i"

$Q_{a,i}$ = the dilution air flowrate at level "i" (mL/min)

$Q_{o,i}$ = the odour flowrate at level "i" (mL/min).

1. Example Volumetric Calibration

A calibration was performed using the volumetric calibration procedure with odour rotameter and dilution air rotameter readings of 9.0 and 40.0, respectively. It should be noted that these values cannot be compared to determine the relative amounts of odourous and clean air supplied to the olfactometer since the rotameters are of different sizes and have different scales to indicate the respective gas flowrates.

Table II.1 lists the time required for the soap bubble to pass between the markings on the soap film flowmeter. Table II.2 includes the odour and air flowrates and the dilution factors at each port determined using the information in Table II.1.

The calibration was repeated one week later for the same odour and dilution air flowrates. Table II.3 presents a comparison of this and the previous calibration results. The data indicate that the calibration performed initially differed from the subsequent calibration by about 1%. Therefore, the first calibration was adopted as a standard program as long as the same flow rates were maintained.

B. Concentration Based Calibration Procedure

Two procedures were developed to verify that the dilution ratios evaluated using the volumetric calibration procedure represented reliable values. Once it had been established that the volumetric procedure produced accurate results, it would not

TABLE II.1: Measured Time between Markings on the Soap Film Flowmeter.

Port No.	Flow Time Between Bubble Meter Markings							
	Dilution Air (sec/L)			Mean	Odourous Gas (sec/10 mL) †			Mean
1	92.0	91.6	91.9	91.8	223.64	220.54	221.25	221.81
2	93.6	93.4	93.5	93.5	75.77	75.79	75.70	75.75
3	90.4	90.9	90.8	90.7	25.16	25.13	25.17	25.15
4	96.2	96.3	96.4	96.3	8.60	8.60	8.62	8.61
5	92.3	91.9	92.1	92.1	3.17	3.15	3.14	3.15
6	97.2	97.5	97.3	97.3	133.94	134.21	134.20	134.12

† Units of odour flow at Port No. 6 are sec/L

TABLE II.2: Air and Odour Flowrates and the Resulting Dilution Factors.

Port No.	Flow Rate (mL/min)		Dilution Factor
	Dilution Air	Odourous Gas	
1	653.6	2.7	242.2
2	641.7	7.9	82.0
3	661.5	23.9	28.7
4	623.1	69.7	9.9
5	651.5	190.5	4.4
6	616.6	447.4	2.4

TABLE II.3: Comparison of Two Calibrations with Air and Odour Rotameter Readings of 9.0 and 40.0, respectively.

Port No.	Dilution Factor			Deviation from the the Mean (%)
	First Calibration	Second Calibration	Mean	
1	242.2	238.9	240.6	0.7
2	82.0	81.0	81.5	0.6
3	28.7	28.2	28.5	1.1
4	9.9	9.8	9.9	0.5
5	4.4	4.5	4.5	1.1
6	2.4	2.4	2.4	0.0

be necessary to perform a concentration based calibration again.

The concentration based technique requires an odourant to be generated and introduced at a known concentration into the olfactometer. The concentrations of the resulting diluted odourous streams can be measured and compared with the original odourant concentration to determine the dilution factors. The dilution factor at each port is calculated using;

$$Z_i = \frac{C_o}{C_i}$$

where Z_i = the dilution factor at port "i"

C_o = the concentration of the odour introduced into the olfactometer

C_i = the odourant concentration at port "i" (same units as C_o).

1. Organic Vapour Analyzer Technique

An organic vapour analyzer (OVA) was used to measure the relative concentrations of n-butanol in gas samples. This instrument was chosen as the means of measuring the odourant concentration due to the simplicity of analyzing the gas samples without elaborate calibrations. In addition, the OVA allowed multiple analyses to be made in rapid succession. As a result, tests could be performed until reproducible results were obtained. The OVA utilizes the principle of hydrogen flame ionization for detection and measurement of organic vapours. It measures an organic vapour concentration by producing a response to the unknown sample which can be related to a gas of known composition with which the instrument has been calibrated previously. The relationship between the response to an unknown vapour and a known vapour is linear. Consequently, it is unnecessary to perform an instrument calibration using the same vapour that is being examined. Instead, the concentration of the unknown sample may be assessed in terms of, say, methane and the results multiplied by a constant factor to determine the actual concentration of the compound of interest. Since this factor is constant over the full range of the OVA's measuring ability, it is not necessary to calibrate the instrument at all if only relative concentrations are required. This principle is demonstrated by the calculation of the dilution factor at each port using the response of the OVA according to

$$Z_i = \frac{C_o}{C_i} = \frac{R_o \times K}{R_i \times K} = \frac{R_o}{R_i}$$

where R_o = the OVA response to the original odour supply

R_i = the OVA response to the gas sample collected at port "i"

K = the constant relating the response of the OVA to the concentration of the organic vapour.

Therefore, is isn't necessary to evaluate the constant "K" if only the relative concentrations, or dilution factors, are required.

a. Experimental Setup

The odour supply was generated in advance of the calibration procedure by continuously renewing the head space above the liquid surface of an odourant contained in a horizontal cylindrical tube. This apparatus is illustrated in Figure II.1. The odourous gas exiting from the odourant tube was collected in three 15 L capacity Tedlar bags connected in series. This arrangement of the bags was used to ensure a homogeneous odourant concentration in each container. A measure of predilution was necessary so that the odourant concentration did not exceed the maximum measuring ability of the OVA. This was accomplished by partially filling the odour bags with clean air before the odourant was introduced. The odourant used in the calibration experiments was n-butanol.

The OVA could not be connected directly to the

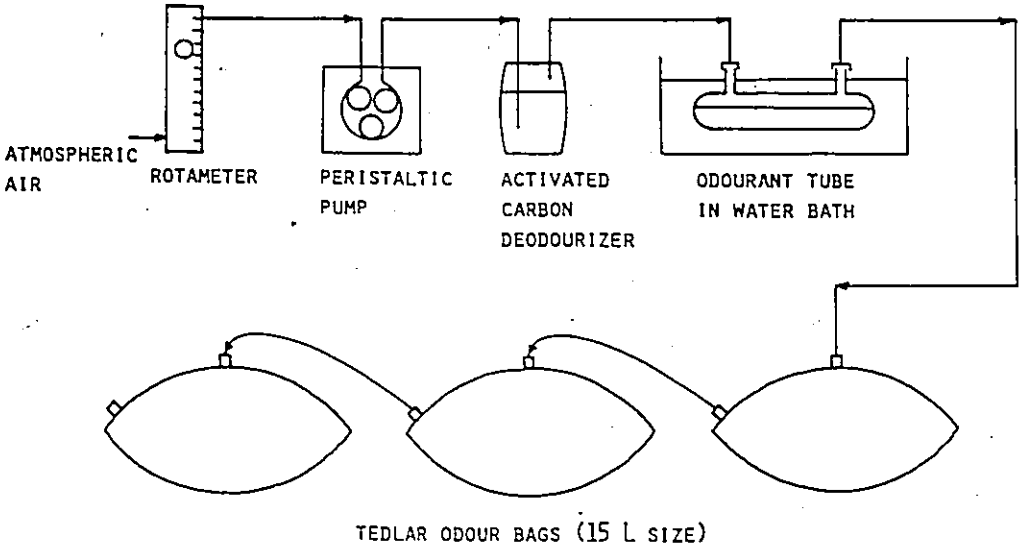


FIGURE II.1: Generation of a Gas Sample for the Olfactometer Calibration.

olfactometer since it required a sample flowrate greater than 1500 mL/min. This flowrate could not be provided by the olfactometer at each port, therefore the samples had to be collected in airtight bags and then analyzed using the OVA. The sample collection apparatus is shown in Figure II.2. Six identical versions of this apparatus were used simultaneously to collect all samples at all dilution levels at the same time.

Before sample generation could begin, it was necessary to prove the integrity of the sampling apparatus. Since the flow of the dilution air can often be much higher than the flow of the odourous gas it is possible that some air flow may be diverted from the sample line into the odour manifold. This diversion would restrict the flow of the odour from the manifold and would produce results inconsistent with the volumetric calibration method. Verification of the apparatus was made by measuring the odour flow and dilution flow separately and adding them together to produce a predicted total flowrate. The total flow was then be measured and compared with the predicted total flow. If the measured flow is less than the predicted flow, it is likely that some of the dilution air has been diverted into the odour manifold. It must be noted that all the individual and combined flows must be measured with the sampling apparatus in place so that all flowrates are measured under the same experimental conditions. This is especially critical because the flow of air and odour to each of the olfactometer ports is extremely pressure sensitive and any changes in pressure resulting from the connection of the sampling apparatus to the

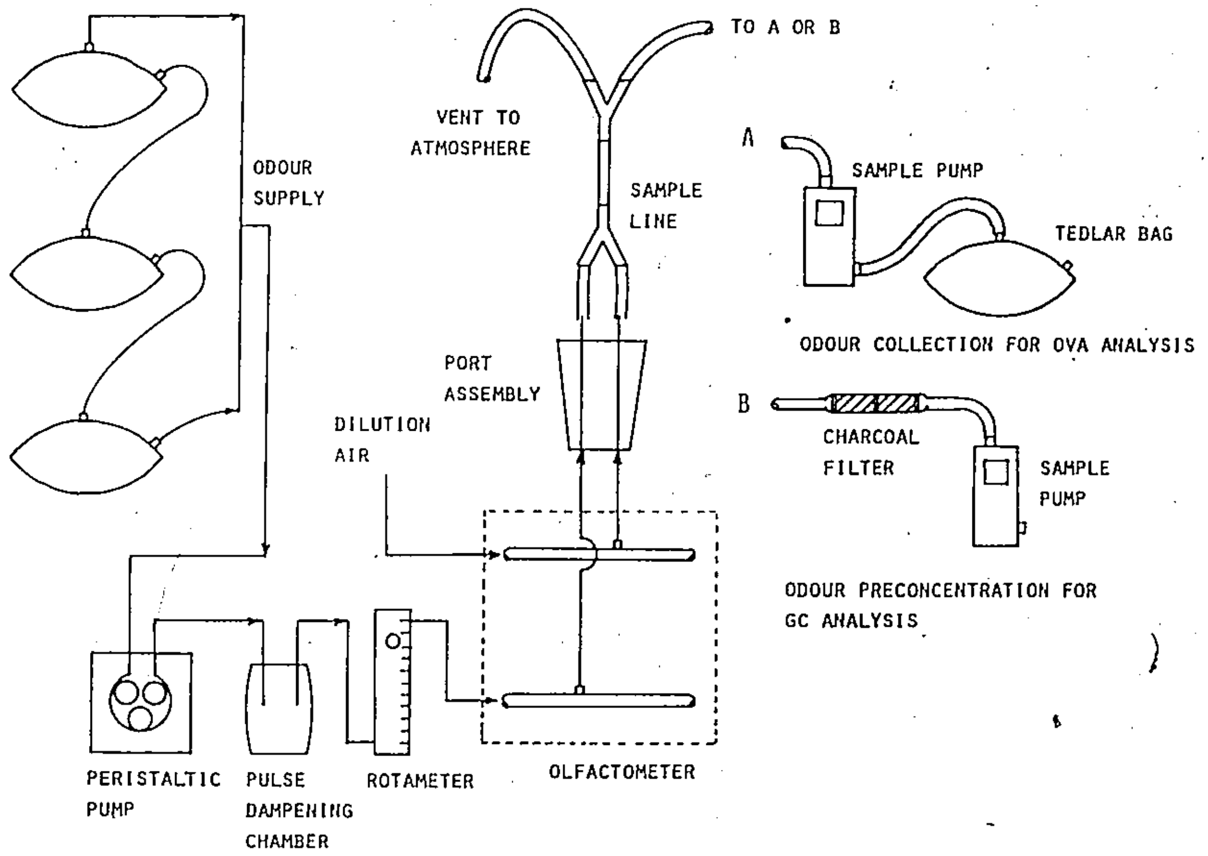


FIGURE II.2: Sample Collection Apparatus for the Olfactometer Calibration.

olfactometer must be taken into consideration.

These verification measurements were performed twice using two different sets of gas flowrates. The results are presented in Tables II.4 and II.5.

The results shown in Tables II.4 and II.5 did not demonstrate any significant deviation of the measured total flow from the predicted total flow. Therefore, it can be concluded that the sampling apparatus would collect the sample without interrupting the odour flow from the odour manifold.

b. Volumetric Calibration

Since it was the purpose of the concentration based calibration procedure to verify the volumetric calibration procedure, it was necessary to perform both calibrations with the sampling apparatus in place. The results shown in Tables II.1, II.2 and II.3 were made with this apparatus in place. Therefore these dilution ratios are valid for any experiment run with the same odour and air flowrates.

c. Concentration Based Calibration

A calibration was performed with the odour rotameter and dilution air rotameter settings of 40.0 and 9.0, respectively. The bag samples collected at each port and the original odour supply were analyzed using the Organic Vapour Analyzer. The results for this calibration are shown in Table II.6.

TABLE II.4: First Verification of Sampling Apparatus.

Port No.	Flowrates (mL/min)				Deviation from the Predicted Total Flow (%)
	Odour Flow	Air Flow	Predicted Total	Measured Total	
1	1.9	632.1	634.0	637.9	+0.6
2	5.3	632.0	637.3	643.7	+1.0
3	16.2	654.9	671.1	672.3	+0.2
4	47.9	576.0	623.9	640.4	+2.6
5	131.7	641.0	772.7	780.8	+1.0
6	337.1	597.9	935.0	941.5	+0.7

TABLE II.5: Second Verification of Sampling Apparatus.

Port No.	Flowrates (mL/min)				Deviation from the Predicted Total Flow (%)
	Odour Flow	Air Flow	Predicted Total	Measured Total	
1	3.0	654.7	657.7	657.0	-0.1
2	8.7	648.2	656.9	659.9	+0.5
3	26.0	665.0	691.0	697.3	+0.9
4	76.1	619.2	695.3	700.4	+0.7
5	199.6	660.1	859.7	861.6	+0.2
6	487.2	618.7	1105.9	1114.1	+0.7

TABLE II.6: OVA Calibration of the Olfactometer.

Port #	OVA Response	Dilution Factors		Deviation From The Mean (%)
		OVA Method	Volume Method	
1	2.5	230.0	240.6	2.3
2	7.6	75.7	81.5	3.7
3	24.0	24.0	28.5	8.6
4	66.0	9.0	9.9	4.8
5	135.0	4.4	4.5	1.1
6	260.0	2.2	2.4	4.4
Bag	575.0	--	--	--

The results in Table II.6 show that the volumetric flow measurements provide a good evaluation of the dilution factor at each port. Much of the variation encountered may be due to the low concentrations of the samples that were generated. In order to determine if this measurement difference could be reduced, another calibration was performed using a slightly modified experimental setup.

Instead of using Tedlar bags as the odour supply, an odour generator was connected directly to the olfactometer. The odour generator supplied a gas stream with a very high n-butanol concentration which exceeded the measuring capability of the OVA. However, the n-butanol concentrations at each of the ports were within the measureable range. Therefore, a comparison between the two calibration methods can be made by normalizing the dilutions with respect to the dilution factor at port 6. These normalized dilution ratios are presented in Table II.7.

TABLE II.7: OVA Calibration Results Relative to Port 8.

Port No.	OVA Response	Dilution Factors Relative to Port 6		Deviation From The Mean (%)
		OVA Method	Volume Method	
1	5.0	104.0	100.3	1.8
2	14.5	35.9	34.0	2.7
3	46.0	11.3	11.9	2.6
4	125.0	4.2	4.1	1.2
5	270.0	1.9	1.9	0.0
6	520.0	1.0	1.0	--

These results indicate that less variation occurs during OVA measurements with higher n-butanol concentrations. This improvement in the agreement of the two calibration procedures further supports the contention that the volumetric calibration technique can adequately predict the actual dilution levels produced by the olfactometer.

2. Preconcentration Technique

A second technique was used to verify the dilution factors predicted by the volumetric calibration procedure. This approach involved passing a known volume of the odourous gas from each of the ports through an activated carbon filter. The amount of odourant collected on the carbon was determined by extracting the odourant into a known volume of carbon disulfide liquid with subsequent injection of a fraction of the solution into a Gas Chromatograph (GC). The response of the GC can be related to the original mass of odourant collected on the carbon filter and , thus, the odourant concentration in the gas.

The odour generator illustrated in Figure II.1 was used to generate an odourous stream of n-butanol in air of a high concentration. The sampling apparatus shown in Figure II.2 was used simultaneously at all six ports and at the effluent point from the odour generator to generate charcoal filter samples for analysis. Once the samples had been analyzed and the concentrations of the gas at each port and in the original odour supply were established, the dilution factor at each port was calculated from

$$Z_i = \frac{C_o}{C_i}$$

where Z_i = the dilution factor at dilution level "i"

C_o = the odourant supply concentration

C_i = the odourant concentration at port "i"

The results for two tests performed in this manner are presented in Table II.8.

The very poor agreement between the two calibration procedures, except at low dilutions, may be explained by the difficulty in extracting the odourant from the charcoal when

TABLE II.8: Dilution Factors According to the GC Analysis of Charcoal Filters.

Port No.	Dilution Factor		
	Volumetric Method	Test #1	Test #2
1	240.	---	970.
2	81.0	360.0	164.0
3	28.2	58.0	36.3
4	9.8	14.8	11.1
5	4.5	5.6	4.6
6	2.4	2.6	2.3

concentrations are very low. An attempt was made to increase the mass of odourant collected on the charcoal by increasing the odour concentration being supplied to ~~the~~ olfactometer and by drawing larger volumes of the odourous gas from each of the ports through the charcoal tubes. Unfortunately, the supply stream concentration exceeded the capacity of the charcoal tube and therefore this concentration was not measured. However, when the dilutions from each of the ports were normalized with respect to port 6, the results shown in Table II.9 are produced.

The results of the third charcoal filter test showed much better agreement between the two calibration procedures except at very high dilutions where the amount of odourant collected on the charcoal was relatively small. The good agreement at the majority of the ports, however, supports the

TABLE II.9: Normalized Dilution Factors

Port No.	Dilution Factor	
	Volumetric Method	Charcoal Test #3
1	100.3	200.5
2	34.0	40.9
3	11.9	11.8
4	4.1	4.0
5	1.9	1.9
6	1.0	1.0

contention that the volumetric calibration procedure is a satisfactory method for assessing the dilutions at each port.

If it is necessary to perform tests such as this in future research, it is suggested that the OVA technique be chosen over the option of using the GC method. Another alternative that could be used in place of these two techniques would be the use of a MIRAN Gas Analyzer for which a tracer gas such as sulfur hexafluoride or Freon could be introduced into the olfactometer at a known concentration. The gas analyzer response at each port could be used to determine the appropriate dilution factors.

Appendix III

Panelist Information

Panelist Information

Name	Age	Sex	Odourous Working Atmosphere?
K. Akers	23	Female	Yes
N. Berends	25	Female	Yes
J. Bewtra	51	Male	No
N. Bewtra	21	Male	No
T. Bures	25	Male	Yes
N. Cavallaro	21	Female	Yes
K. Chan	30	Male	No
A. Chandra	18	Male	No
P. Chevalier	21	Male	No
G. Chodola	25	Male	No
L. Coon	24	Female	No
D. Dick	24	Male	Yes
P. Doan	29	Male	Yes
K. Ellwood	24	Male	No
T. Ferranti	22	Female	Yes
L. Gelmini	25	Male	Yes
A. Gnyp	55	Male	No
A. Godo	23	Female	No
M. Godo	25	Male	No
R. Iravani	29	Male	No
C. Jennings	27	Female	Yes
G. Jones	25	Male	No
M. LaPointe	60	Female	No
R. Lappan	23	Male	No
R. Lashkari	40	Male	No
K. Liebsch	20	Male	No
C. MacInnis	61	Male	No
J. McCorquodale	19	Male	No
C. McDonald	21	Female	No
W. McKennie	62	Male	No
J. McIntosh	46	Male	Yes
W. Miller	49	Male	No
R. Nease	26	Female	No
J. Nicell	23	Male	No
B. Palmer	23	Female	No
A. Ramos	30	Male	No
C. Rogers	24	Female	Yes
G. Ryan	53	Male	No
C. St.Pierre	48	Male	No
J. Scott	22	Male	Yes
D. Simon	25	Male	No
R. Stager	49	Male	No
D. Stein	23	Female	No
D. Stephan	33	Male	Yes
E. Sullivan	24	Female	No

Name	Age	Sex	Odourous Working Atmosphere?
C. Talpas	21	Male	No
N. Thanik	20	Female	Yes
D. Watt	48	Male	No
M. Wellisch	24	Female	No
G. White	25	Male	Yes
A. Wollin	30	Male	No
T. Wong	19	Male	No
B. Youdelis	54	Male	No
R. Zytner	27	Male	No

Total No. of Panelists = 54

Group	% Of Total Group
Age between 18 and 29 *	70
Over the age of 30	30
Over the age of 40	24
Over the age of 50	13
Male	69
Female	31
Odourous working atmosphere	28
Non-odourous working atmosphere	72

* People below the age of 18 were not asked to participate in these experiments because they are considered to be minors under the laws of Ontario.

Appendix IV

Analysis of Raw Panel Data

Analysis of Raw Panel Data

For illustrative purposes, consider a 10-member panel evaluating an odour with a six level dynamic olfactometer using a ternary forced-choice technique in ascending series of concentration. Typical raw data collected during a test are summarized in Tables IV.1 and IV.2.

The data in Table IV.1 can be simplified by replacing the panelists' identification of the odourous ports with the numbers zero (0) or one (1); zero (0) indicating an incorrect choice and one (1) indicating a correct choice of an odourous port. These simplified data are presented in Table IV.3. At each port the number of panelists who correctly choose subsequent odourous ports consistently from their initial correct choice are totaled and expressed as a percentage of the full panel. These percentages are the values of the percent probability of detection at each of the six dilution levels.

The percent probability of discrimination is determined from the panelists' indications of the dilution level at which they are certain, beyond a doubt, about the presence of the odour. Care must be taken to ensure that the panelists' claims of the dilution levels at which they begin to discriminate the odour correspond with the dilution levels after which they consistently detect the odour. If there isn't correspondence then the dilution level at discrimination for that particular panelist is adjusted to a dilution level at which the individual consistently

TABLE IV.1: Panelists' Indication of Odourous Tubes

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
C.T.	3	1	1	1	3	2
D.S.	2	1	1	1	3	2
M.W.	3	2	1	1	3	2
L.G.	1	1	1	1	3	2
R.I.	3	3	2	2	3	2
D.St	1	2	1	1	3	2
C.M.	1	2	3	3	1	2
R.S.	3	3	2	1	3	2
W.M.	1	1	2	2	3	2
K.E.	3	3	1	1	3	2

TABLE IV.2: Panelists' Degree of Annoyance and Dilution Level of Discrimination.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
C.T.	0	0	1	2	3	4	4
D.S	0	0	0	0	0	0	3
M.W.	1	1	1	3	4	8	4
L.G.	1	1	1	2	3	4	4
R.I.	0	0	0	0	0	2	6
D.St	0	0	0	0	3	3	5
C.M.	0	0	0	0	0	2	6
R.S.	0	0	1	2	4	4	3
W.M.	0	0	0	2	2	2	4
K.E.	0	0	0	0	1	4	4

TABLE IV.3: Summary of Correct and Incorrect Responses and the Resulting Probability of Detection

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
C.T.	0	0	1	1	1	1
D.S.	1	0	1	1	1	1
M.W.	0	0	1	1	1	1
L.G.	0	0	1	1	1	1
R.I.	0	1	0	0	1	1
D.St	0	0	1	1	1	1
C.M.	0	0	0	0	0	1
R.S.	0	1	0	1	1	1
W.M.	0	0	0	0	1	1
K.E.	0	1	1	1	1	1
Correct from this portion (%)	0	10	60	70	90	100

detects the odour. The dilution levels at which the panelists discriminate are identified in Table IV.4 by the letter "D". The percentage of people who discriminate at each port produces the values for the percent probability of discrimination curve of the Odour Impact Model.

A person is considered to have complained if he/she expresses a degree of annoyance greater than zero. Table IV.4 indicates the panelists who have complained at each dilution level with the letter "C". The percent probability of complaint curve encompasses only those panelists who both discriminate and complain about the odour. These panelists are identified in Table IV.4 with both a "D" and a "C" at certain dilution levels. Complaints which do not correspond to a concentration at which the panelist discriminates the odour cannot be ascribed to the odour and, therefore, they are adjusted to zero. These adjusted complaint levels are shown in Table IV.5.

The predicted degree of annoyance is calculated by averaging the panelists' complaint levels at each dilution level. Two sets of panel annoyance values have been included. The method of evaluation depends on whether the annoyance of those who discriminate and complain about the odour is to be evaluated (only non-zero annoyance values are included) or if the full panel's annoyance (all annoyance values are included) is wanted.

The results of the odour impact model calculations are summarized in Table IV.6. If the odour impact model is to be presented as a function of concentration rather than dilutions,

TABLE IV.4: Panelists' Probability of Discrimination and Complaint.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
C.T.	–	–	C	DC	DC	DC
D.S.	–	–	D	D	D	D
M.W.	C	C	C	DC	DC	DC
L.G.	C	C	C	DC	DC	DC
R.I.	–	–	–	–	–	DC
D.St	–	–	–	–	DC	DC
C.M.	–	–	–	–	–	DC
R.S.	–	–	C	DC	DC	DC
W.M.	–	–	–	C	DC	DC
K.E.	–	–	–	D	DC	DC
% Discrim.	0	0	10	60	80	100
% Complaint	0	0	0	40	70	90

TABLE IV.5: Degree of Annoyance at Each Dilution Level.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
C.T.	0	0	0	2	3	4
D.S.	0	0	0	0	0	0
M.W.	0	0	0	3	4	8
L.G.	0	0	0	2	3	4
R.I.	0	0	0	0	0	2
D.St	0	0	0	0	3	3
C.M.	0	0	0	0	0	2
R.S.	0	0	0	2	4	4
W.M.	0	0	0	0	2	2
K.E.	0	0	0	0	1	4
Mean (only non-zero)	0.0	0.0	0.0	2.3	2.9	3.7
Mean (all values)	0.0	0.0	0.0	0.9	2.0	3.3

TABLE IV.6: Reduced Data for the Odour Impact Model.

Point	Dilutions	Concentration ($\mu g/M^3$)	PD	PDn	PC	DA
1	1765.	95.9	0	0	0	0
2	576.	294	10	0	0	0
3	183.	925	60	10	0	0
4	58.9	2920	70	60	40	0.9
5	21.3	7950	90	80	70	2.0
6	7.3	23200	100	100	90	3.3

the concentration of the odour supply must be known. In this example, the data that have been used correspond to methyl isoamylketone with an odour supply concentration of 1.692×10^5 $\mu g/M^3$.

The data presented in Table IV.6 are illustrated in Figure IV.1 as functions of odour concentration.

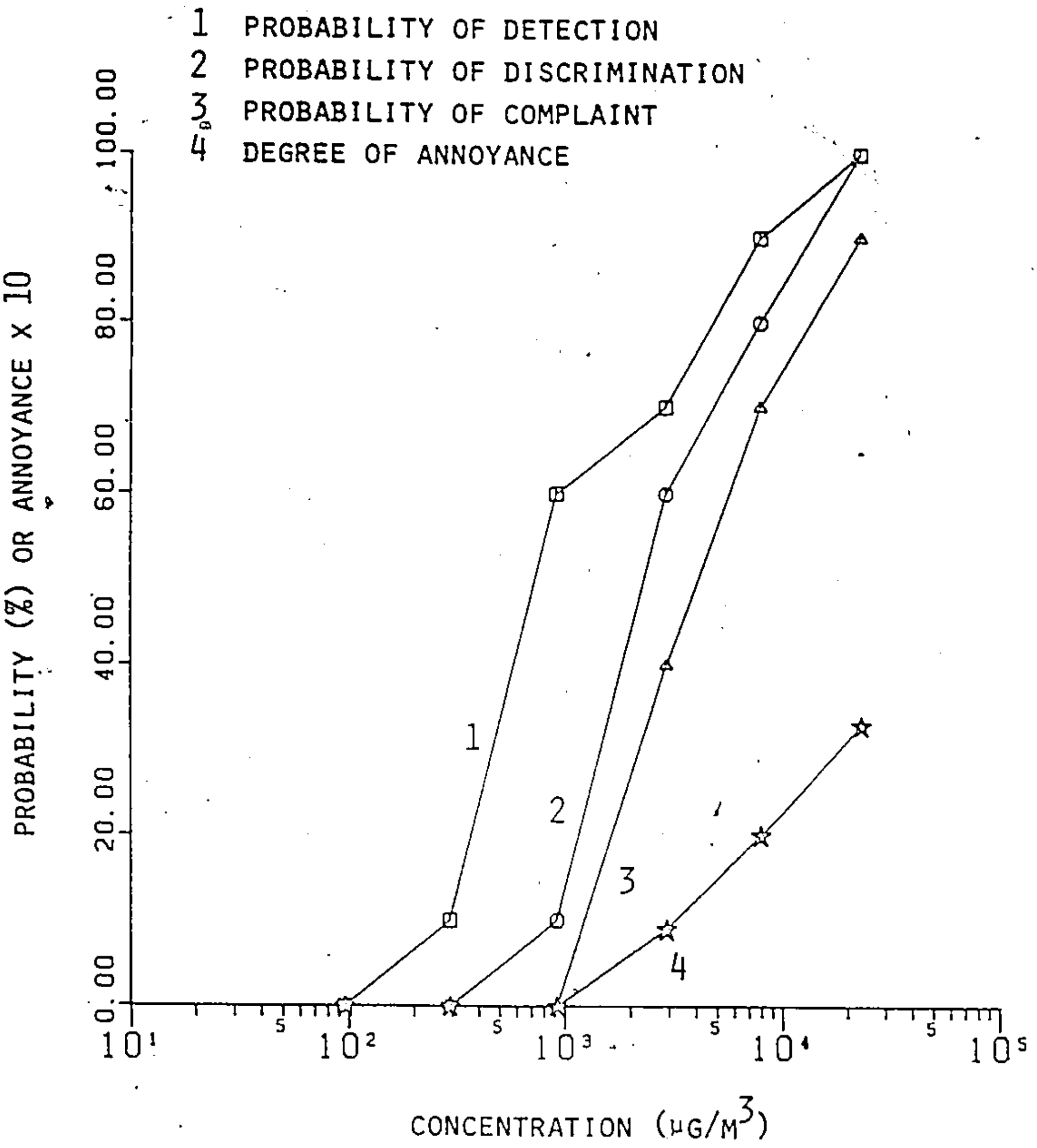


FIGURE IV.1: Odour Impact Model for Methyl Isoamylketone Using a 10-Member Panel.

Appendix V

Statistical Analysis of Odour Impact Model Data

Statistical Analysis of Odour Impact Model Data

It is often useful to compare the mean scores of a number of samples to determine whether a statistically significant difference exists with respect to a particular measuring instrument. The intent is to establish whether a difference between sample means should be regarded as evidence that there is a real difference on some measuring scale between means of the examined groups and not just a difference which has occurred because of sampling errors. This analysis is called a test of significance.

A. The Null Hypothesis

The question of whether or not a sample could have been drawn from a particular population can be examined through use of what is known as a "null hypothesis". This hypothesis is a statement making the proposition that there is no real difference between the sample mean and the corresponding population mean. That is, $\mu_1 = \mu_2$ or $\mu_1 - \mu_2 = 0$ represents the null hypothesis designated as H_o. If there is an observed difference, this is assumed to be due to chance or sampling error. Therefore, the aim of the null hypothesis is to set up a test situation in which the it can be examined and a conclusion can be made as to whether the hypothesis may or may not be rejected. If the null hypothesis is rejected, then the observed difference between the means is considered to be significant and not due to chance.

To test a null hypothesis, H_o, it is necessary to assume that no difference exists between the population means. When measurements have been made, the differences between the sample means are observed, and then the probability of obtaining an difference, $\bar{X}_1 - \bar{X}_2$, which is larger than the observed difference is determined. The sample means, $\bar{X}_1$ and $\bar{X}_2$ are estimates of the population means, μ_1 and μ_2. If the probability is small, the examiner may reject the null hypothesis. If H_o is retained at a specified level of significance, this would indicate that the difference between sample means was not sufficiently large to rule out those differences which may arise by chance. Rejection of the null hypothesis would indicate that the difference between the observed means was so large that the difference would rarely occur due to sampling error if the value μ_1 had equaled μ_2. When a null hypothesis is rejected, it is concluded that there is a real difference between sample means [17].

The rejection or retention of H_o depends on the level of significance chosen as a basis for the decision. The most commonly used levels are the 5% and 1% levels of significance. The 5% level of significance specifies that the chances are 5 in 100 that differences in the means due to experiment could be obtained when in reality there were no differences between population means. The 1% level of significance would be used to make the chances 1 in 100 of incorrectly concluding $\mu_1 - \mu_2 = 0$ based on the sample mean difference, $\bar{X}_1 - \bar{X}_2$. [17]

B. Analysis of Variance (ANOVA)

The previous discussion was limited to the comparison of two sample means, however, the same procedure may be extended to the comparison of any number of sample means using a method called the Analysis of Variance (ANOVA).

1. Theory [1,17]

When K populations are to be studied it is assumed that each will be normally distributed and to have the same variance, σ^2. Also, the hypothesis is made that the population means, μ_1, μ_2, ..., μ_K, are all identical. If a random sample of size N is drawn from each of the K populations, then a set of K means ($\bar{X}_1$, $\bar{X}_2$, ..., $\bar{X}_K$) and K variances (s_1^2, s_2^2, ...,s_K^2) can be calculated. Since the population variances are all assumed to be equal to σ^2, all sample variances, s_j^2's, may be averaged to produce an estimate of σ^2. This estimate is calculated according to

$$MV_{wg} = \frac{1}{K} \sum_{j=1}^{K} s_j^2 \qquad (V.1)$$

where MV_{wg} = the Mean of Variances withing groups

K = the number of populations being compared.

s_j^2 = the variance of sample j

Since each sample variance is of the form

$$s_j^2 = \frac{ss_j}{N_j - 1} \qquad (V.2)$$

where ss_j = the sum of the square of measurements within a sample
N_j = the number of measurements within a sample.

and the N_j's are equal, therefore the mean variance, $\bar{s}^2$, may be written as

$$\bar{s}^2 = \frac{1}{K(N-1)} \sum_{j=1}^{K} ss_j \qquad (V.3)$$

Also, since it has been assumed that the K different $\bar{X}$'s are estimates of the same quantity, μ, the variance of the sample means,

$$s_{\bar{X}}^2 = \frac{1}{K-1} \cdot \sum_{j=1}^{K} (\bar{X}_j - \bar{X})^2 \qquad (V.4)$$

is an estimate of σ^2/N, the variance of the sample distribution of $\bar{X}$, which is the mean of K sample means. Therefore, N times the variance of the means provides an estimate of the common population variance, σ^2. This estimate is written as

$$MV_{bg} = N \cdot s_{\bar{X}}^2 \qquad (V.5)$$

This quantity will be referred to as MV_{bg}, representing N times the Mean of the Variance between groups.

When K samples are randomly drawn, the two quantities MV_{wg} and MV_{bg} are independant estimates of the same variance, σ^2. If the population means, μ_1, μ_2, ..., μ_k, are different from each other in any way, the statistic MV_{bg} will estimate a quantity larger than σ^2. Therefore, in analysis of variance the sample values of MV_{bg} and MV_{wg} are compared by forming their ratio, F, in terms of

$$F_c = \frac{MV_{bg}}{MV_{wg}} \qquad (V.6)$$

When this ratio is larger than unity by some substantial amount, dictated by the chosen level of significance, this is taken to indicate that the population means differ from one another. The ratio, F_c, may exceed unity by mere chance due to the random sampling from the respective populations. Also, this ratio can be less than unity. If this is the case, then evidence suggests that any difference among population means is only slight when compared to the variance, σ^2.

Once the F-statistic has been calculated for a particular set of sample data, a table of values of the F-distribution may be consulted to determine if significant differences exist between groups being studied. In this table two sets of degrees of freedom (df) are always involved. The two degrees of freedom are calculated from

$$df_{bg} = K - 1 \qquad (V.7)$$

$$df_{wg} = N_t - K \qquad (V.8)$$

where df_{bg} = the degrees of freedom between groups
df_{wg} = the degrees of freedom within groups
N_t = the total number of observations
K = the total number of samples.

The value of F_α from the table determines whether the null hypothesis is to be rejected, or not. If $F_c \geq F_\alpha$ at a particular level of significance, α, then the null hypothesis is rejected and the conclusion is made that the sample means $\bar{X}_j$ are not all drawn from the sampe population. That is, there is a statistically significant difference between means.

2. Rejection and Non-Rejection of the Null Hypothesis

Two cases may arise from the use of ANOVA. If $F_c \geq F_\alpha$ then the null hypothesis is immediately rejected and the conclusion is made that there is a significant difference between the means. However, if $F_c < F_\alpha$ then the null hypothesis is not rejected but neither is it accepted. That is, the alternative to rejecting the null hypothesis is not necessarily to accept it.

A significance test may result in four possible situations as demonstrated in Table V.1.

TABLE V.1: Situations Arising from a Significance Test.

Actual Situation	Conclusion	
	Sample is from Population (accept H_o)	Sample is not from Population (reject H_o)
Sample is from population	CORRECT	INCORRECT (Type I error - rejecting a true hypothesis)
Sample is not from population	INCORRECT (Type II error - accepting a false hypothesis)	CORRECT

The error in concluding that the sample doesn't come from the population when, in fact, it does is called a Type I error. The error in concluding that a sample is from the population when in reality it isn't is called a Type II error. In most cases, the aim is to avoid a Type I error. But if the alternative to rejecting the H_o is to accept it, in reducing to a minimum level the probability of rejecting a true hypothesis, the probability that a Type II error will be made is increased. That is, a false hypothesis will be accepted.

In order to estimate the probability of committing a Type II error, it is necessary to hypothesize a true population mean. This is not possible very often. Therefore, one must be aware of the conditions under which an acceptance of the null hypothesis can be made with a low probability of making a Type II error.

The alternative to rejecting the null hypothesis when $F_c < F_\alpha$ requires careful consideration. For small values of F_c (less than unity), accepting the null hypothesis is reasonable. Also, when $F_c = 1.0$, it is still possible to justify the conclusion that the null hypothesis, H_o, is true. But for intermediate values where $1.0 < F_c < F_\alpha$, the most realistic alternative is to withold judgement since the probability of making a Type II error is substantial. Effectively, these are the best conclusions which can be made about the equality of sample means.[1]

It is possible to increase the confidence in making a conclusion to accept a null hypothesis by performing the Cochran

Test for the Homogeneity of Variances. If the variances for each of the sample populations are equal and the ANOVA test doesn't allow a rejection of H_o then the null hypothesis may be accepted with a lower probability of making a Type II error. The test for the homogeneity of variances may be made by calculating a parameter, g, according to

$$g = \frac{\text{Maximum Value of } s_j^2}{\sum_{j=1}^{K} s_j^2} \qquad (V.7)$$

This parameter is the ratio of the largest sample variance to their total. The hypothesis that $\sigma_1^2 = \sigma_2^2 = \ldots \sigma_K^2$ is accepted if

$$g \leq g_\alpha$$

where g_α is given in a table at levels of significance, $1-\alpha$. This standard table is entered with n, the number of observations within each group, and K, the number of variances being considered. This test is only applicable to comparisons between equal sized samples.

If it is found that the variances are not equal then it is not adviseable to accept the null hypothesis unless F_c is very small since one of the requirements of the ANOVA method is that the variances should be equal.

C. Confidence Limits of a Mean

Once a value has been determined from measurements performed on random samples it is useful to determine the limits between which the mean, $\bar{X}$, would be expected to occur if the test were repeated with any other random samples. That is, two values may be determined which shall be designated $\bar{X}_L$ and $\bar{X}_U$ and which will be smaller and larger than $\bar{X}$, respectively. These upper and lower values of the mean are called the "confidence limits" of $\bar{X}$ and define a confidence interval in which $\bar{X}$ may be expected to occur.

The first step in finding the confidence limits of $\bar{X}$ consists of deciding how often a wrong statement of confidence limits is tolerable. If it is tolerable to be wrong not more than 5 times out of 100, then a 95% confidence level may be chosen. Once this value has been decided upon, the values of $\bar{X}_L$ and $\bar{X}_U$ may be determined by making use of the values of $\bar{X}$, the sample mean, and s, the sample standard deviation, which are calculated using

$$\bar{X} = \frac{1}{N} \cdot \sum_{i=1}^{N} X_i \tag{V.8}$$

$$s = \sqrt{\frac{\sum_{i=1}^{N} (X_i - \bar{X})^2}{(N - 1)}} \tag{V.9}$$

where $\bar{X}$ = the sample mean

X_i = observation i of the sample

s = the sample standard deviation

N = the number of observations in the sample.

The population mean will lie somewhere between the limits defined by

$$\bar{X}_P = \bar{X} \pm t_\alpha \cdot \frac{s}{N^{1/2}} \qquad \text{(V.10)}$$

where t_α is the Student's t-statistic whose value depends on the value of N and the confidence level which is chosen. Therefore, the lower and upper bounds of the limits are defined by

$$\bar{X}_L = \bar{X} - t_\alpha \cdot \frac{s}{N^{1/2}} \qquad \text{(V.11)}$$

and

$$\bar{X}_U = \bar{X} + t_\alpha \cdot \frac{s}{N^{1/2}} \qquad \text{(V.12)}$$

The determination of the confidence limits for a mean depends on the fact that the data are normally distributed. If the data are not normally distributed then confidence limits cannot be calculated unless the data can be functionally altered to produce a normal or Student's t-distribution. For example, if a set of measurements is log-normally distributed then the confidence limits of the data can be determined by performing the same calculations as shown above except the logarithms of the measurements must be used instead of the actual values of the measurements. Once the upper and lower bounds of the confidence limits have been determined for the logarithm of the measurements, then they can be converted to the original form of the data by taking the antilogarithm of the limits. The confidence interval for this type of data will not be distributed evenly on both sides of the mean as shown in equation V.10 but instead will be skewed due to the log-normal distribution of the data.

D. Application of Statistics to the Odour Impact Model

The Analysis of Variance (ANOVA) may be used to compare the annoyance of a panel at any odourant concentration, the mean detection threshold (ED_{50}), and the mean discrimination threshold (D_{50}) with similar values produced by any number of other panels.

1. The Degree of Annoyance Curve

Unfortunately, a statistical test does not exist which may be used to compare an entire curve with another without mathematical expressions which describe the curves. Since no equation has been determined which fits a panel's degree of annoyance curve, one must be content to compare the curves at certain selected points.

In this study, ANOVA was applied to six evenly spaced (on the logarithmic scale) concentration values at which the panel produced annoyance ratings of the odours. The test was applied to see if the mean annoyance ratings of individuals on a panel differ with respect to the means of other panels at the same comparison points. ANOVA requires values of the mean and variance of each panel before a comparison may be made. These are calculated for the degree of annoyance curve at any chosen concentration by

$$\overline{DA}_{j,k} = \frac{1}{N_j} \cdot \sum_{i=1}^{N_j} DA_{i,j,k} \qquad (V.13)$$

and
$$s_{j,k}^2 = \frac{1}{N_j - 1} \cdot \sum_{i=1}^{N_j} (DA_{i,j,k} - \overline{DA}_{j,k})^2 \qquad (V.14)$$

where $\overline{DA}_{j,k}$ = the mean degree of annoyance of panel j at comparison point k

$DA_{i,j,k}$ = the degree of annoyance of panelist i on panel j at comparison point k

$s_{j,k}^2$ = the variance of panel j at comparison point k.

These calculations result in a mean and variance value for each panel at each comparison point. The results may be used to perform the ANOVA test and to determine confidence limits at each comparison point.

2. Thresholds

The detection and discrimination thresholds are log-normally distributed. Therefore ANOVA cannot be applied to thresholds in their usual form. Rather, the logarithm of each value must be determined to convert the values to a coordinate system in which the data are normally distributed.

The calculation of the mean and variance are performed using

$$(\overline{\text{Log } X_j}) = \frac{1}{N_j} \cdot \sum_{i=1}^{N_j} (\text{Log } X_{i,j}) \qquad (V.15)$$

and
$$s_j^2 = \frac{1}{N_j - 1} \cdot \sum_{i=1}^{N_j} (\text{Log } X_{i,j} - \overline{\text{Log } X_j})^2 \qquad (V.16)$$

where $\overline{\text{Log } X_j}$ = the mean logarithm of the panelists' thresholds

$\text{Log } X_{i,j}$ = the logarithm of the threshold of panelist i on panel j

s_j^2 = the variance in the logarithm of the thresholds of panel j

N_j = the number of panelists on panel j.

ANOVA is applied to these values in the usual manner since these figures meet the normal distribution requirements of the statistical test. Confidence limits must also be developed using these values due to the method's restriction to normally distributed data.

3. Statistical Analysis of Results Between Panels

Confidence limits may be calculated for the results of a single panel for such values as the degree of annoyance and the mean panel threshold. However, confidence limits cannot be determined for points along the detection, discrimination, and complaint curves because only one value is produced at each concentration for each panel. Therefore, for these curves confidence limits must be determined using the results of a multiple number of panels.

Tests like ANOVA require a mean and a variance from each panel. Therefore, the analysis of variance technique cannot be used to compare detection, discrimination, and complaint curves.

Appendix VI

n-Butyl Acetate

n-Butyl Acetate

Synonyms: n-butyl acetate
butyl acetate
butyl acetic ether

Formula: $CH_3CO_2(CH_2)_3CH_3$

Physical Properties:

Molecular Weight:	116.16
Melting Point (°C):	78.
Boiling Point (°C):	126.5
Specific Gravity:	0.882

Vapour Pressure (mm Hg)	Temperature (°C)
1.0	-16.0
3.0	0.0
5.7	10.0
7.5	15.0
10.0	20.0
30.0	40.0
70.0	60.0
100.0	68.0
340.0	100.0
600.0	118.0
760.0	126.5

C.A.S. No: 123-86-4

Chemical Supplier: Aldrich Chemical Company, Inc.

Chemical Purity: 99.8 %
GLC Grade
0.003 % Water
0.0005 % Evaporation Residue

ACGIH Threshold Limit Values (mg/M^3): [20]

Time Weighted Average (TWA)	710
Short Term Exposure Limit (STEL)	950

<u>Odour Data</u>:

Characteristic/quality [22]	sweet, ester
Hedonic Tone [22]	pleasant
Lowest Reported Threshold (mg/M^3) [18]	33.1
Highest Reported Threshold (mg/M^3) [18]	94.7
Odour Impact Model Detection Threshold (mg/M^3)	1.00
Odour Impact Model Discrimination Threshold (mg/M^3)	3.10

<u>Odour Impact Models</u>:

- evaluated by 5 10-member panels in a single session
- 23 panelists participated
- see the figures for the individual panel models and the combined odour impact model

TABLE VI.1: Panelists' Indication of Odourous Tubes for Panel One.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	3	2	3	1	2	3
2	3	3	3	1	2	3
3	3	1	1	3	2	3
4	2	1	3	2	2	3
5	1	1	2	1	2	3
6	2	2	3	1	2	3
7	2	3	3	1	2	3
8	1	1	2	1	2	3
9	1	3	3	2	2	3
10	3	3	3	1	2	3
Odourant Concentration = 2.14×10^5 $\mu g/M^3$						

TABLE VI.2: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel One.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	1	4	6	5
2	0	0	1	2	3	4	3
3	0	1	1	1	3	4	5
4	0	0	0	1	2	3	4
5	0	0	0	4	4	5	5
6	0	0	0	1	2	2	3
7	0	0	0	1	2	4	4
8	0	0	0	1	2	3	4
9	0	0	0	0	0	1	6
10	0	0	0	0	0	1	4

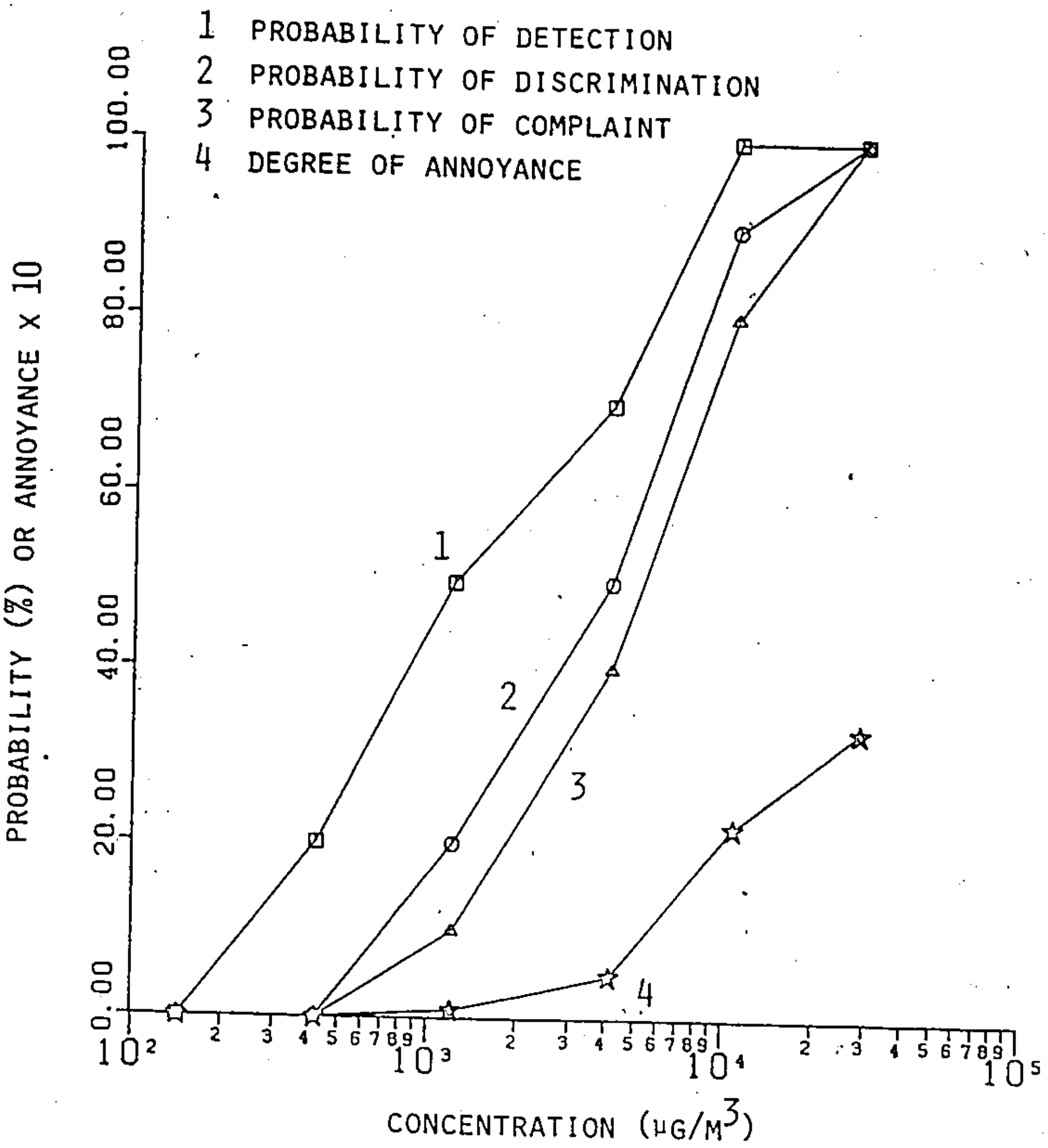


FIGURE VI.1: Panel One Odour Impact Model.

TABLE VI.3: Panelists' Indication of Odourous Tubes for Panel Two.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	3	3	1	2	3
2	3	2	2	3	2	3
3	1	1	1	3	2	3
4	3	2	3	1	2	3
5	3	2	3	1	2	3
6	3	3	1	3	2	3
7	3	2	2	2	2	3
8	3	1	3	1	2	3
9	1	1	1	1	2	3
10	2	2	3	1	2	3
Odourant Concentration = 2.14×10^5 $\mu g/M^3$						

TABLE VI.4: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Two.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	1	2	4	6	4
2	0	0	0	0	0	1	5
3	0	0	1	1	2	5	3
4	0	0	0	1	1	2	4
5	0	0	0	1	2	5	4
6	0	0	0	0	2	4	5
7	0	0	0	0	2	3	5
8	0	0	0	0	1	1	3
9	0	0	0	0	2	4	5
10	0	0	0	1	2	3	6

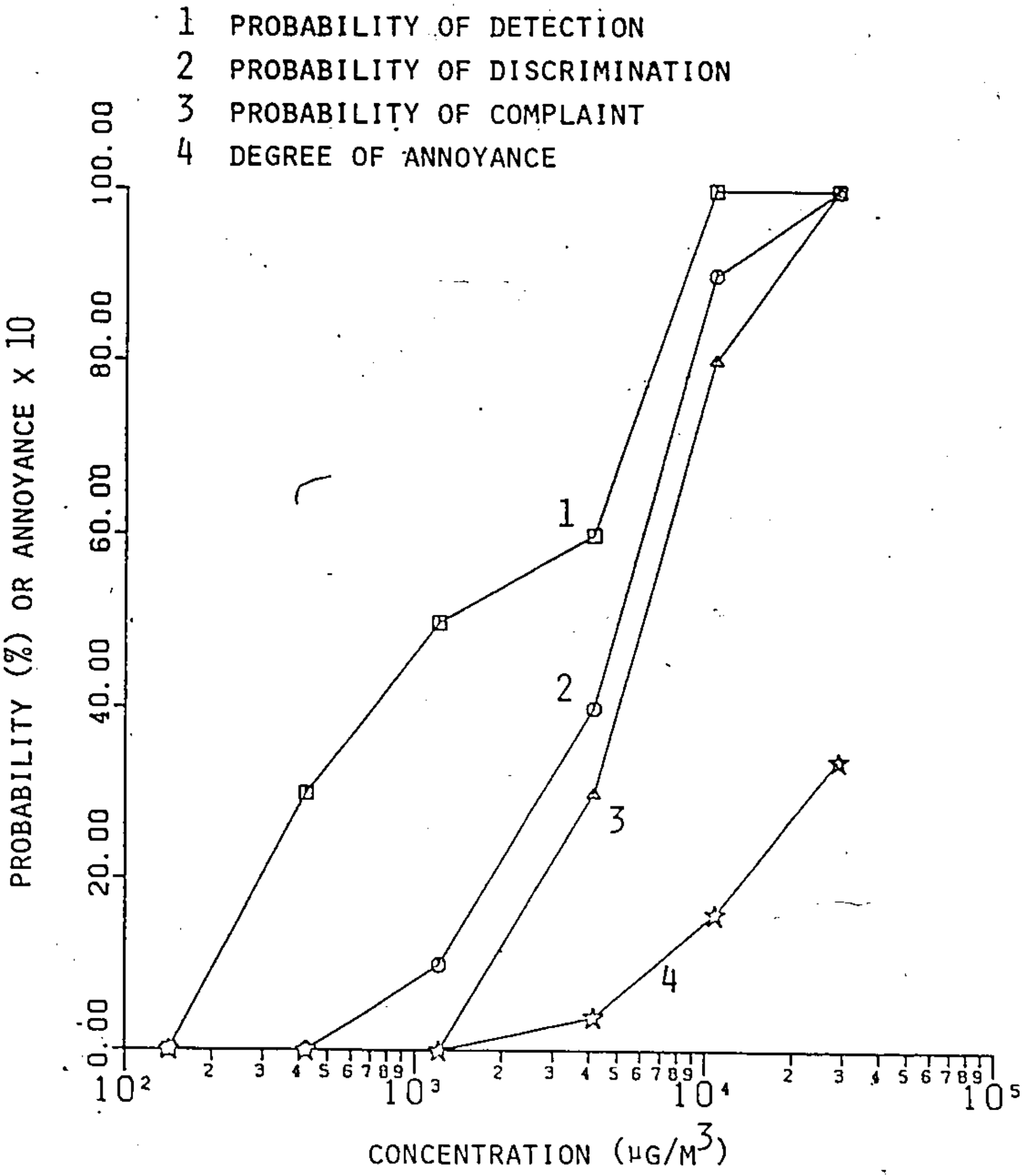


FIGURE VI.2: Panel Two Odour Impact Model.

TABLE VI.5: Panelists' Indication of Odourous Tubes for Panel Three.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	3	2	1	1	2	3
2	2	3	2	1	2	3
3	1	3	3	1	2	3
4	2	1	3	1	2	3
5	2	2	2	3	2	3
6	1	3	3	1	2	3
7	3	1	2	1	2	3
8	1	3	3	1	2	3
9	3	2	3	1	2	3
10	3	1	3	1	2	3
Odourant Concentration = 2.08×10^5 $\mu g/M^3$						

TABLE VI.6: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Three.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	4	6	5
2	0	0	1	2	3	3	3
3	0	0	0	2	4	4	4
4	0	0	0	0	1	2	5
5	1	2	2	3	4	5	4
6	0	0	0	1	2	3	5
7	0	0	0	0	2	3	6
8	0	0	0	0	1	1	4
9	0	0	0	0	2	4	4
10	0	0	0	2	4	6	4

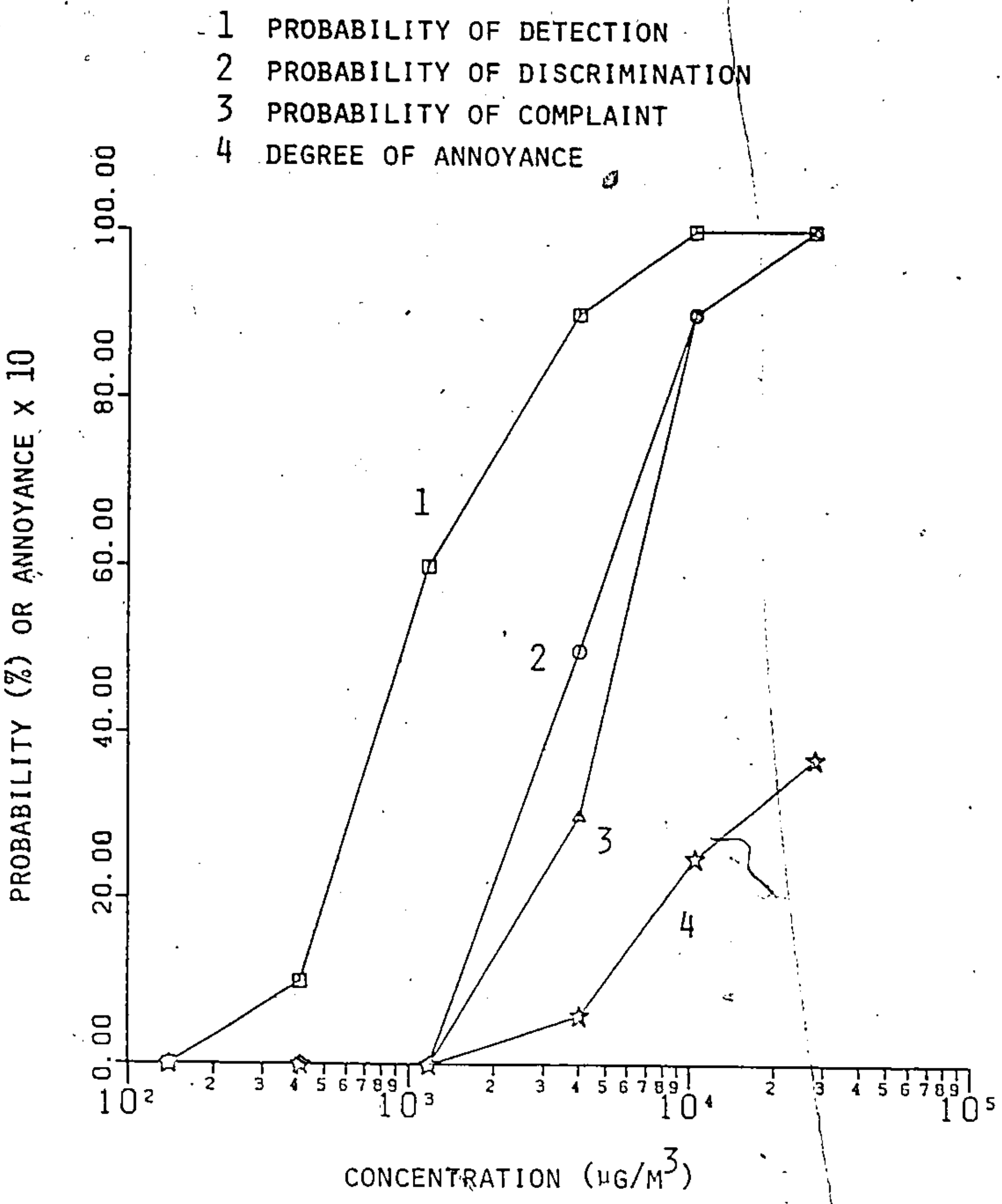


FIGURE VI.3: Panel Three Odour Impact Model.

TABLE VI.7: Panelists' Indication of Odourous Tubes for Panel Four.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	3	1	2	1	2	3
2	3	2	3	1	2	3
3	2	3	3	1	2	3
4	2	2	2	1	2	3
5	3	3	2	2	2	3
6	1	3	3	1	2	3
7	3	3	3	1	2	3
8	3	1	3	1	2	3
9	3	2	3	1	2	3
10	3	1	2	1	2	3
Odourant Concentration = 2.08×10^5 $\mu g/M^3$						

TABLE VI.8: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Four.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	2	2	3	4
2	0	0	0	0	2	5	5
3	0	0	1	1	2	2	3
4	0	0	0	0	0	3	6
5	0	0	0	0	1	2	6
6	1	1	1	2	4	5	4
7	0	0	1	1	3	3	3
8	0	1	2	2	3	3	3
9	0	0	1	1	3	4	3
10	0	0	0	0	2	4	4

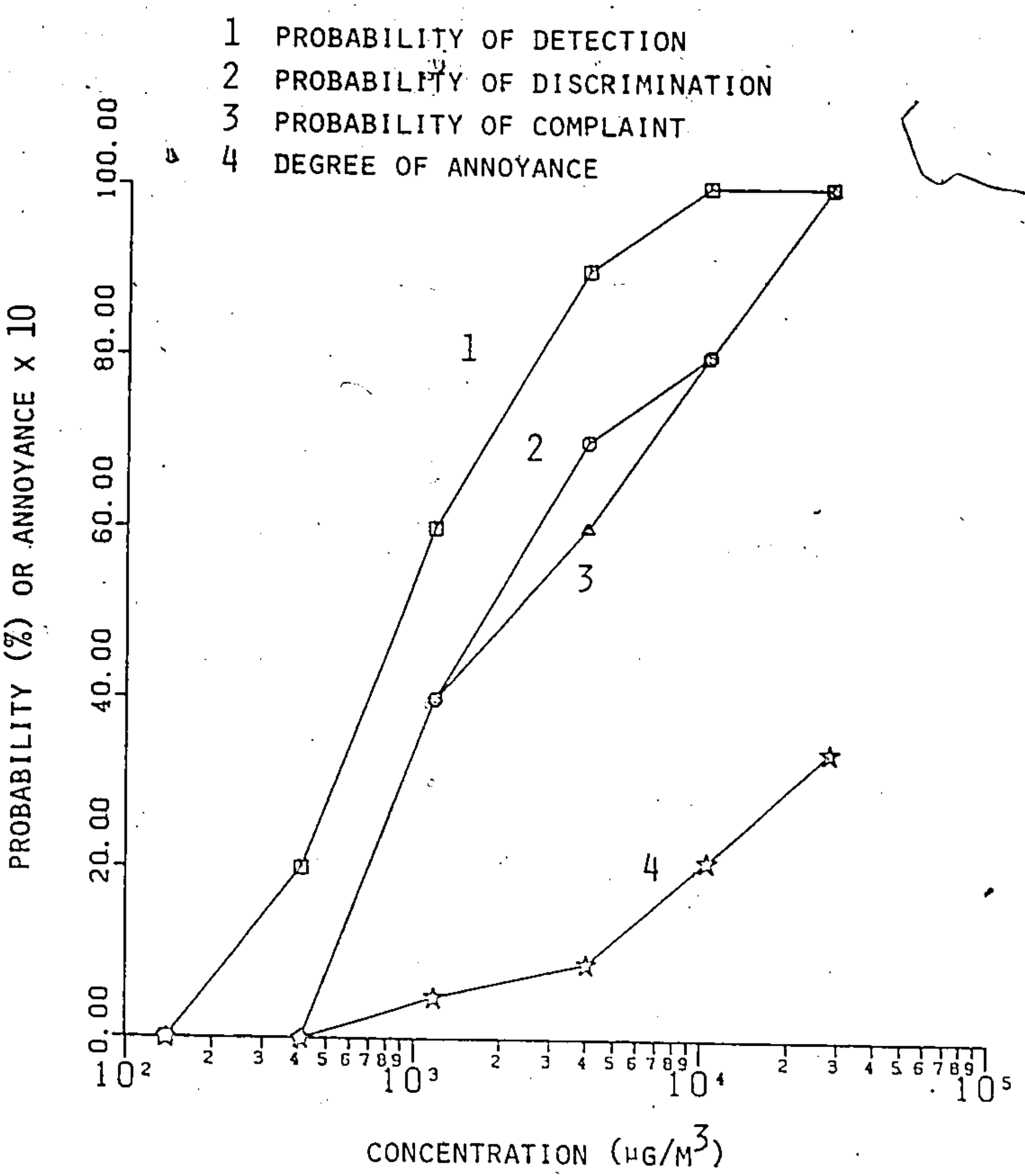


FIGURE VI.4: Panel Four Odour Impact Model.

TABLE VI.9: Panelists' Indication of Odourous Tubes for Panel Five.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	3	3	3	1	2	3
2	2	3	3	1	2	3
3	2	1	3	1	2	3
4	1	3	1	1	2	3
5	2	3	2	2	2	3
6	3	2	3	1	2	3
7	3	2	3	1	2	3
8	3	2	1	3	2	3
9	1	1	3	1	2	3
10	2	1	3	1	2	3
Odourant Concentration = 2.08×10^5 $\mu g/M^3$						

TABLE VI.10: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Five.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	1	3	4	5	3
2	0	0	0	0	0	1	4
3	0	0	0	0	2	2	4
4	0	0	0	1	3	6	4
5	0	0	0	0	4	5	5
6	0	0	0	1	2	2	4
7	0	0	0	1	2	2	3
8	0	0	0	0	1	2	5
9	0	0	0	1	2	5	4
10	0	0	0	1	2	4	4

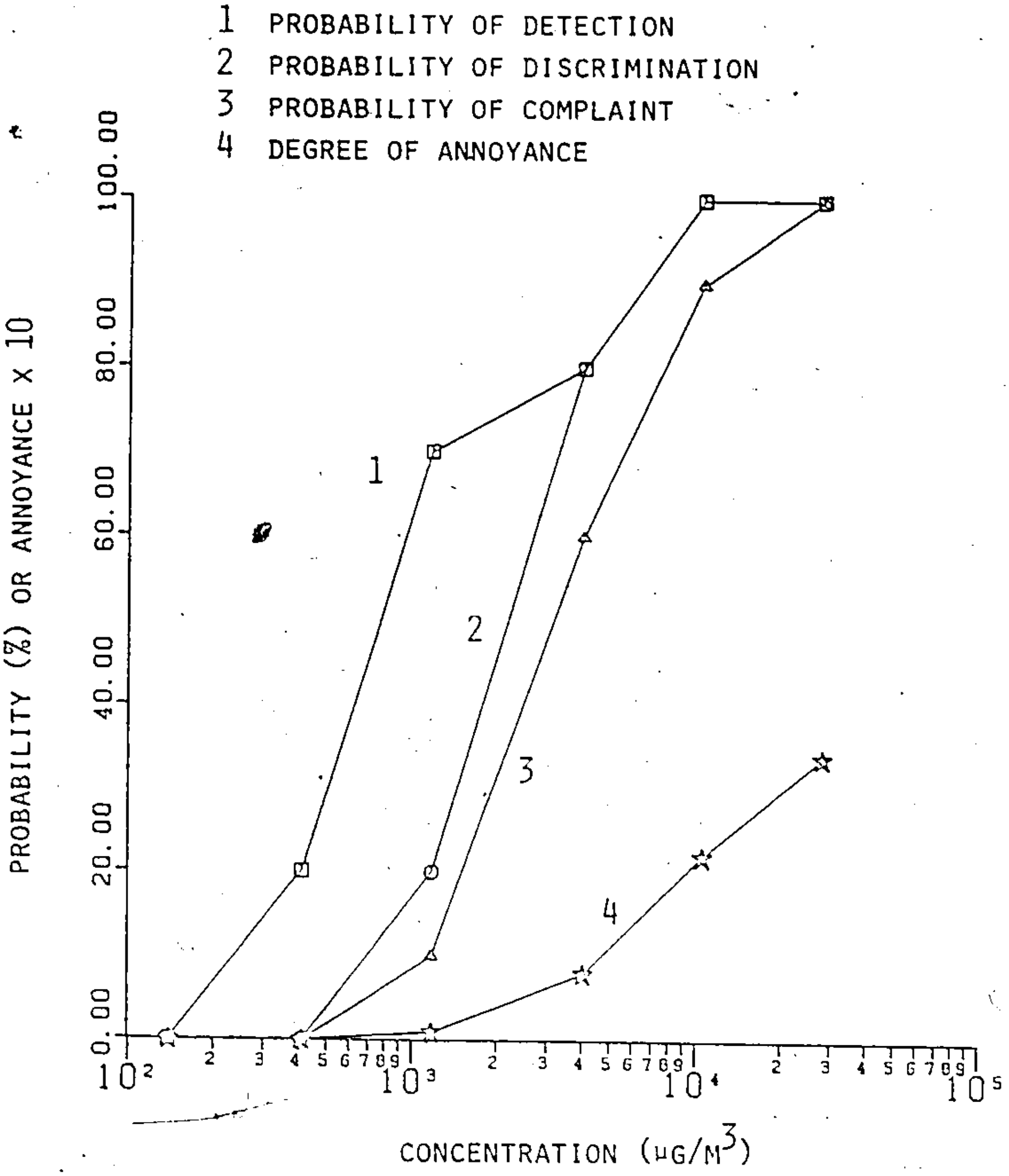


FIGURE VI.5: Panel Five Odour Impact Model.

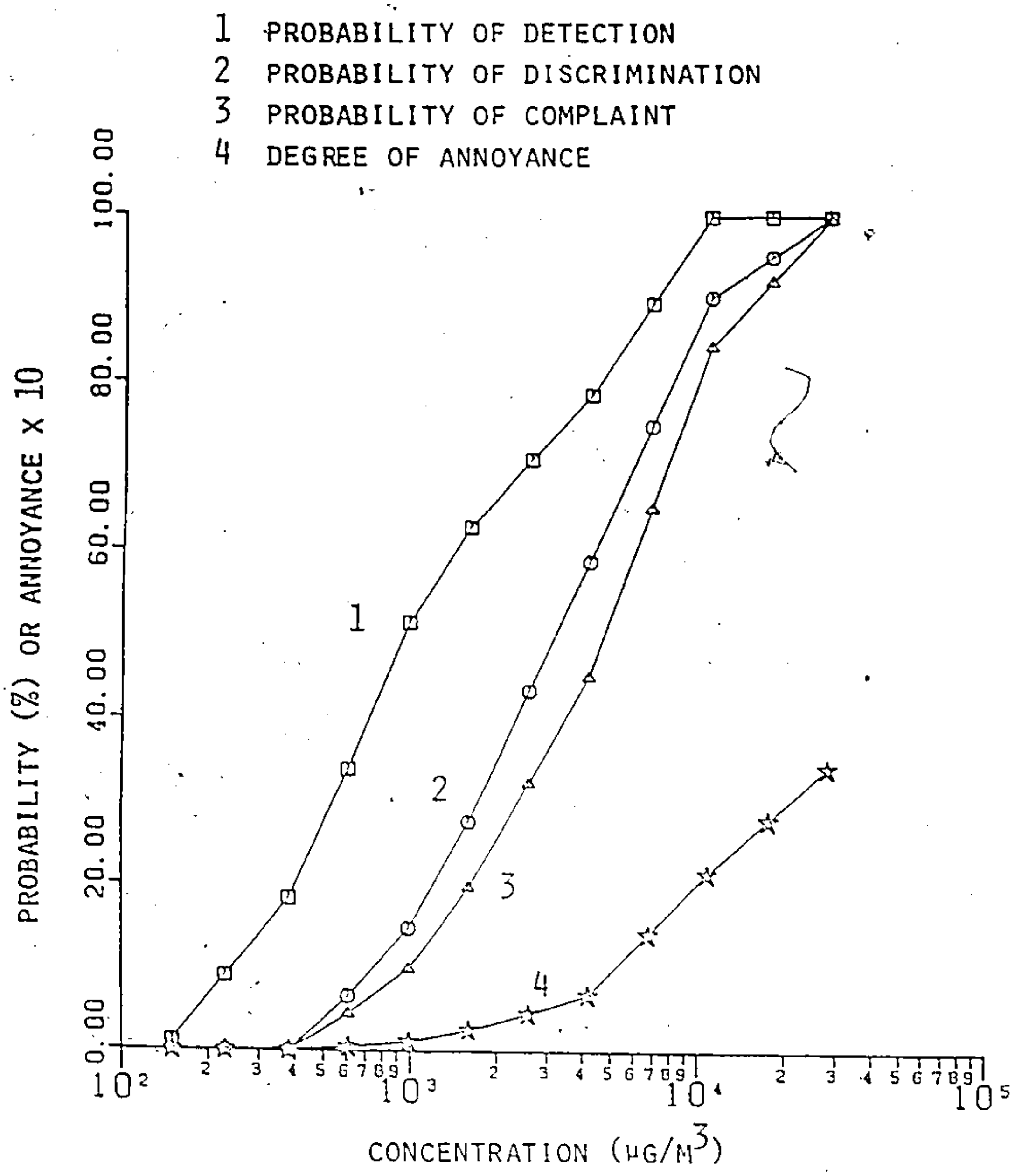


FIGURE VI.6: Odour Impact Model for n-Butyl Acetate.

Appendix VII

Propylene Glycol Monomethyl Ether

Propylene Glycol Monomethyl Ether

Synonyms: propylene glycol monomethyl ether
1-methoxy-2-propanol

Formula: $CH_3CH(OH)CH_2OCH_3$

Physical Properties:

Molecular Weight: 90.12
Melting Point (°C): -
Boiling Point (°C): 118.5
Specific Gravity: 0.922

C.A.S. No: 107-98-2

Chemical Supplier: Aldrich Chemical Company, Inc.

Chemical Purity: 98+ %

ACGIH Threshold Limit Values (mg/M³): [20]

Time Weighted Average (TWA)	360
Short Term Exposure Limit (STEL)	540

Odour Data:

Lowest Reported Threshold (mg/M³) [18]	360.
Highest Reported Threshold (mg/M³) [18]	360.
Odour Impact Model Detection Threshold (mg/M³)	121.
Odour Impact Model Discrimination Threshold (mg/M³)	215.

Odour Impact Models:

- evaluated by 5 10-member panels in a single session
- 23 panelists participated
- see the figures for the individual panel models and the combined odour impact model

TABLE VII.1: Panelists' Indication of Odourous Tubes for Panel One.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	3	3	1	3	2	3
2	2	3	2	1	2	3
3	1	2	1	1	3	3
4	2	1	2	2	1	3
5	2	1	1	3	2	3
6	3	1	2	2	2	3
7	1	1	2	1	2	3
8	3	2	3	2	2	3
9	3	3	2	1	2	3
10	1	3	2	2	2	3
Odourant Concentration = 3.72×10^6 $\mu g/M^3$						

TABLE VII.2: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel One.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	1	2	2	6
2	0	0	0	0	0	1	6
3	0	0	0	0	0	3	5
4	0	0	0	0	0	1	6
5	0	0	0	0	0	1	6
6	0	0	0	0	1	3	5
7	0	0	0	1	2	2	4
8	0	0	0	0	1	3	5
9	0	0	0	0	3	4	5
10	0	0	0	0	0	1	6

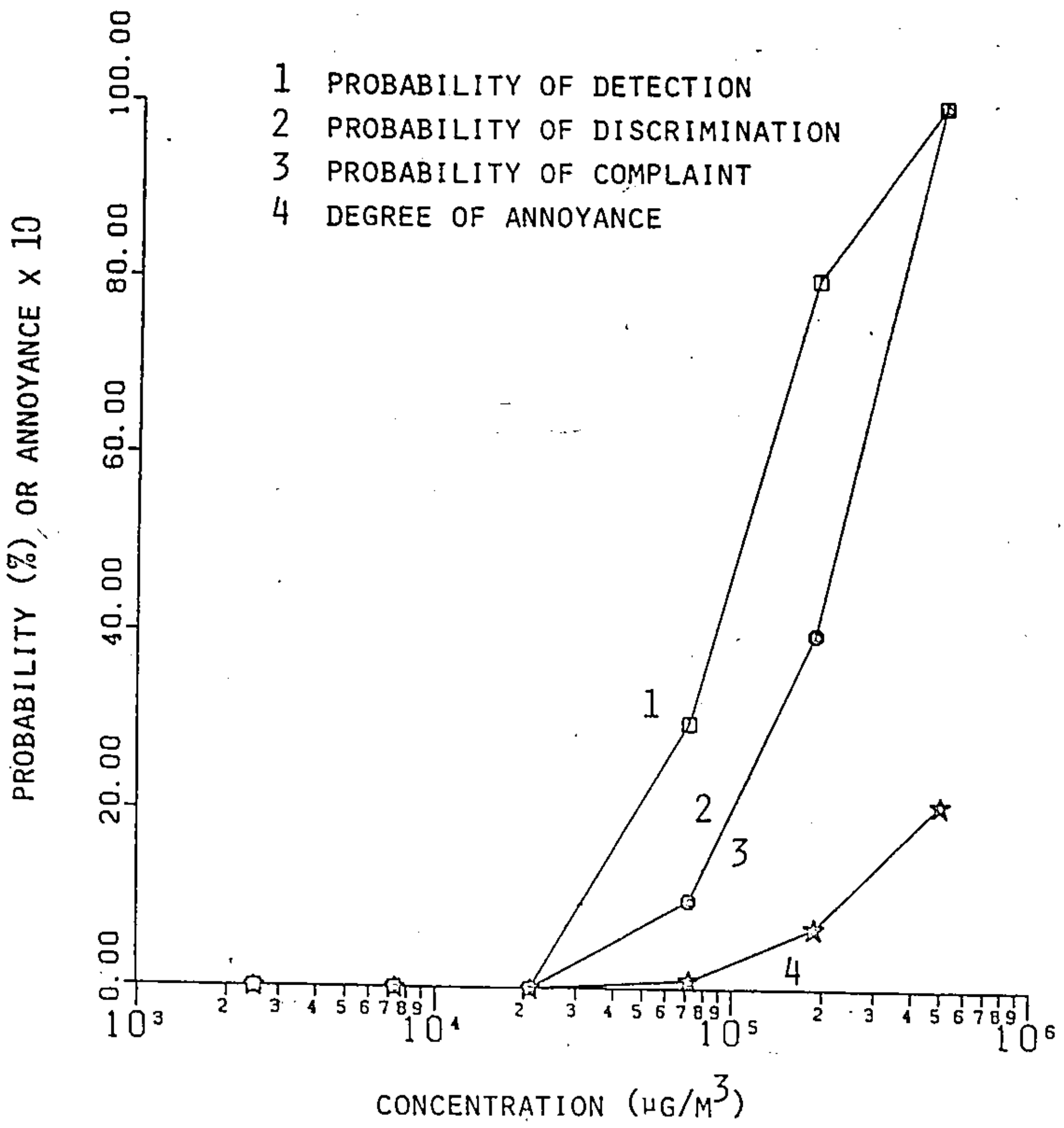


FIGURE VII.1: Panel One Odour Impact Model.

TABLE VII.3: Panelists' Indication of Odourous Tubes for Panel Two.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	2	3	3	2	3
2	2	3	1	1	3	3
3	3	2	3	2	2	3
4	3	3	2	3	3	3
5	1	2	2	2	2	3
6	2	2	3	2	1	3
7	2	1	2	1	2	3
8	3	2	3	2	1	3
9	1	3	2	1	2	3
10	1	1	2	1	2	3
Odourant Concentration = 3.72×10^6 $\mu g/M^3$						

TABLE VII.4: Panelists' Degree of Annbyance and Dilution Level of Discrimination for Panel Two.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	1	5
2	0	0	0	0	0	2	6
3	1	1	1	1	1	2	6
4	0	0	0	0	0	0	6
5	0	0	0	0	0	1	6
6	0	0	0	0	0	1	6
7	0	0	0	0	0	2	5
8	0	0	0	0	0	2	6
9	0	0	0	0	0	1	4
10	0	0	0	0	1	3	5

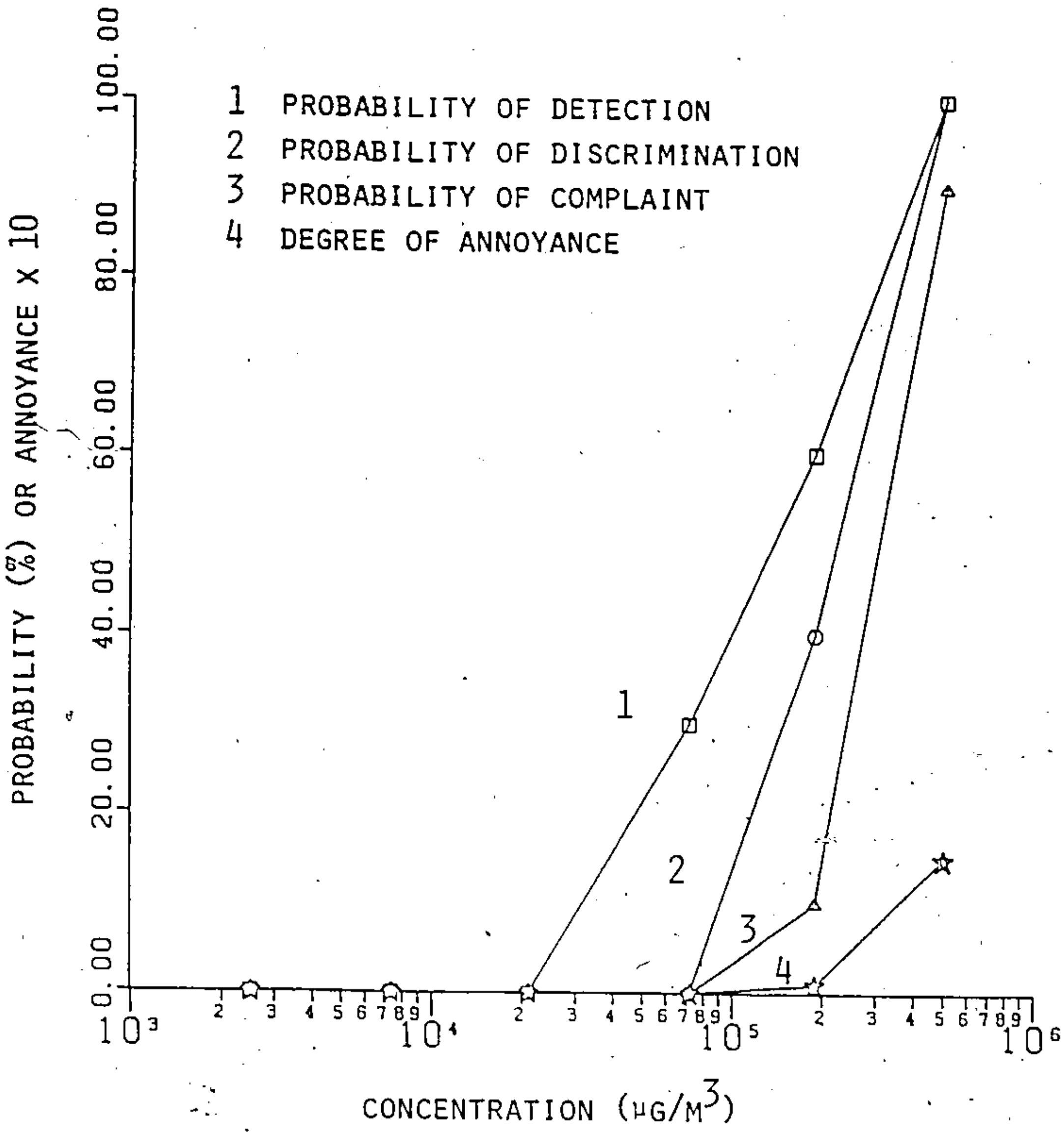


FIGURE VII.2: Panel Two Odour Impact Model.

TABLE VII.5: Panelists' Indication of Odourous Tubes for Panel Three.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	3	3	3	2	1	3
2	3	2	2	1	3	3
3	2	3	3	3	2	3
4	1	1	2	1	2	3
5	2	2	2	2	2	3
6	2	2	3	3	2	3
7	3	1	2	3	3	3
8	3	2	1	1	1	3
9	2	1	2	2	2	3
10	1	3	3	1	2	3
Odourant Concentration = 3.64×10^6 $\mu g/M^3$						

TABLE VII.6: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Three.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	3	6
2	0	1	1	1	1	1	6
3	0	0	0	0	0	1	6
4	0	0	0	0	0	2	6
5	0	0	0	0	0	1	6
6	0	0	0	0	0	0	6
7	0	0	0	0	0	1	6
8	0	0	0	0	0	1	6
9	0	0	0	0	0	1	6
10	0	0	1	1	3	5	3

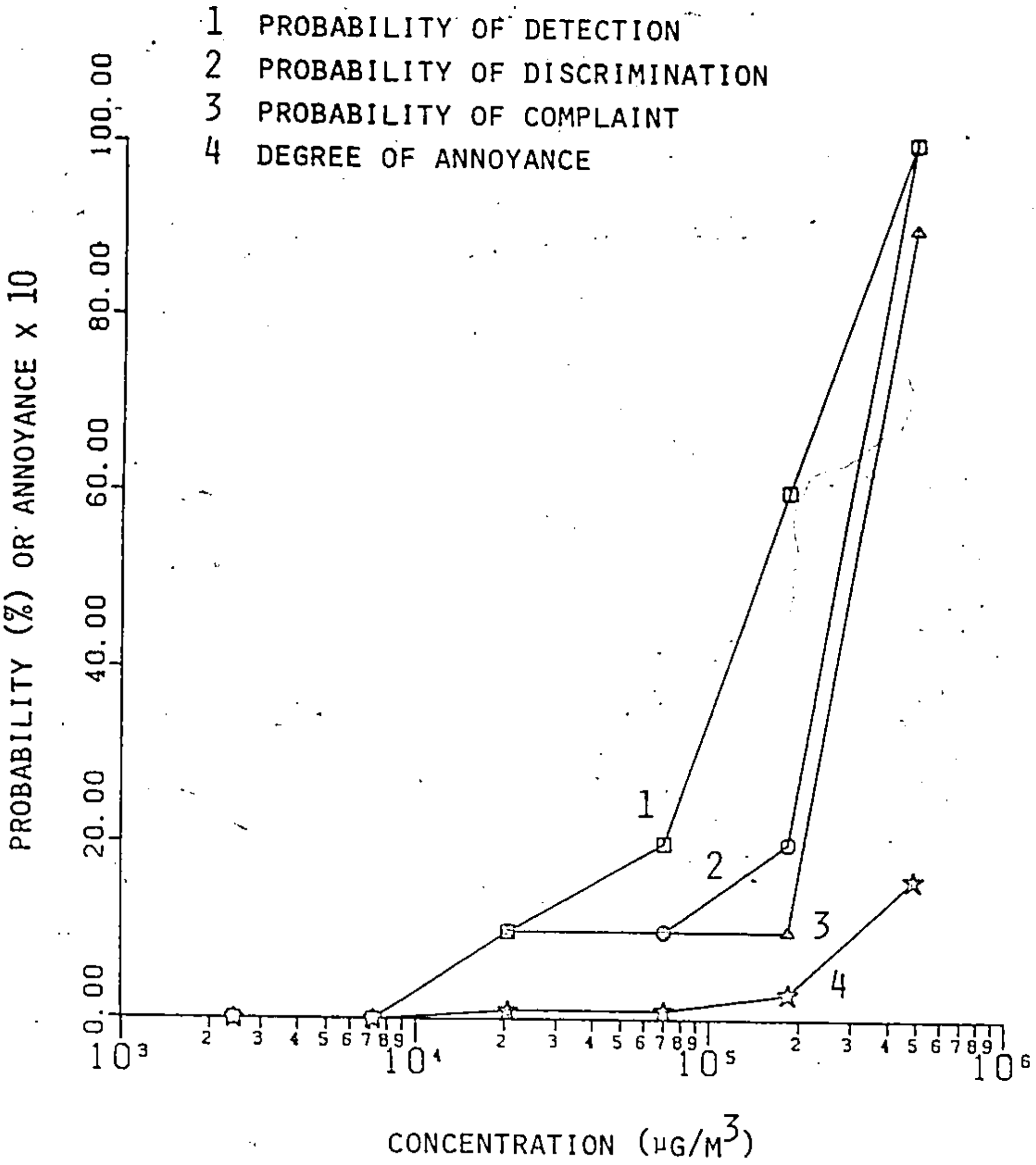


FIGURE VII.3: Panel Three Odour Impact Model.

TABLE VII.7: Panelists' Indication of Odourous Tubes for Panel Four.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	2	1	2	1	2	3
2	1	3	2	3	2	3
3	3	3	1	2	3	3
4	3	2	3	3	2	3
5	2	2	1	3	3	3
6	3	1	2	3	1	3
7	2	1	3	2	2	3
8	3	1	1	3	2	3
9	1	1	2	1	2	3
10	3	2	2	1	2	3
Odourant Concentration = 3.64×10^6 $\mu g/M^3$						

TABLE VII.8: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Four.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	1	1	1	2	3	3	4
2	0	0	0	1	3	7	4
3	0	0	0	0	0	1	6
4	0	0	0	0	1	1	6
5	3	3	3	3	3	4	6
6	0	0	0	0	0	2	6
7	0	0	0	0	0	0	6
8	0	0	0	1	1	3	4
9	0	0	0	0	3	4	3
10	0	0	0	0	1	3	5

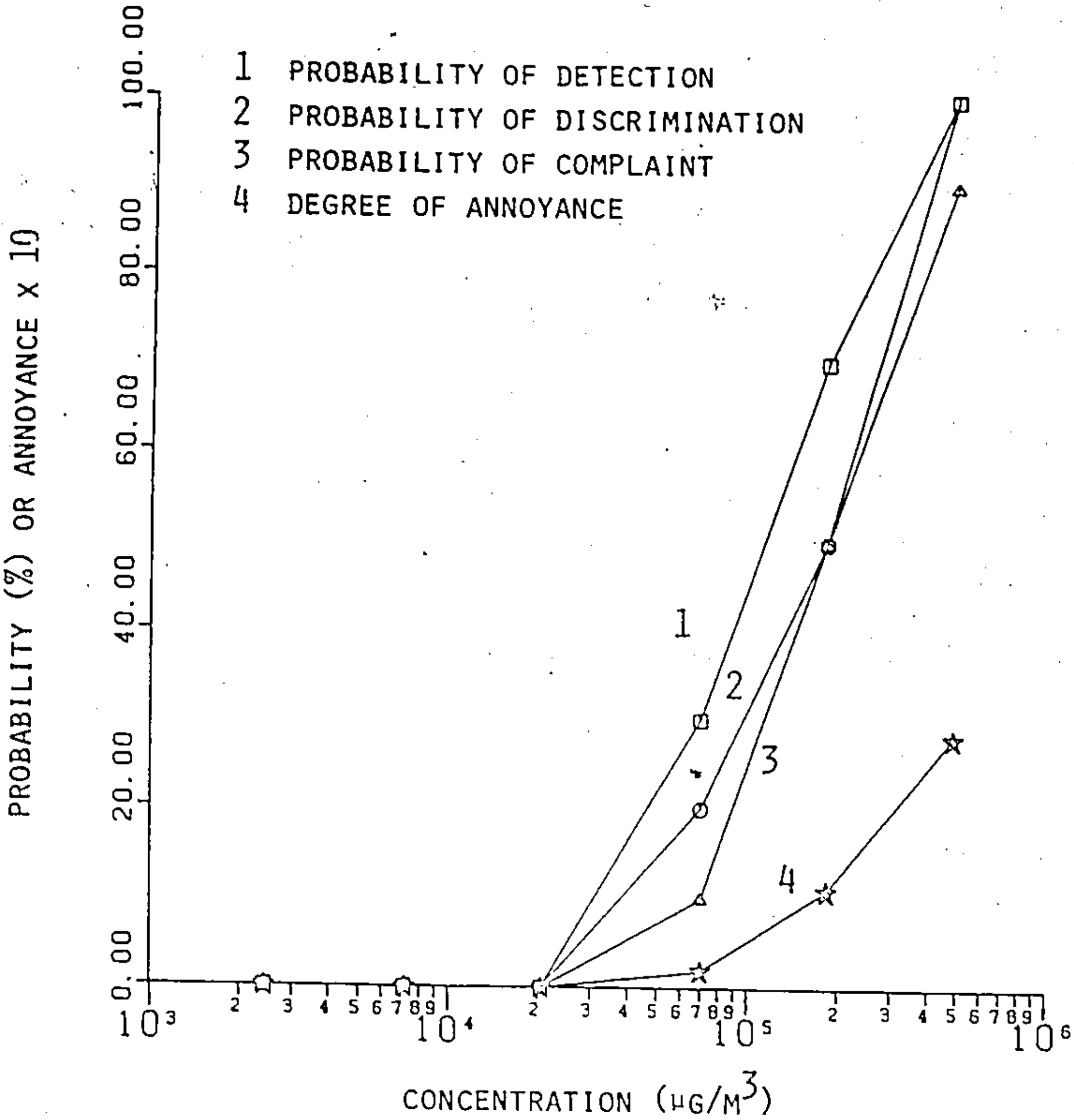


FIGURE VII.4: Panel Four Odour Impact Model.

TABLE VII.9: Panelists' Indication of Odourous Tubes for Panel Five.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	2	2	2	1	3
2	3	3	1	1	2	3
3	2	2	1	3	2	3
4	2	1	3	1	2	3
5	1	3	2	3	2	3
6	3	3	3	2	2	3
7	3	3	3	1	2	3
8	3	1	3	2	2	3
9	2	3	1	1	1	3
10	2	3	2	1	1	3

Odourant Concentration = 3.38×10^6 $\mu g/M^3$

TABLE VII.10: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Five.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	1	6
2	0	0	0	0	0	1	5
3	0	0	0	0	2	7	5
4	0	0	0	1	1	4	6
5	0	0	0	0	0	1	6
6	0	0	0	0	0	1	6
7	0	0	0	0	1	1	4
8	0	0	0	1	2	4	5
9	0	0	0	0	1	2	5
10	0	0	0	0	0	0	6

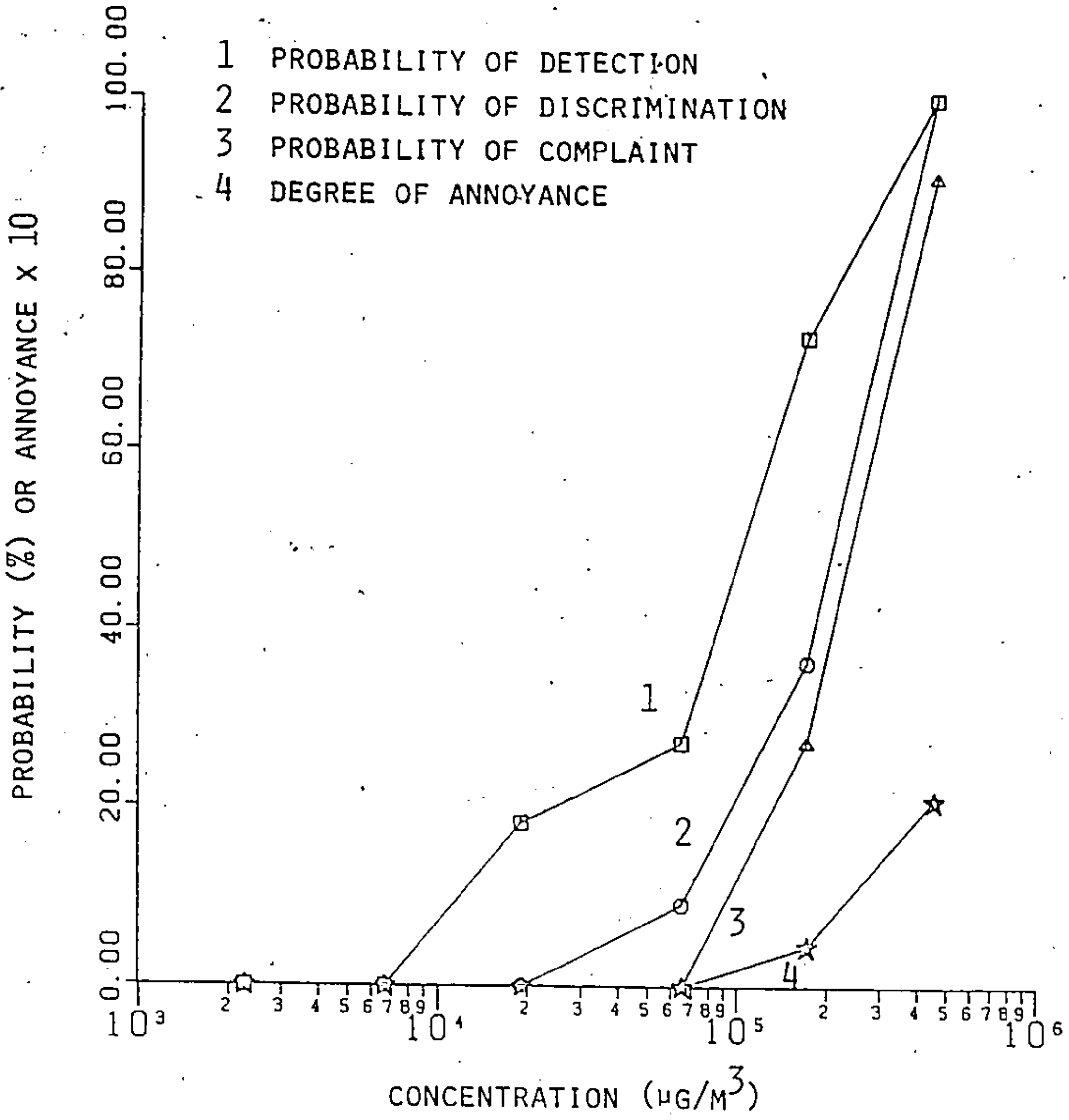


FIGURE VII.5: Panel Five Odour Impact Model.

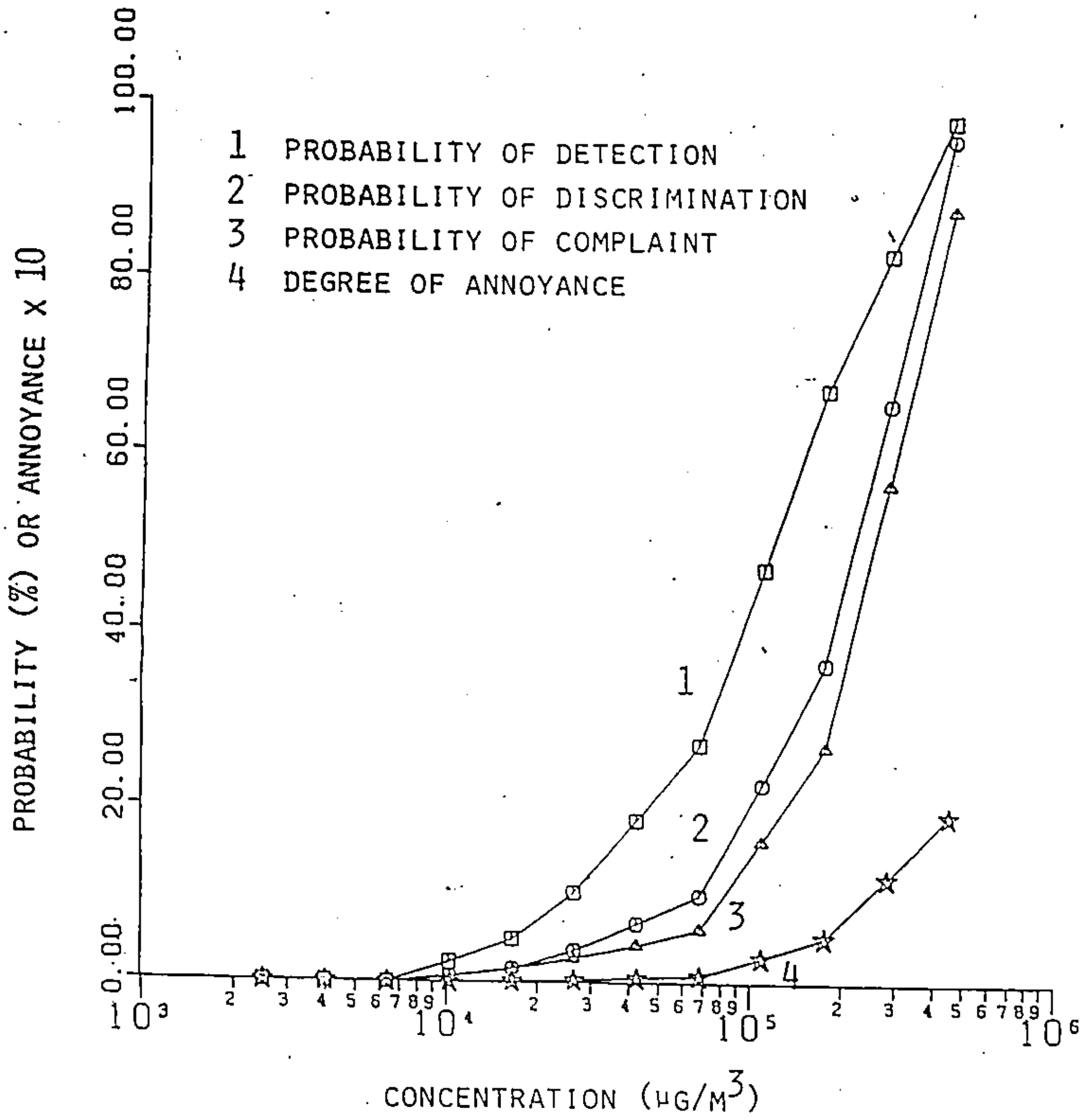


FIGURE VII.6: Odour Impact Model for Propylene Glycol Monomethyl Ether.

Appendix VIII

Methyl Isoamylketone

Methyl Isoamylketone

Synonyms: methyl isoamylketone
5-methyl-2-hexanone

Formula: $(CH_3)_2CHCH_2CH_2COCH_3$

Physical Properties:

Molecular Weight:	114.19
Melting Point (°C):	-
Boiling Point (°C):	145.0
Specific Gravity:	0.888

C.A.S. No: 110-12-3

Chemical Supplier: Aldrich Chemical Company, Inc.

Chemical Purity: 99+ %

ACGIH Threshold Limit Values (mg/M³): [20]

Time Weighted Average (TWA)	240
Short Term Exposure Limit (STEL)	none

Odour Data:

Characteristic/quality [22]	sweet, sharp
Hedonic Tone [22]	pleasant
Lowest Reported Threshold (mg/M³) [18]	0.06
Highest Reported Threshold (mg/M³) [18]	0.34
Odour Impact Model Detection Threshold (mg/M³)	0.63
Odour Impact Model Discrimination Threshold (mg/M³)	1.40

Odour Impact Models:

- evaluated by 5 10-member panels in a single session
- 26 panelists participated
- see the figures for the individual panel models and the combined odour impact model

TABLE VIII.1: Panelists' Indication of Odourous Tubes for Panel One.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	3	1	2	1	3	2
2	1	1	2	3	1	2
3	2	2	3	1	3	2
4	1	1	3	1	3	2
5	2	1	1	1	3	2
6	1	2	2	1	3	2
7	3	2	1	1	3	2
8	2	2	1	1	3	2
9	2	1	2	1	3	2
10	2	2	1	1	3	2
Odourant Concentration = 1.39×10^5 $\mu g/M^3$						

TABLE VIII.2: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel One.

Panelist	Dilution Level No. 1	2	3	4	5	6	Discriminate at Dilution Level No.
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	1	4
2	0	0	0	1	1	2	5
3	0	0	0	0	0	0	4
4	0	0	0	1	1	2	4
5	0	0	1	1	2	3	5
6	0	0	0	0	2	6	5
7	0	0	0	0	1	2	5
8	0	0	0	1	3	4	4
9	0	0	0	1	3	5	4
10	0	0	0	1	2	3	4

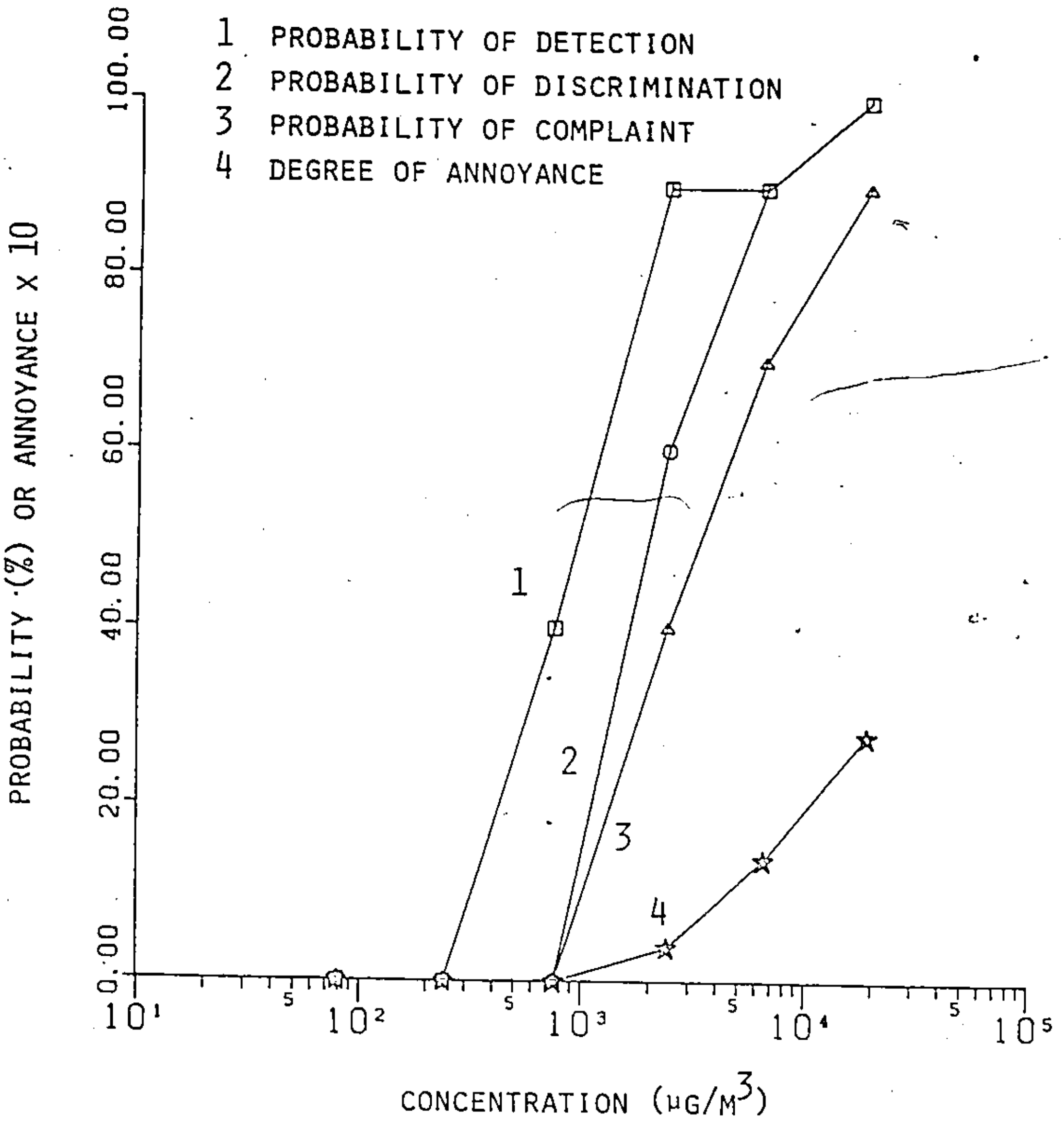


FIGURE VIII.1: Panel One Odour Impact Model.

TABLE VIII.3: Panelists' Indication of Odourous Tubes for Panel Two.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	2	2	1	1	3	2
2	1	3	1	1	3	2
3	1	2	1	1	3	2
4	1	3	2	1	3	2
5	2	3	3	1	3	2
6	3	2	3	3	3	2
7	2	2	1	1	3	2
8	1	2	1	1	3	2
9	2	1	2	1	3	2
10	2	2	1	1	3	2

Odourant Concentration = 1.33×10^5 $\mu g/M^3$

TABLE VIII.4: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Two.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	1	3	4	5
2	0	0	1	3	4	5	3
3	0	0	0	0	1	4	5
4	0	0	0	1	1	2	4
5	0	0	0	0	0	2	3
6	0	0	0	0	1	4	5
7	0	0	0	1	2	3	4
8	0	0	0	2	3	4	4
9	0	0	0	1	1	2	4
10	0	0	1	2	4	7	3

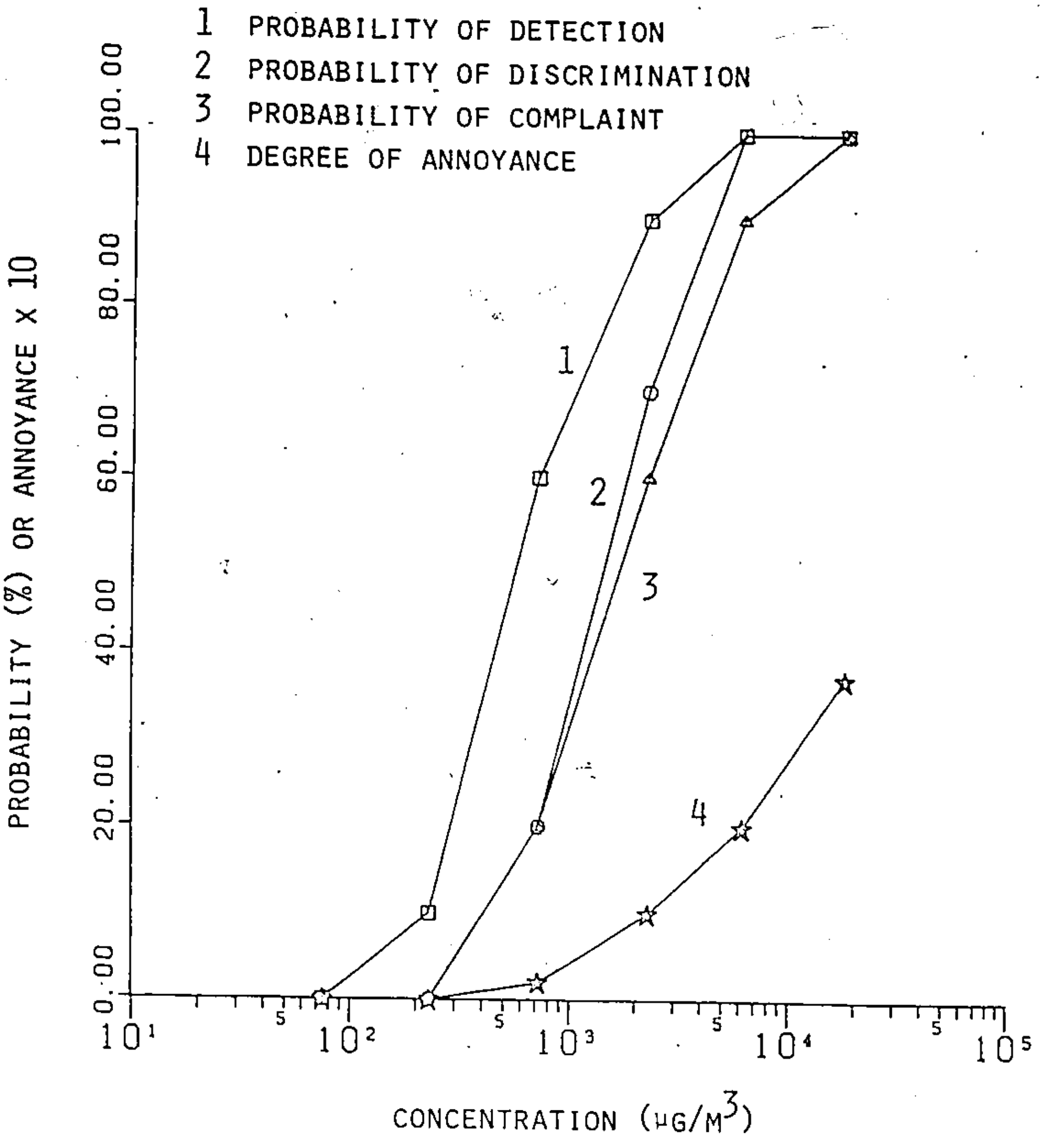


FIGURE VIII.2: Panel Two Odour Impact Model.

TABLE VIII.5: Panelists' Indication of Odourous Tubes for Panel Three.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	2	2	2	1	3	2
2	3	3	2	1	3	2
3	3	3	1	1	3	2
4	2	1	1	1	3	2
5	3	2	1	1	3	2
6	3	2	1	1	3	2
7	2	2	3	2	3	2
8	1	3	1	1	3	2
9	2	3	2	1	3	2
10	1	1	1	1	3	2
Odourant Concentration = 1.33×10^5 $\mu g/M^3$						

TABLE VIII.6: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Three.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	1	2	3	4
2	0	0	0	2	4	7	4
3	0	0	0	0	1	5	4
4	0	0	0	0	1	3	4
5	0	0	0	1	2	3	4
6	0	0	0	1	1	1	3
7	0	0	0	0	0	2	6
8	0	0	4	4	9	10	3
9	0	1	1	3	4	5	1
10	0	0	1	2	5	8	3

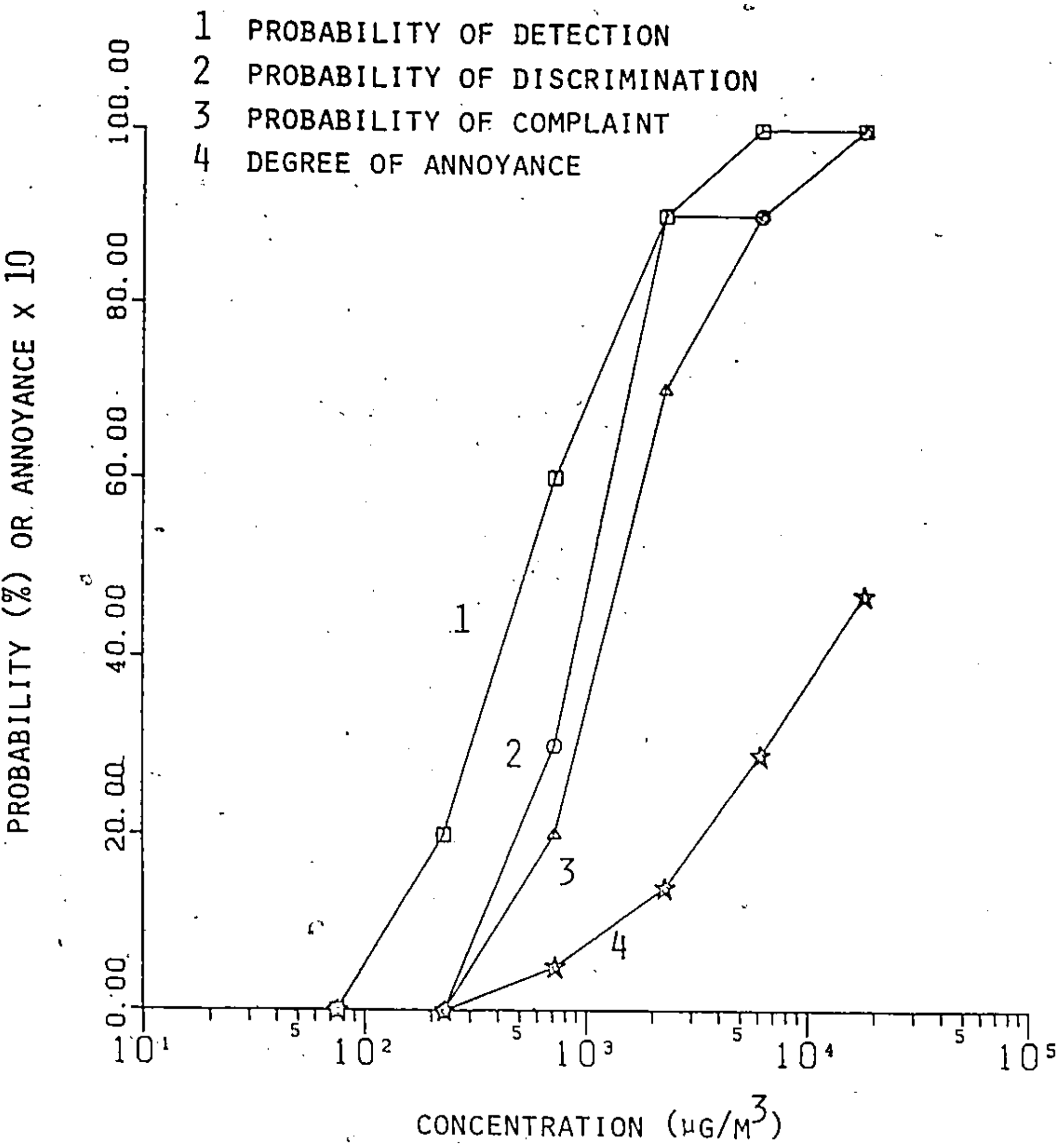


FIGURE VIII.3: Panel Three Odour Impact Model.

TABLE VIII.7: Panelists' Indication of Odourous Tubes for Panel Four.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	3	3	1	1	3	2
2	3	2	1	1	3	2
3	3	3	1	1	3	2
4	3	1	2	1	3	2
5	1	3	2	3	3	2
6	3	3	1	1	3	2
7	3	1	3	2	3	2
8	1	3	1	1	3	2
9	3	1	1	1	3	2
10	1	2	1	1	3	2
Odourant Concentration = 1.69 × 10^5 $\mu g/M^3$						

TABLE VIII.8: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Four.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	1	1	2	3	3
2	0	0	0	0	1	5	3
3	0	1	1	2	4	6	2
4	0	0	0	2	3	4	4
5	1	1	1	1	2	3	6
6	0	0	1	2	4	5	3
7	0	0	0	1	2	4	5
8	1	1	1	2	4	4	4
9	0	0	1	2	2	3	3
10	0	0	0	0	1	1	3

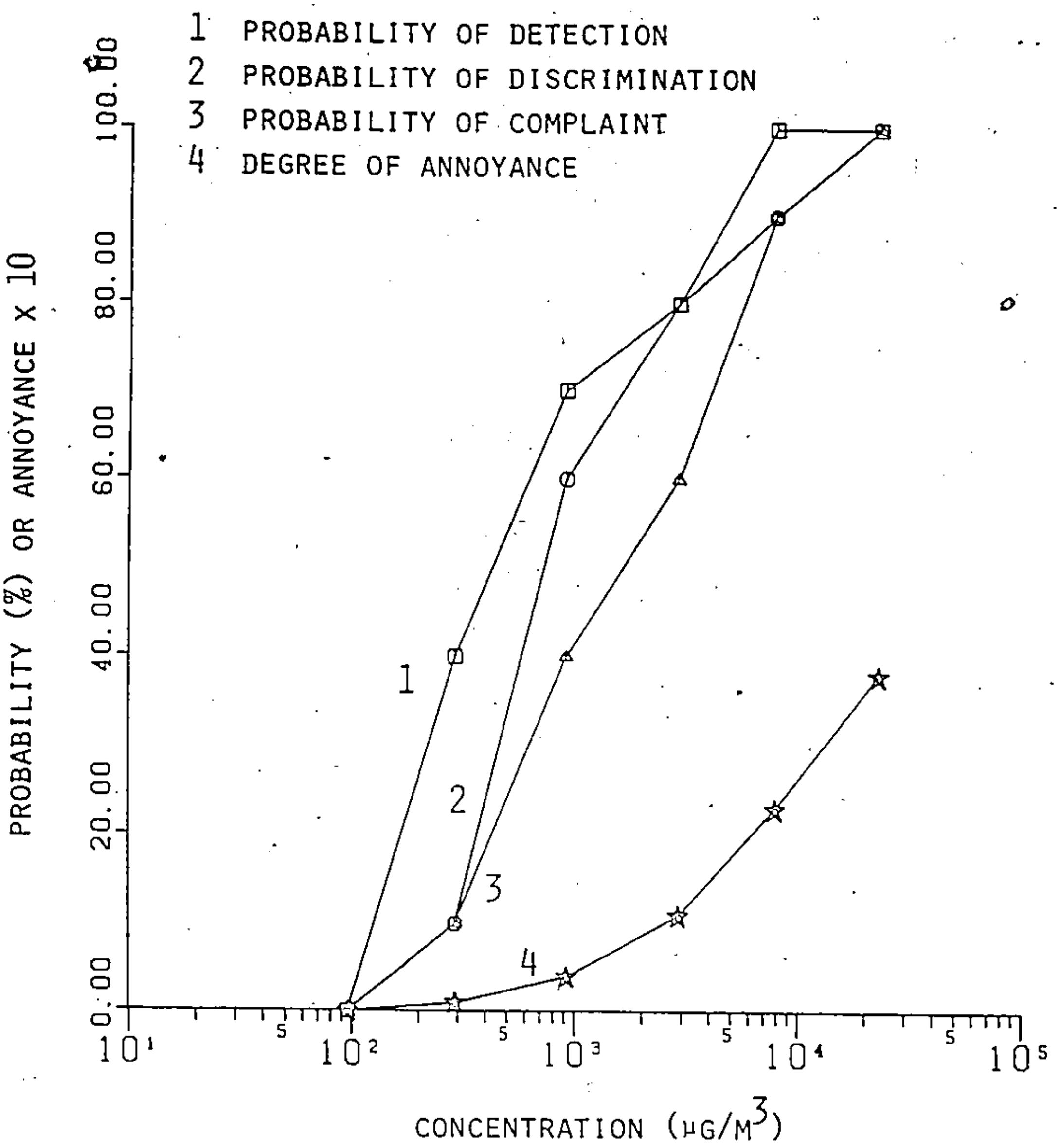


FIGURE VIII.4: Panel Four Odour Impact Model.

TABLE VIII.9: Panelists' Indication of Odourous Tubes for Panel Five.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	3	1	1	1	3	2
2	2	1	1	1	3	2
3	3	2	1	1	3	2
4	1	1	1	1	3	2
5	3	3	2	2	3	2
6	1	2	1	1	3	2
7	1	2	3	3	1	2
8	3	3	2	1	3	2
9	1	1	2	2	3	2
10	3	3	1	1	3	2

Odourant Concentration = 1.69×10^5 $\mu g/M^3$

TABLE VIII.10: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Five.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	1	2	3	4	4
2	0	0	0	0	0	0	3
3	1	1	1	3	4	8	4
4	1	1	1	2	3	4	4
5	0	0	0	0	0	2	6
6	0	0	0	0	3	3	5
7	0	0	0	0	0	2	6
8	0	0	1	2	4	4	3
9	0	0	0	2	2	2	4
10	0	0	0	0	1	4	4

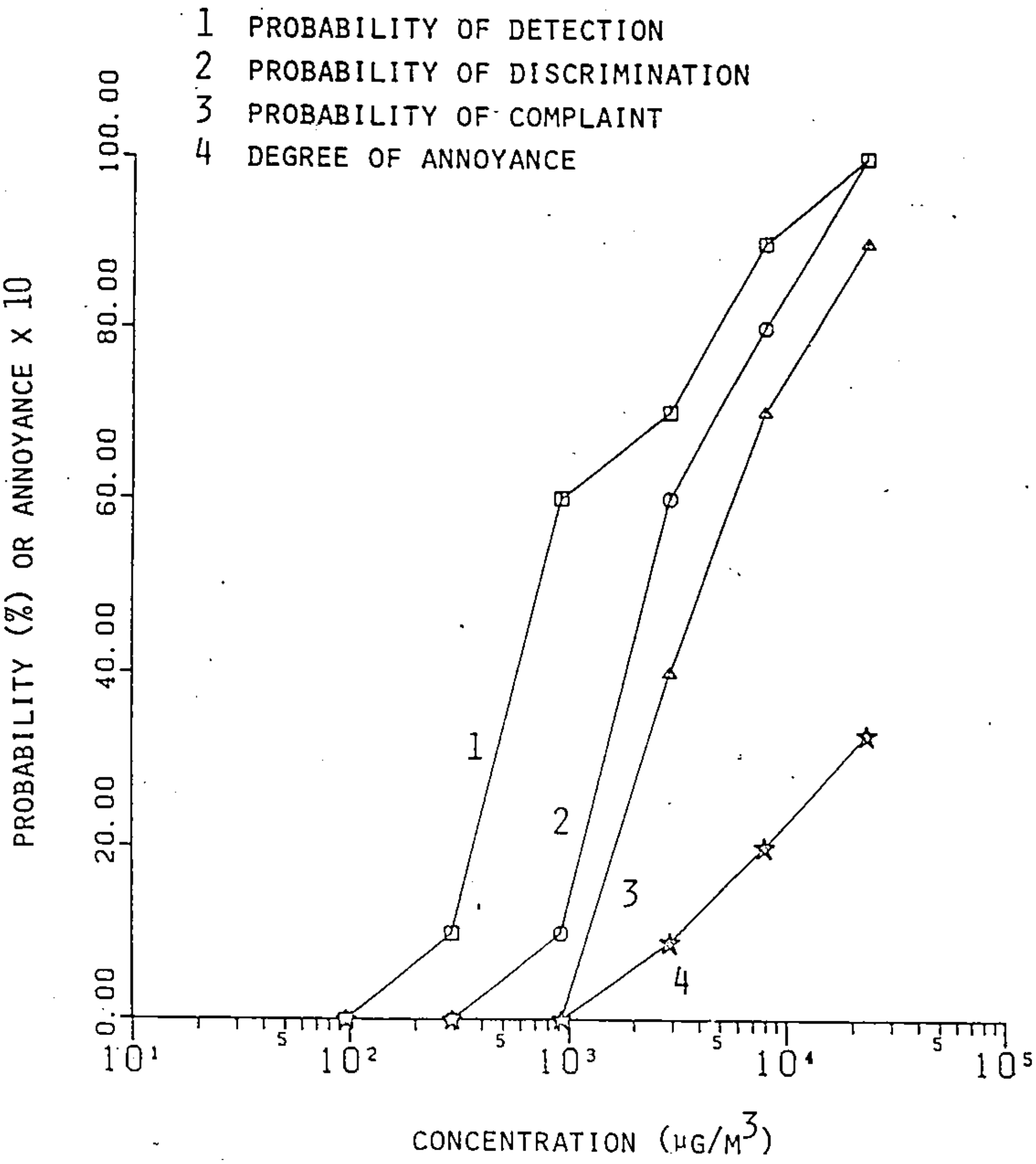


FIGURE VIII.5: Panel Five Odour Impact Model.

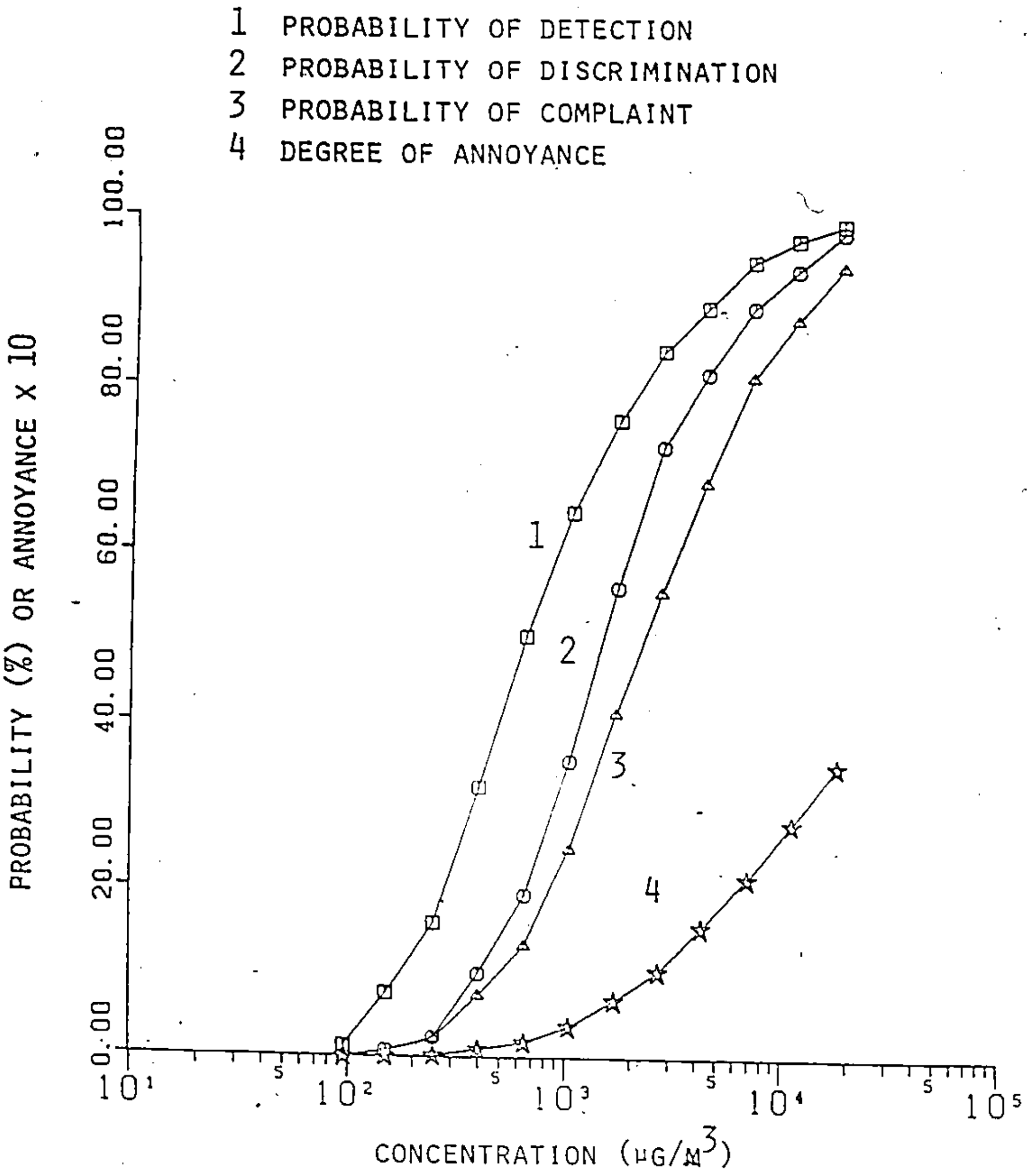


FIGURE VIII.6: Odour Impact Model for Methyl Isoamylketone.

Appendix IX

Isobutanol

Isobutanol

Synonyms: isobutanol
isobutyl alcohol
2-methyl-1-propanol

Formula: $(CH_3)_2CHCH_2OH$

Physical Properties:

Molecular Weight:	74.12
Melting Point (°C):	-108.
Boiling Point (°C):	108.
Specific Gravity:	0.803

Vapour Pressure (mm Hg)	Temperature (°C)
1.0	-9.0
5.0	11.6
10.0	21.7
20.0	32.4
40.0	44.1
60.0	51.7
100.0	61.5
200.0	75.9
400.0	91.4
760.0	108.0

C.A.S. No: 78-83-1

Chemical Supplier: Aldrich Chemical Company, Inc.

Chemical Purity: 99+ %
Spectophotometric Grade

ACGIH Threshold Limit Values (mg/M^3): [20]

Time Weighted Average (TWA)	150
Short Term Exposure Limit (STEL)	225

Odour Data:

Characteristic/quality [22]	sweet, musty
Hedonic Tone [22]	pleasant
Lowest Reported Threshold (mg/M^3) [18]	0.36
Highest Reported Threshold (mg/M^3) [18]	225.
Odour Impact Model Detection Threshold (mg/M^3)	2.64
Odour Impact Model Discrimination Threshold (mg/M^3)	6.70

Odour Impact Models:

- evaluated by 5 10-member panels in the first session and 2 additional 10-member panels one week later
- 25 panelists participated in the first session
- 20 panelist participated in the second session
- a total of 28 different panelists participated
- see the figures for the individual panel models and the combined odour impact model

TABLE IX.1: Panelists' Indication of Odourous Tubes for Panel One.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	3	1	2	1	2	3
2	2	2	1	3	1	3
3	2	2	3	1	2	3
4	3	1	1	1	2	3
5	3	2	3	1	3	3
6	1	1	3	1	2	3
7	2	2	3	1	2	3
8	1	2	3	1	2	3
9	2	2	2	1	2	3
10	2	3	1	3	2	3
Odourant Concentration = 4.55 × 10^5 $\mu g/M^3$						

TABLE IX.2: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel One.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	1	2	4	4
2	0	0	0	0	1	1	5
3	0	0	0	2	3	3	4
4	0	0	0	1	2	4	4
5	0	0	0	0	0	0	6
6	0	0	3	3	4	5	3
7	0	0	1	2	2	2	3
8	0	0	1	2	3	6	4
9	0	0	0	2	3	3	3
10	1	1	2	3	4	5	4

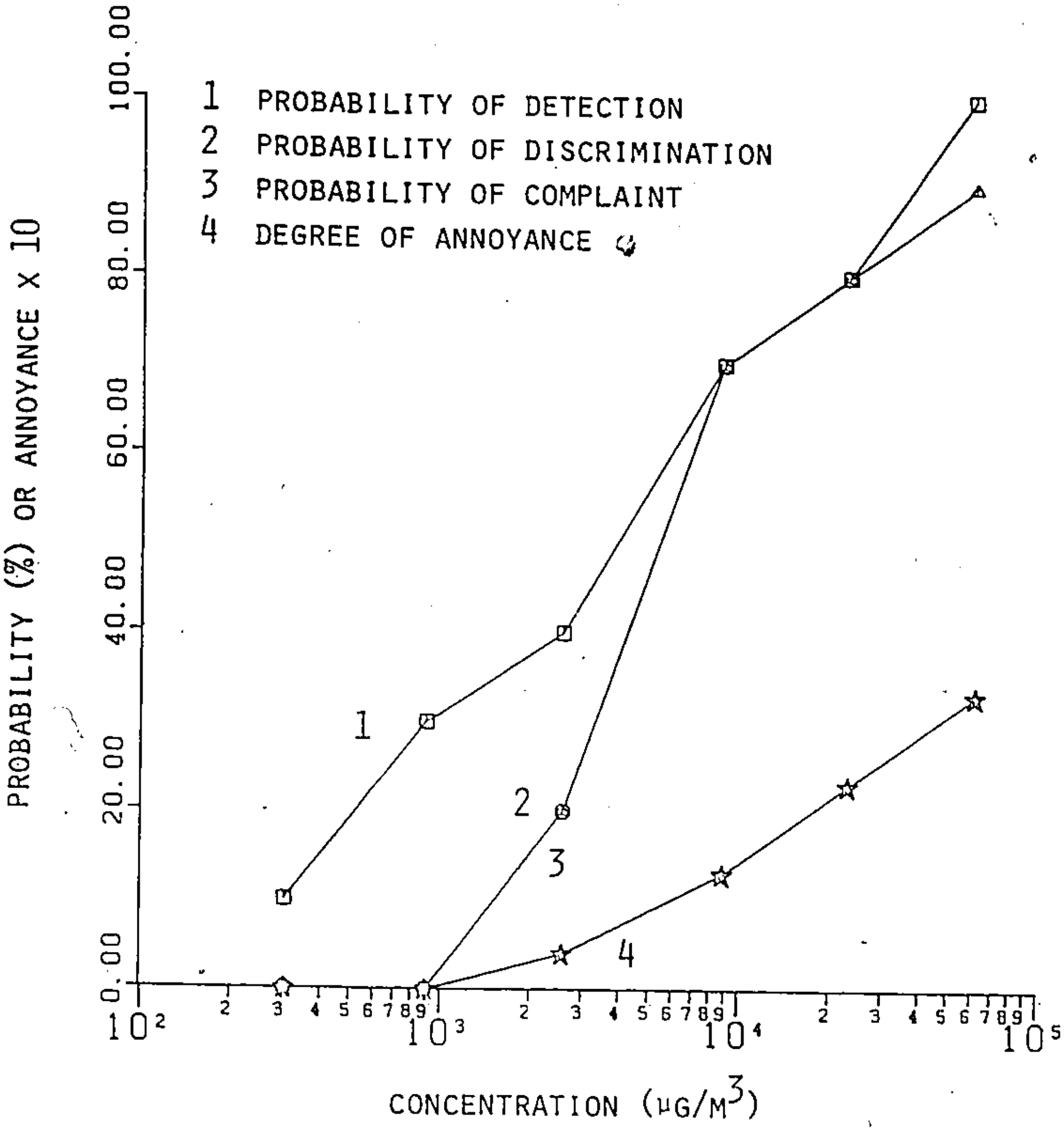


FIGURE IX.1: Panel One Odour Impact Model.

TABLE IX.3: Panelists' Indication of Odourous Tubes for Panel Two.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	2	3	1	2	3
2	2	2	3	1	3	3
3	1	3	3	2	1	3
4	3	2	3	1	2	3
5	3	1	3	1	2	3
6	2	1	2	1	1	3
7	3	1	3	1	2	3
8	1	3	3	1	2	3
9	1	1	3	2	1	3
10	1	3	2	1	2	3
Odourant Concentration = 4.55×10^5 $\mu g/M^3$						

TABLE IX.4: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Two.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	1	4
2	0	0	0	0	1	2	4
3	0	0	0	0	0	1	6
4	0	0	0	4	4	4	4
5	0	0	1	1	2	3	2
6	0	0	0	0	0	0	6
7	0	0	0	0	1	2	3
8	0	0	1	2	2	3	3
9	1	1	1	1	1	1	6
10	0	0	0	0	1	3	4

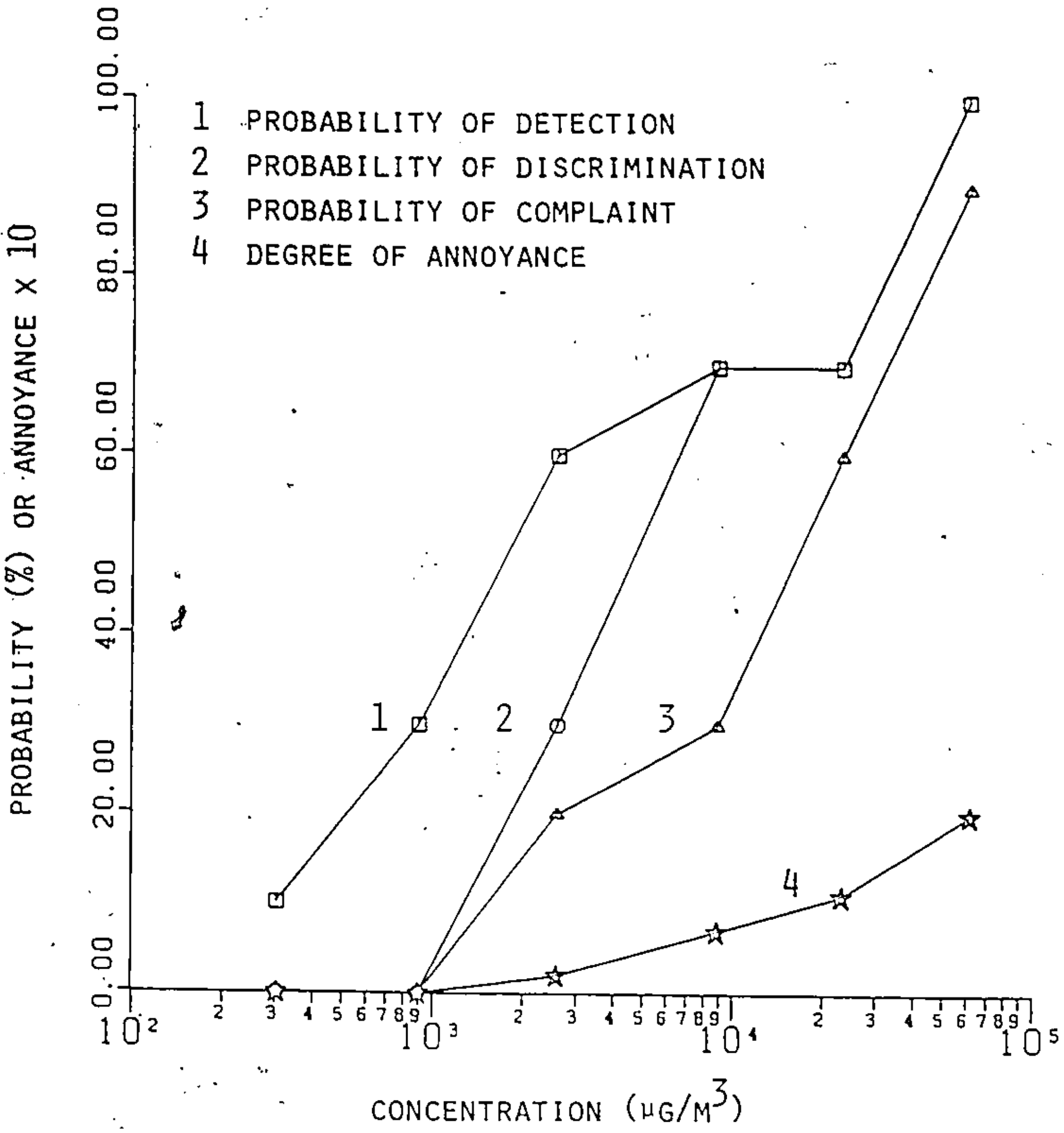


FIGURE IX.2: Panel Two Odour Impact Model.

TABLE IX.5: Panelists' Indication of Odourous Tubes for Panel Three.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	1	3	1	2	3
2	3	3	3	1	2	3
3	2	3	1	1	2	3
4	1	2	1	1	2	3
5	3	3	1	2	2	3
6	2	3	1	2	3	3
7	3	2	1	1	2	3
8	1	2	2	2	2	3
9	3	2	2	2	2	3
10	1	1	3	1	2	3
Odourant Concentration = 4.37×10^5 $\mu g/M^3$						

TABLE IX.6: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Three.

Panelist	Dilution Level No. 1	2	3	4	5	6	Discriminate at Dilution Level No.
	Degree of Annoyance (0-10)						
1	0	0	0	0	3	3	5
2	0	0	0	1	2	4	4
3	0	0	0	0	1	3	5
4	0	0	0	0	1	2	3
5	0	0	3	3	3	4	4
6	0	0	0	0	1	2	6
7	0	0	0	1	2	5	4
8	1	1	1	1	1	1	6
9	0	0	0	0	0	1	6
10	0	0	1	2	4	7	4

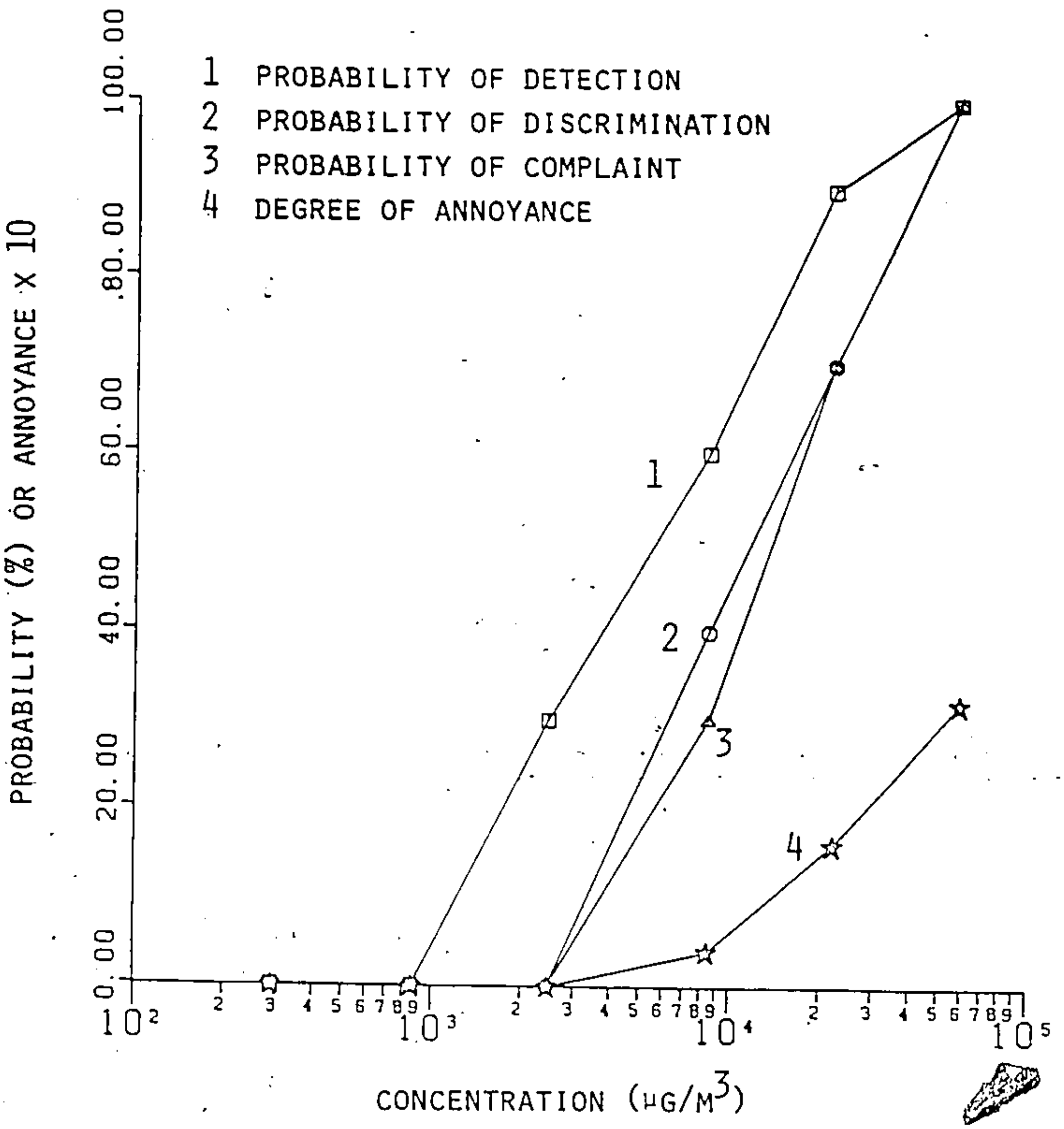


FIGURE IX.3: Panel Three Odour Impact Model.

TABLE IX.7: Panelists' Indication of Odourous Tubes for Panel Four.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	1	3	3	1	3
2	3	2	3	1	2	3
3	3	2	3	1	2	3
4	1	1	3	2	2	3
5	1	2	3	1	2	3
6	2	3	1	2	3	3
7	1	1	3	1	2	3
8	2	3	3	1	2	3
9	2	3	3	1	2	3
10	2	2	3	1	2	3
Odourant Concentration = 4.37×10^5 $\mu g/M^3$						

TABLE IX.8: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Four.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	0	6
2	0	0	1	2	2	3	3
3	0	1	2	2	3	3	2
4	0	0	0	0	1	4	5
5	0	0	0	0	1	1	4
6	0	0	0	0	0	3	6
7	0	0	0	1	3	4	4
8	0	0	0	1	2	3	3
9	0	0	0	1	2	3	4
10	0	0	0	2	3	4	4

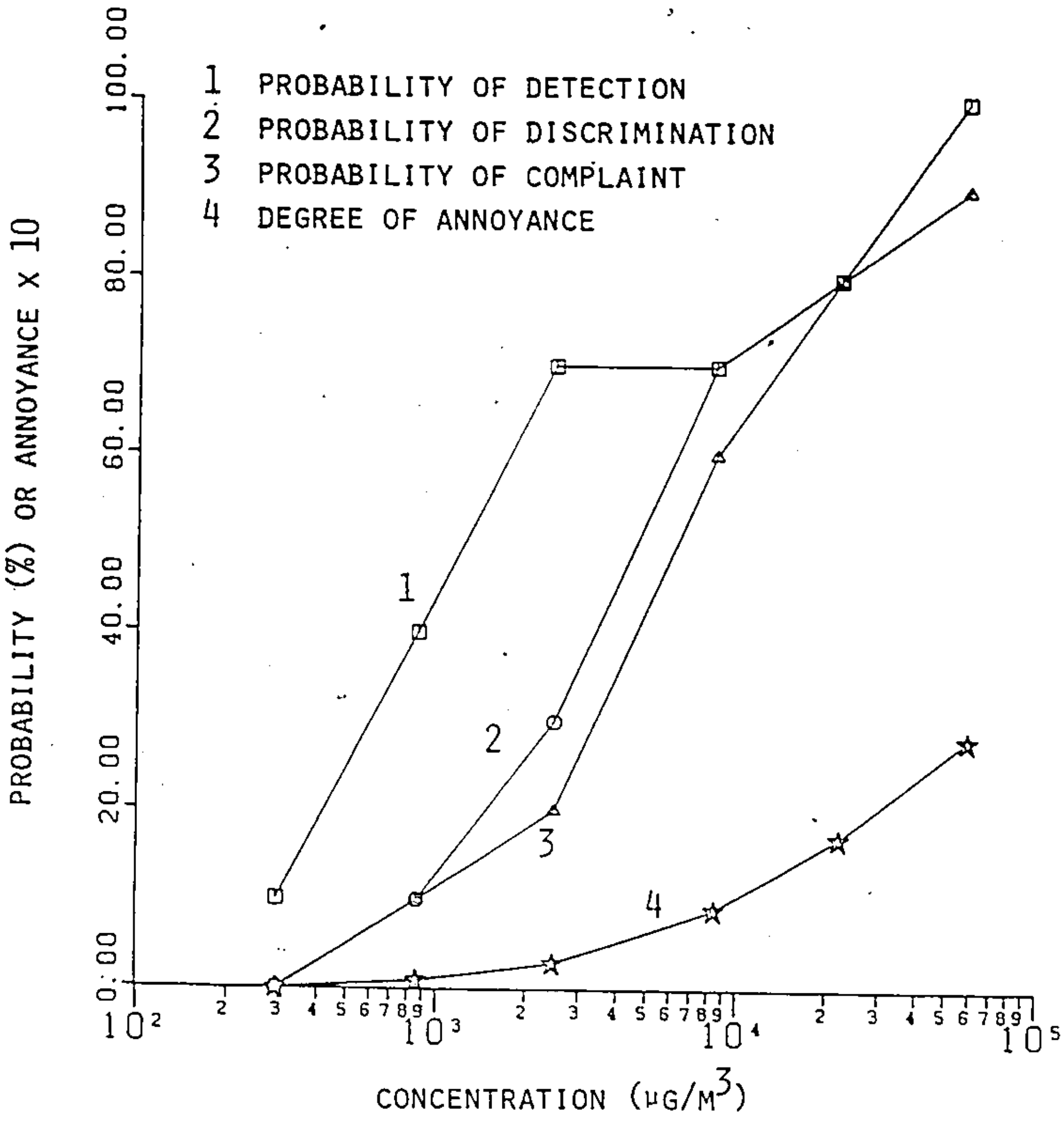


FIGURE IX.4: Panel Four Odour Impact Model.

TABLE IX.9: Panelists' Indication of Odourous Tubes for Panel Five.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	2	1	1	2	3
2	3	2	1	3	2	3
3	3	1	2	1	2	3
4	1	1	1	1	1	3
5	3	2	3	1	2	3
6	2	2	3	1	2	3
7	3	3	1	3	2	3
8	2	1	3	1	2	3
9	3	1	2	3	2	3
10	2	3	3	1	2	3

Odourant Concentration = 4.37×10^5 $\mu g/M^3$

TABLE IX.10: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Five.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	1	2	4	4
2	0	0	0	0	0	0	6
3	0	0	0	2	2	3	4
4	1	1	1	1	2	2	5
5	0	0	0	0	1	1	6
6	0	0	2	3	3	5	3
7	0	0	0	0	0	1	6
8	0	0	1	2	2	2	3
9	0	0	0	0	0	0	4
10	0	0	1	1	2	3	2

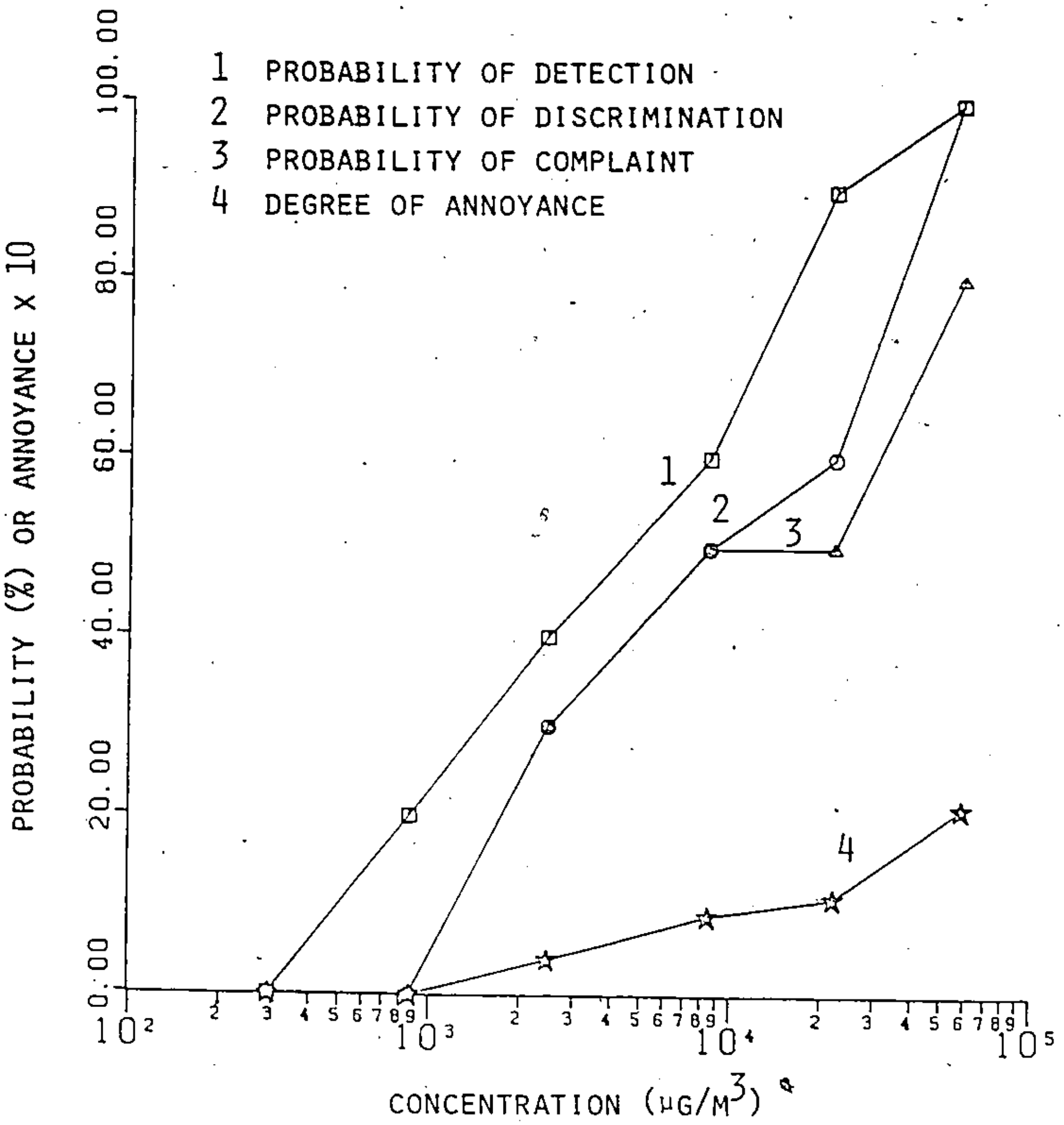


FIGURE IX.5: Panel Five Odour Impact Model.

TABLE IX.11: Panelists' Indication of Odourous Tubes for Panel Six.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	3	3	1	2	3
2	1	1	1	1	2	3
3	2	3	2	2	1	3
4	1	1	2	1	2	3
5	1	2	3	1	2	3
6	2	2	3	1	2	3
7	2	1	2	3	2	3
8	1	3	3	1	2	3
9	3	3	1	3	2	3
10	1	2	1	1	2	3
Odourant Concentration = 4.68×10^5 $\mu g/M^3$						

TABLE IX.12: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Six.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	1	6
2	0	0	0	0	2	2	5
3	0	0	0	0	0	2	6
4	0	0	1	2	2	3	3
5	0	0	0	1	1	1	3
6	0	0	0	1	1	1	3
7	0	0	0	0	0	1	6
8	0	0	0	0	1	2	5
9	0	0	0	0	0	1	6
10	0	0	0	0	0	1	6

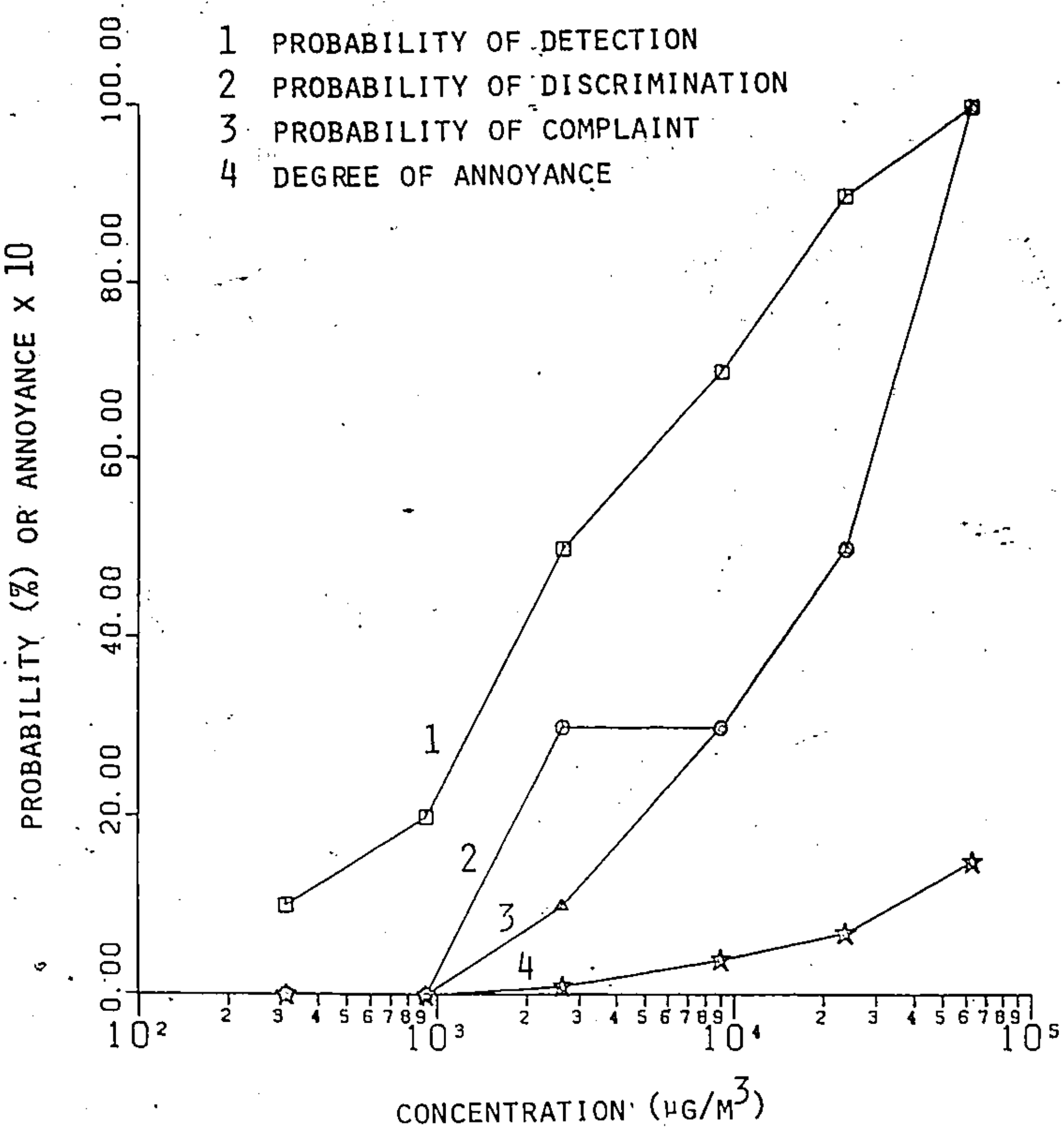


FIGURE IX.6: Panel Six Odour Impact Model.

TABLE IX.13: Panelists' Indication of Odourous Tubes for Panel Seven.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	1	1	3	1	2	3
2	1	2	1	1	2	3
3	2	2	3	1	2	3
4	3	2	1	1	2	3
5	1	3	3	1	2	3
6	2	2	3	1	2	3
7	1	2	3	1	2	3
8	1	3	3	1	2	3
9	1	1	3	1	2	3
10	2	2	1	1	2	3
Odourant Concentration = 4.68×10^5 $\mu g/M^3$						

TABLE IX.14: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Seven.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	1	3	5	4
2	0	0	0	0	3	5	4
3	0	0	0	1	2	2	4
4	0	0	0	1	3	4	5
5	0	0	0	3	4	4	4
6	0	0	1	1	2	2	3
7	0	0	0	1	1	3	6
8	0	0	2	3	5	7	3
9	0	0	3	4	6	8	3
10	0	0	0	0	2	2	5

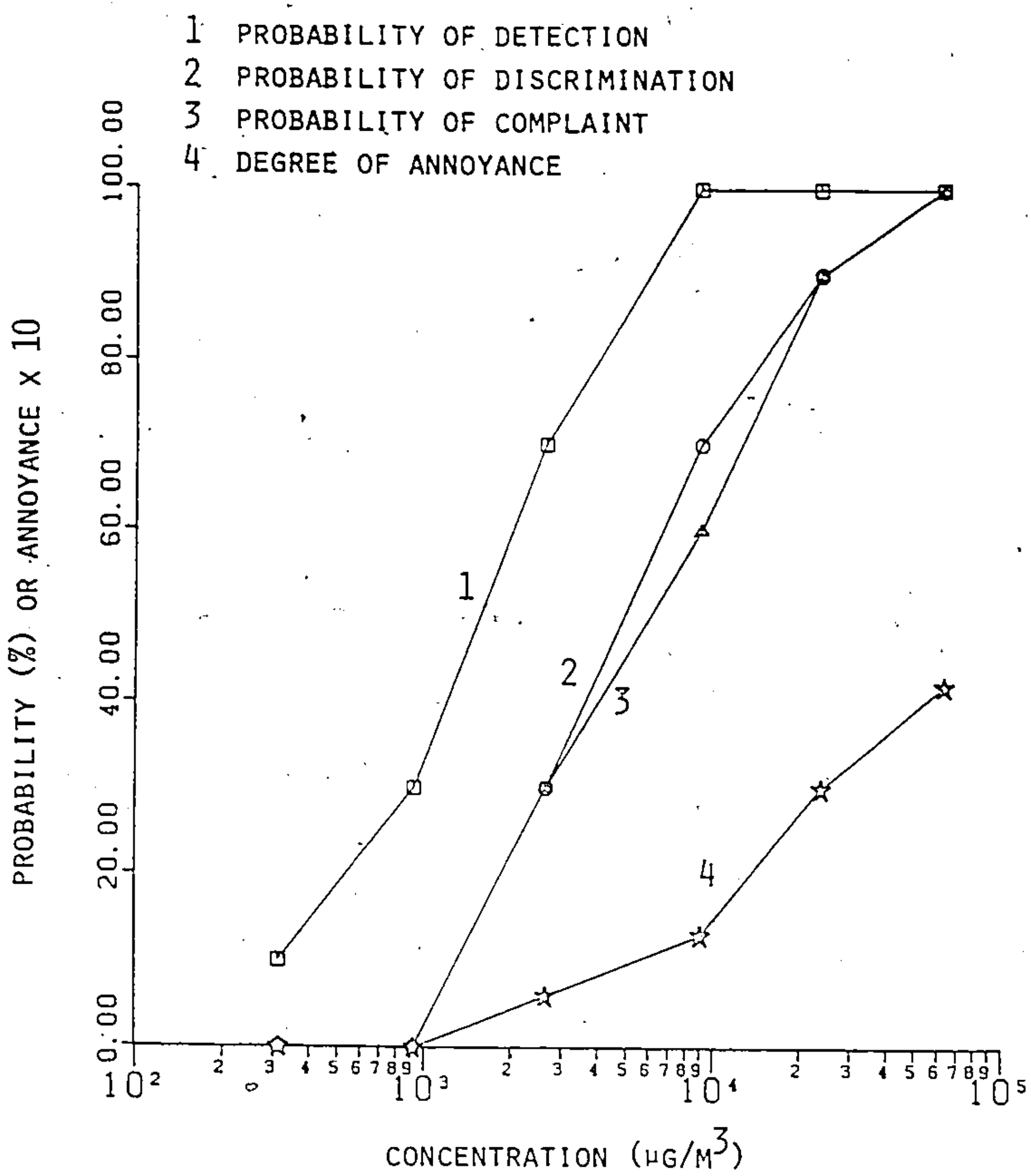


FIGURE IX.7: Panel Seven Odour Impact Model.

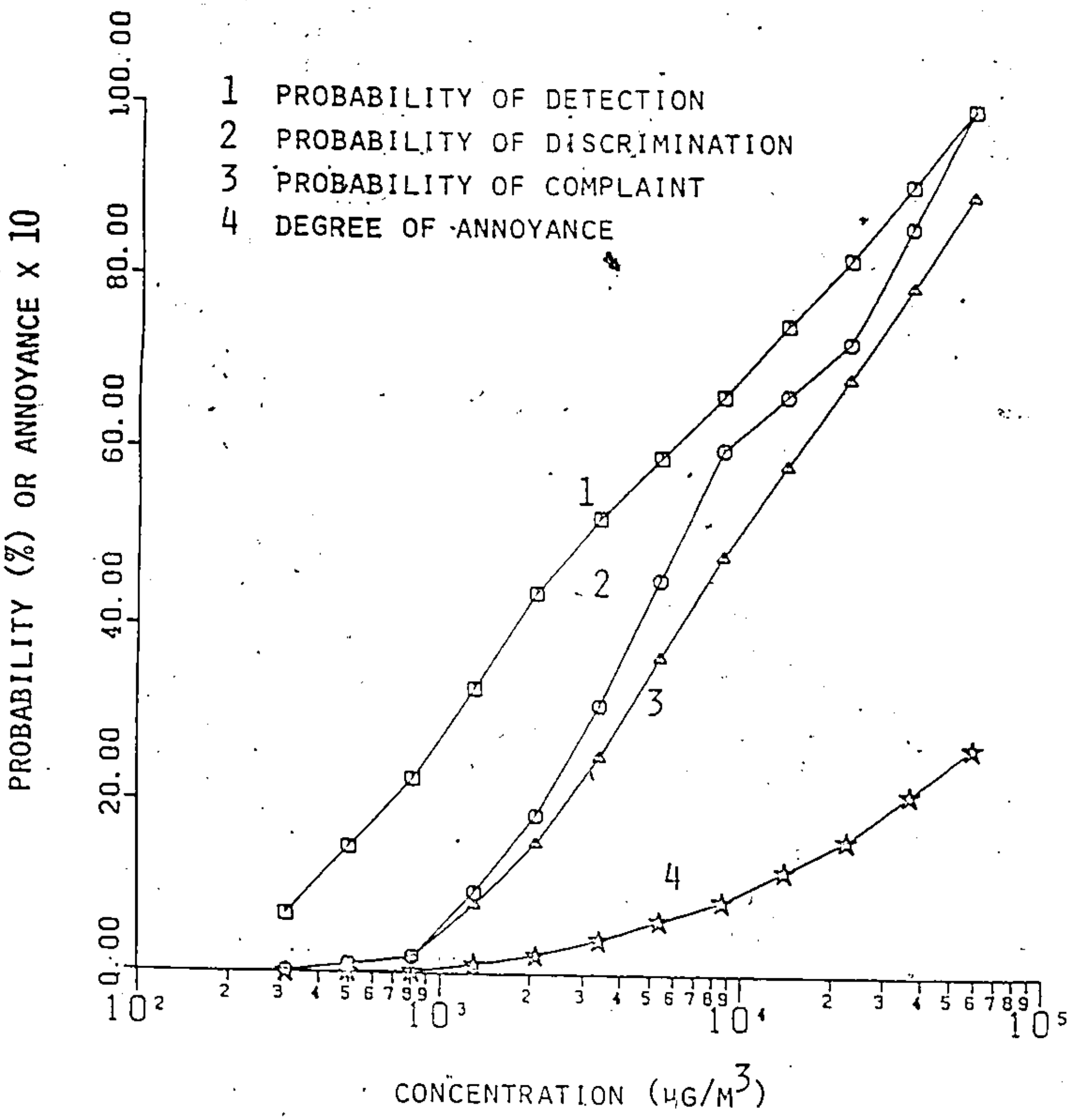


FIGURE IX.8: Odour Impact Model for Isobutanol.

Appendix X

n-Butanol

n-Butanol

Synonyms: n-butanol
butyl alcohol
1-butanol

Formula: $CH_3(CH_2)_3OH$

Physical Properties:

Molecular Weight: 74.12
Melting Point (°C): -90.
Boiling Point (°C): 117.7
Specific Gravity: 0.810

Vapour Pressure (mm Hg)	Temperature (°C)
1.0	-1.2
5.0	20.0
10.0	30.2
20.0	41.5
40.0	53.4
60.0	60.3
100.0	70.1
200.0	84.3
400.0	100.8
760.0	117.7

C.A.S. No: 71-36-3

Chemical Supplier: Aldrich Chemical Company, Inc.

Chemical Purity: 99.9 %
GLC Grade

ACGIH Threshold Limit Values (mg/M³): [20]

Time Weighted Average (TWA) 150 (ceiling)
Short Term Exposure Limit (STEL) none

Odour Data:

Characteristic/quality [22]	rancid, sweet
Hedonic Tone [22]	neutral to pleasant
Lowest Reported Threshold (mg/M^3) [18]	0.36
Highest Reported Threshold (mg/M^3) [18]	150.0
Odour Impact Model Detection Threshold (mg/M^3)	3.10
Odour Impact Model Discrimination Threshold (mg/M^3)	6.90

Odour Impact Models:

- evaluated by 5 10-member panels in a single session
- 28 panelists participated
- see the figures for the individual panel models and the combined odour impact model

TABLE X.1: Panelists' Indication of Odourous Tubes for Panel One.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	2	2	2	2	2
	Dilution Factor					
	1651.	549.8	184.6	60.6	21.1	7.3
1	1	1	2	2	2	2
2	2	3	2	2	2	2
3	3	1	2	2	2	2
4	2	1	3	2	2	2
5	1	3	1	2	2	2
6	1	2	2	2	2	2
7	3	2	2	2	2	2
8	3	2	1	3	3	2
9	2	3	2	2	2	2
10	1	3	3	2	2	2
Odourant Concentration = 1.13 × 10^6 $\mu g/M^3$						

TABLE X.2: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel One.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	1	3	5	5
2	0	0	0	1	3	5	4
3	0	0	0	1	2	2	5
4	0	2	2	5	8	10	4
5	0	0	0	1	2	2	5
6	0	3	4	4	5	6	2
7	0	0	1	3	6	8	4
8	2	2	4	5	7	7	3
9	0	0	1	2	4	5	4
10	0	0	0	3	4	4	4

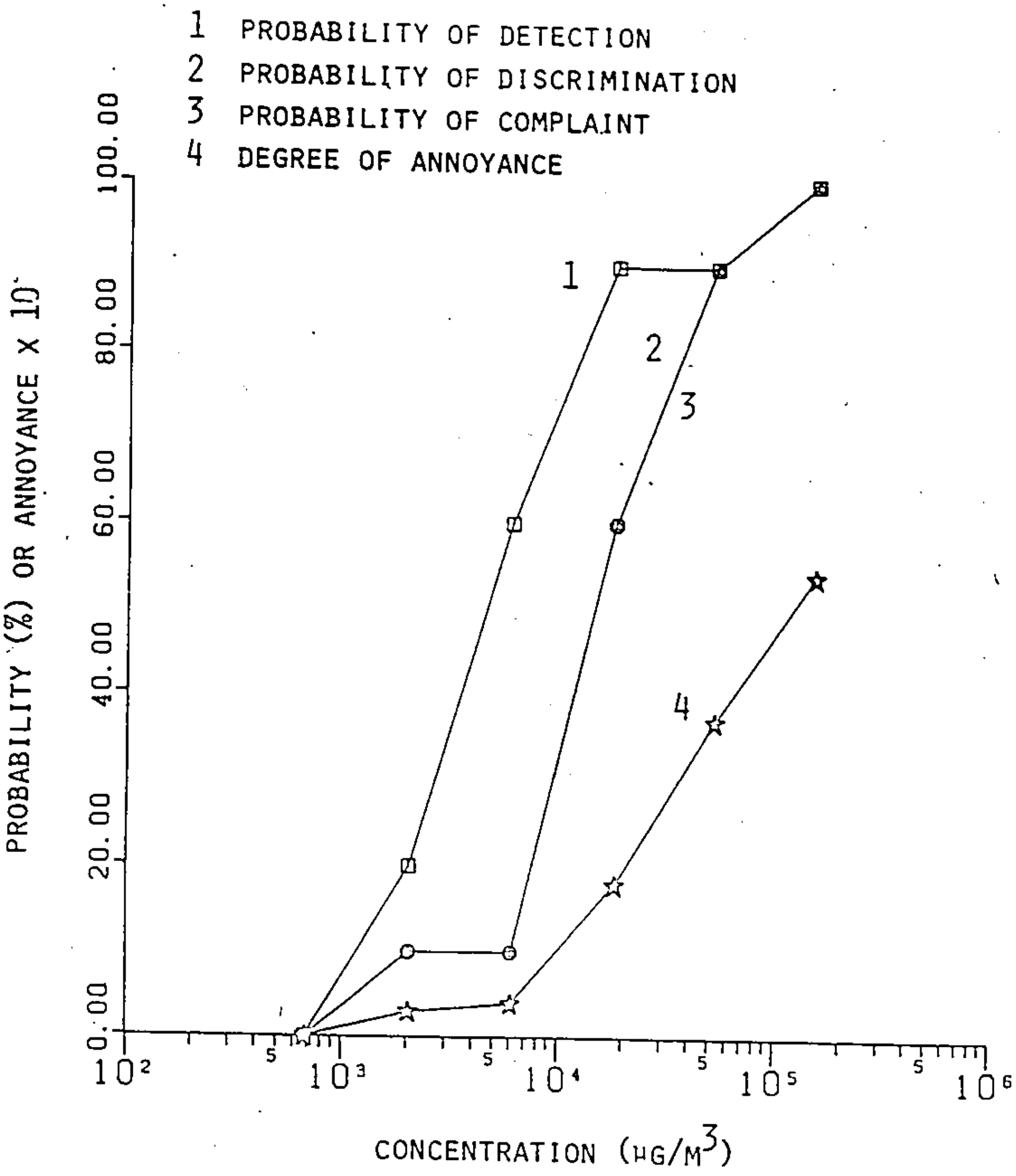


FIGURE X.1: Panel One Odour Impact Model.

TABLE X.3: Panelists' Indication of Odourous Tubes for Panel Two.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	2	2	2	2	2
	Dilution Factor					
	1651.	549.8	184.6	60.6	21.1	7.3
1	2	2	2	2	2	2
2	1	3	2	2	2	2
3	2	3	2	2	2	2
4	1	2	2	2	2	2
5	3	2	1	1	3	2
6	2	1	2	2	2	2
7	3	1	1	3	2	2
8	1	2	1	2	2	2
9	3	1	2	2	2	2
10	1	3	1	2	2	2
Odourant Concentration = 1.13 x 10^6 $\mu g/M^3$						

TABLE X.4: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Two.

Panelist	Dilution Level No. 1	2	3	4	5	6	Discriminate at Dilution Level No.
	Degree of Annoyance (0-10)						
1	1	1	3	4	4	4	3
2	2	2	2	4	4	5	4
3	0	0	2	2	3	4	3
4	0	0	4	5	8	10	3
5	0	0	0	0	0	1	6
6	0	0	0	1	2	2	5
7	0	0	1	1	2	2	5
8	0	0	0	1	2	3	4
9	0	0	2	2	2	2	3
10	0	0	0	0	1	3	5

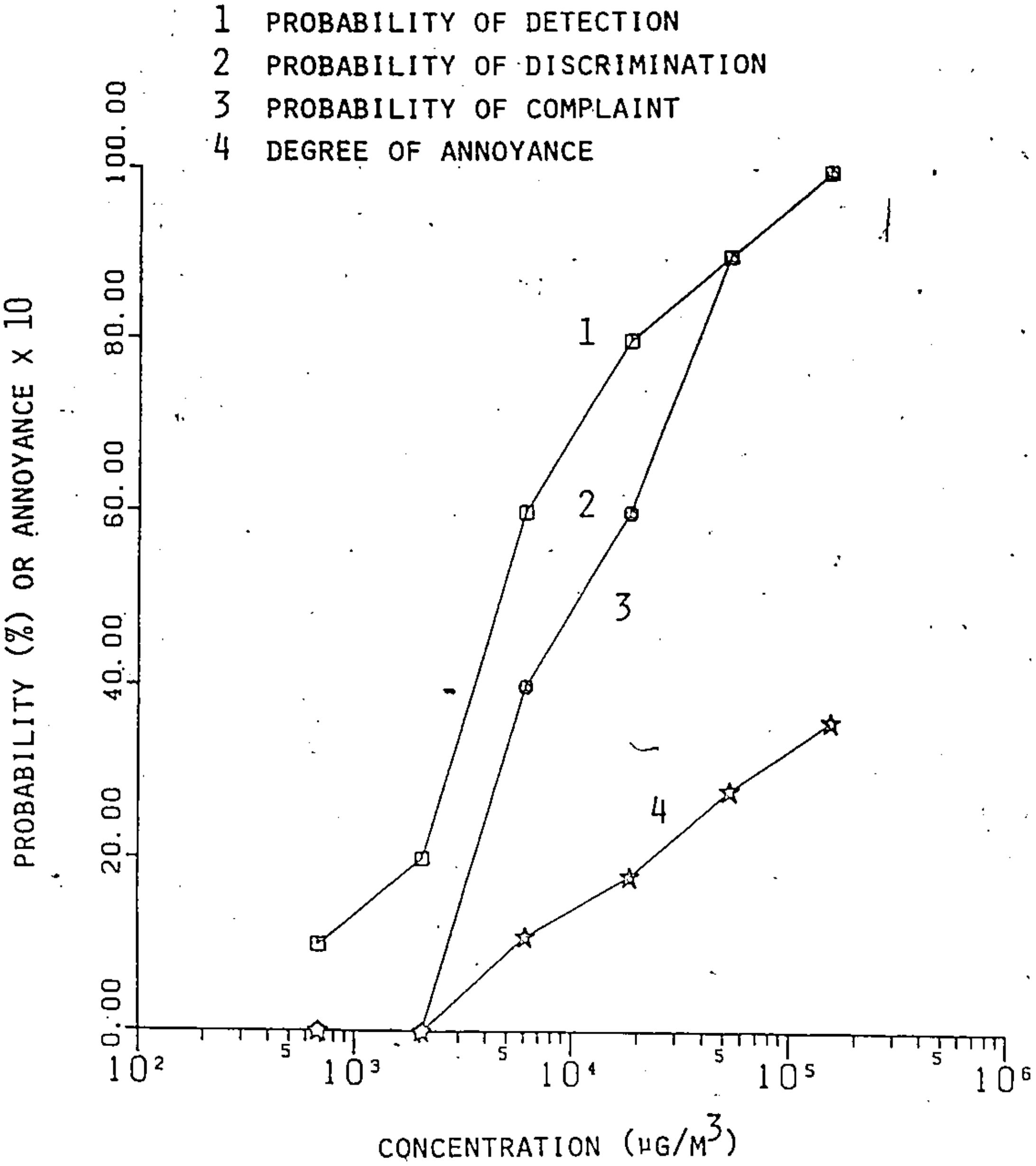


FIGURE X.2: Panel Two Odour Impact Model.

TABLE X.5: Panelists' Indication of Odourous Tubes for Panel Three.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	2	2	2	2	2
	Dilution Factor					
	1651.	549.8	184.6	60.6	21.1	7.3
1	3	1	1	2	2	2
2	3	2	2	2	2	2
3	1	2	2	2	2	2
4	1	3	1	2	2	2
5	2	2	2	2	2	2
6	1	1	2	2	2	2
7	2	3	2	2	2	2
8	1	3	2	2	2	2
9	3	2	2	2	2	2
10	3	2	2	2	2	2
Odourant Concentration = 1.13×10^6 $\mu g/M^3$						

TABLE X.6: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Three.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	1	1	5
2	0	0	2	4	7	9	3
3	1	1	3	3	4	4	3
4	2	2	2	4	5	5	3
5	1	2	5	5	8	10	3
6	0	0	0	1	2	3	3
7	0	0	2	3	4	7	4
8	0	0	0	0	0	1	6
9	0	0	1	1	6	7	3
10	0	1	3	5	6	8	3

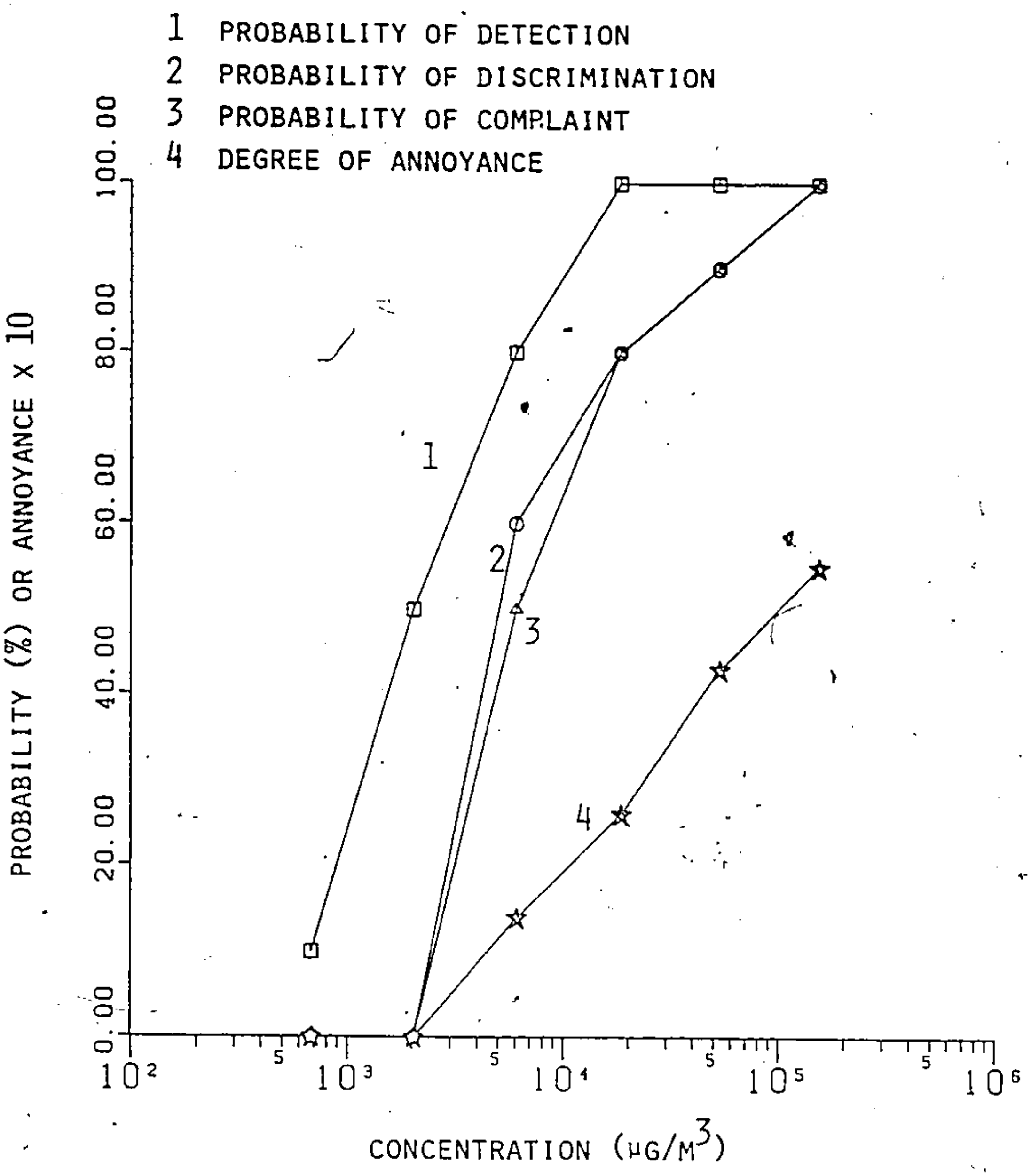


FIGURE X.3: Panel Three Odour Impact Model.

TABLE X.7: Panelists' Indication of Odourous Tubes for Panel Four.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	2	2	2	2	2
	Dilution Factor					
	1651.	549.8	184.6	60.6	21.1	7.3
1	1	3	2	2	2	2
2	2	3	1	2	2	2
3	1	1	2	2	2	2
4	3	2	3	2	2	2
5	1	2	2	2	2	2
6	3	3	2	2	2	2
7	1	2	2	2	2	2
8	2	3	2	2	2	2
9	1	2	2	2	2	2
10	1	3	2	2	2	2
Odourant Concentration = 1.13 × 10^6 $\mu g/M^3$						

TABLE X.8: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Four.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	1	1	1	1	3
2	0	0	0	1	3	7	4
3	0	0	1	2	7	7	4
4	0	0	0	2	4	7	4
5	0	0	0	1	2	4	3
6	0	0	1	3	3	4	3
7	0	0	2	3	4	6	3
8	0	1	2	3	3	3	4
9	0	0	1	2	4	6	3
10	0	0	1	1	2	2	3

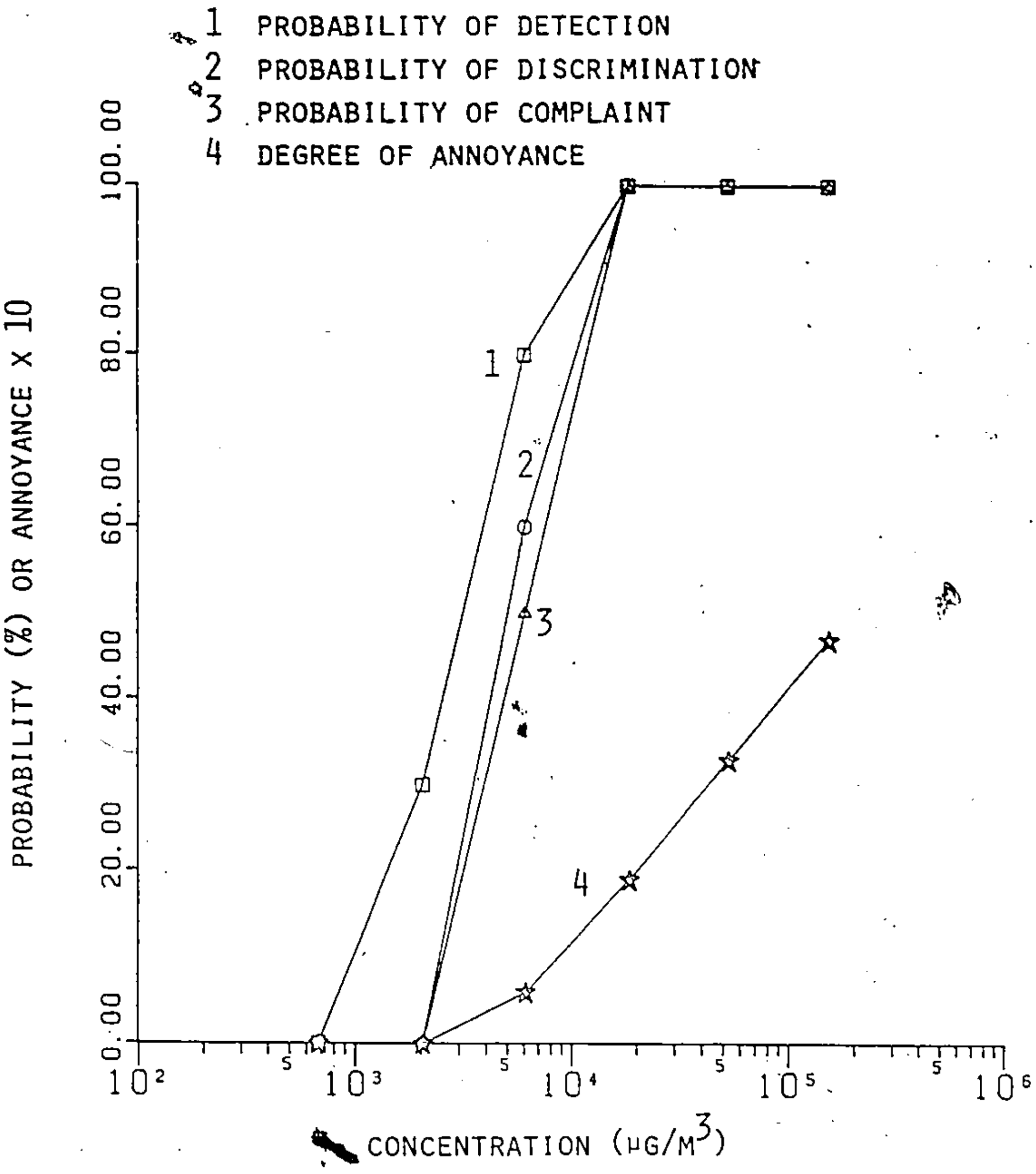


FIGURE X.4: Panel Four Odour Impact Model.

TABLE X.9: Panelists' Indication of Odourous Tubes for Panel Five.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	2	2	2	2	2
	Dilution Factor					
	1651.	549.8	184.6	60.6	21.1	7.3
1	1	3	2	2	2	2
2	3	2	3	2	2	2
3	2	3	2	2	2	2
4	3	1	2	2	2	2
5	1	2	2	2	2	2
6	1	2	2	2	2	2
7	3	2	1	2	2	2
8	1	2	2	2	2	2
9	1	2	2	2	2	2
10	3	2	2	2	2	2
Odourant Concentration = 1.13 × 10^6 $\mu g/M^3$						

TABLE X.10: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Five.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	1	1	3	5	3
2	0	0	0	1	3	7	4
3	0	0	2	3	4	4	3
4	0	0	1	2	2	3	3
5	0	2	2	8	8	8	3
6	0	0	1	1	2	5	3
7	0	0	2	4	8	10	4
8	0	0	1	3	4	5	3
9	1	1	2	4	4	4	4
10	0	0	1	3	3	3	3

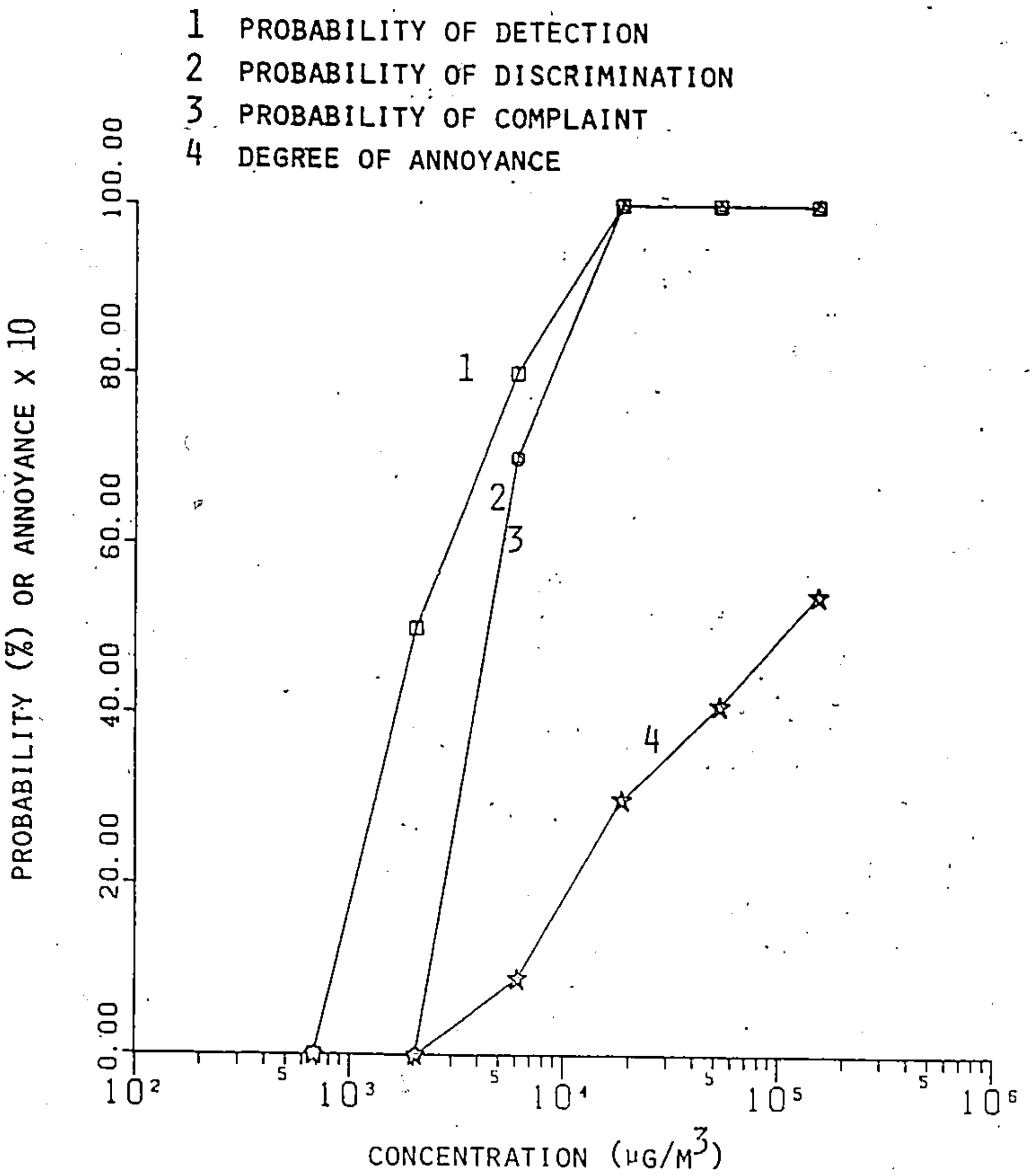


FIGURE X.5: Panel Five Odour Impact Model.

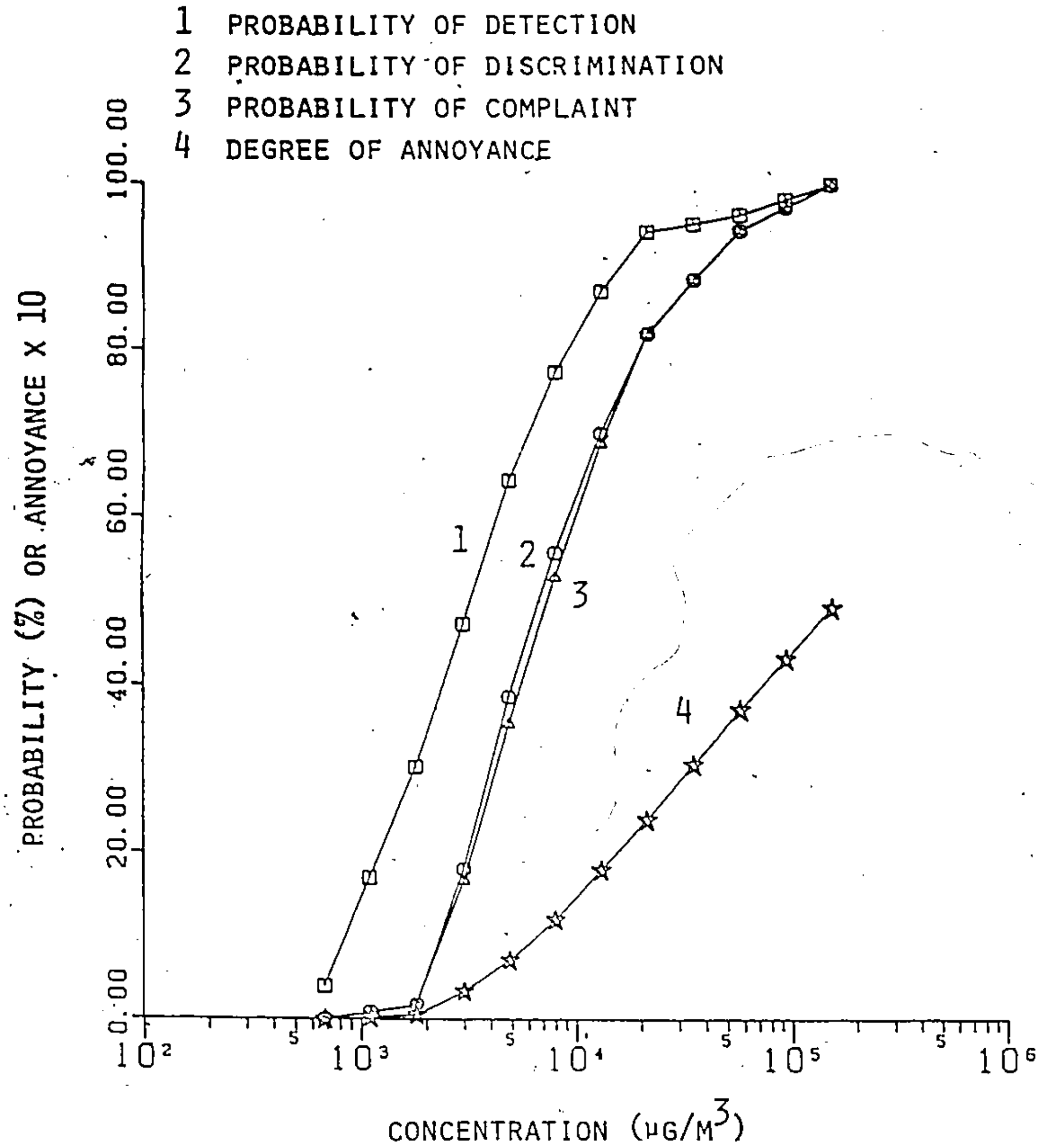


FIGURE X.6: Odour Impact Model for n-Butanol.

Appendix XI

Octane

Octane

<u>Synonyms</u>: octane
n-octane

<u>Formula</u>: $CH_3(CH_2)_6CH_3$

<u>Physical Properties</u>:

Molecular Weight: 114.23
Melting Point (°C): -57.
Boiling Point (°C): 125.6
Specific Gravity: 0.703

Vapour Pressure (mm Hg)	Temperature (°C)
1.0	-14.0
5.0	8.3
10.0	19.2
20.0	31.5
40.0	45.1
60.0	53.8
100.0	65.7
200.0	83.6
400.0	104.0
760.0	125.6

<u>C.A.S. No</u>: 111-65-9

<u>Chemical Supplier</u>: Aldrich Chemical Company, Inc.

<u>Chemical Purity</u>: 99+ %

<u>ACGIH Threshold Limit Values (mg/M^3)</u>: [20]

Time Weighted Average (TWA)	1450
Short Term Exposure Limit (STEL)	1800

Odour Data:

Characteristic/quality [22]	none available
Hedonic Tone [22]	none available
Lowest Reported Threshold (mg/M^3) [18]	725.
Highest Reported Threshold (mg/M^3) [18]	1208.3
Odour Impact Model Detection Threshold (mg/M^3)	61.8
Odour Impact Model Discrimination Threshold (mg/M^3)	129.

Odour Impact Models:

- evaluated by 5 10-member panels in the first session and 2 additional 10-member panels one week later
- 22 panelists participated in the first session
- 20 panelists participated in the second session
- a total of 27 panelists participated
- see the figures for the individual panel models and the combined odour impact model

TABLE XI.1: Panelists' Indication of Odourous Tubes for Panel One.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	3	2	2	3	3	2
2	1	2	1	3	2	2
3	1	2	2	1	3	2
4	3	1	1	1	3	2
5	2	2	1	1	2	2
6	1	2	1	3	2	2
7	1	3	2	3	3	2
8	3	2	2	3	3	2
9	3	2	2	2	3	2
10	1	3	2	2	3	2

Odourant Concentration = 2.73×10^6 $\mu g/M^3$

TABLE XI.2: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel One.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	2	2	5
2	0	0	0	1	1	2	4
3	0	0	0	0	1	2	4
4	0	0	0	0	0	1	4
5	0	0	0	0	2	2	5
6	0	0	0	0	0	2	6
7	1	1	1	2	3	4	5
8	0	0	0	0	0	1	6
9	0	0	0	1	1	2	6
10	0	0	0	0	1	4	5

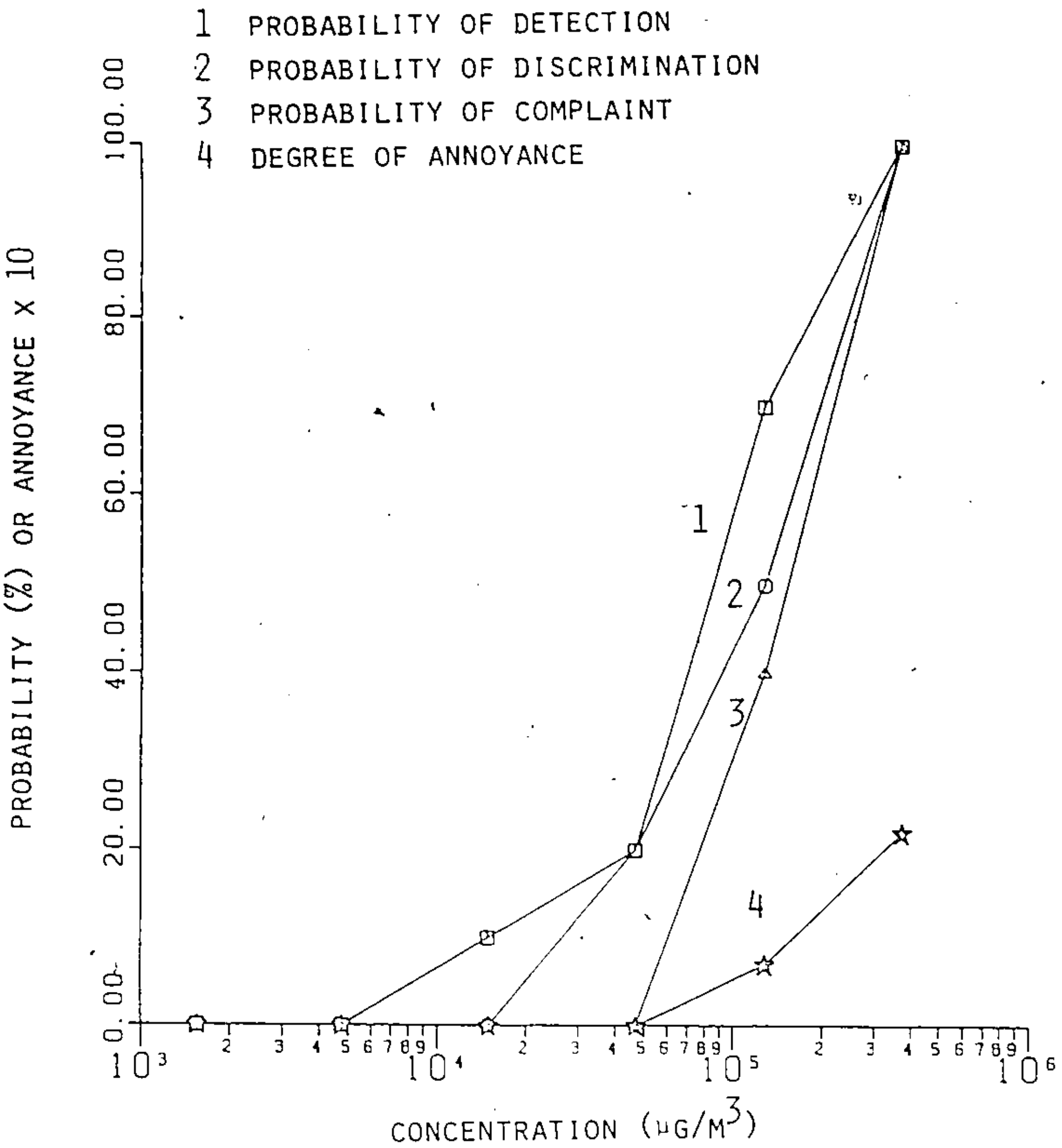


FIGURE XI.1: Panel One Odour Impact Model.

TABLE XI.3: Panelists' Indication of Odourous Tubes for Panel Two.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	3	1	3	1	1	2
2	3	2	2	3	3	2
3	3	1	3	3	3	2
4	3	3	1	3	1	2
5	1	2	1	1	3	2
6	1	1	3	1	3	2
7	3	1	2	3	2	2
8	1	1	1	1	3	2
9	3	3	3	3	3	2
10	3	1	2	1	3	2
Odourant Concentration = 2.62×10^6 $\mu g/M^3$						

TABLE XI.4: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Two.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	2	6
2	0	0	0	0	0	3	6
3	0	0	0	0	0	1	6
4	0	0	0	0	0	2	6
5	0	0	0	0	0	4	6
6	0	0	0	0	0	2	6
7	0	0	0	0	1	3	6
8	0	0	0	0	0	1	5
9	0	0	0	0	0	4	5
10	0	0	0	0	0	1	6

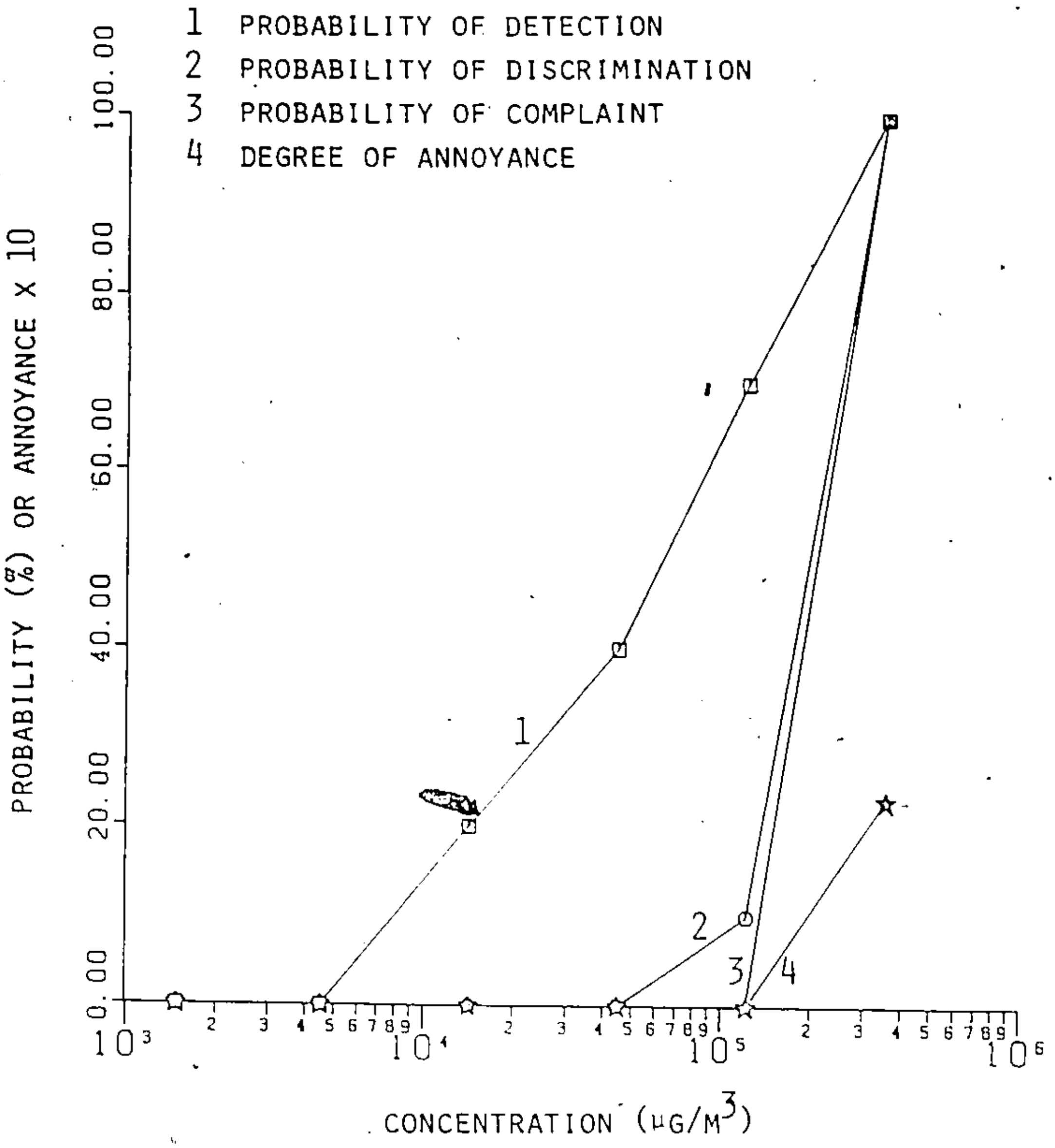


FIGURE XI.2: Panel Two Odour Impact Model.

TABLE XI.5: Panelists' Indication of Odourous Tubes for Panel Three.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	3	2	1	1	3	2
2	1	1	2	2	2	2
3	3	2	2	1	3	2
4	3	3	2	2	3	2
5	3	3	2	3	3	2
6	3	2	2	3	3	2
7	2	2	1	3	3	2
8	1	1	3	2	3	2
9	3	1	1	2	2	2
10	3	2	3	3	3	2
Odourant Concentration = 2.62×10^6 $\mu g/M^3$						

TABLE XI.6: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Three.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	1	2	5
2	0	0	0	0	0	1	6
3	1	1	1	1	2	2	5
4	0	0	0	0	1	1	6
5	0	0	0	0	3	5	5
6	0	0	0	0	0	1	6
7	0	0	0	0	0	1	5
8	0	0	0	0	1	3	5
9	0	0	0	0	1	3	5
10	0	0	0	0	1	2	5

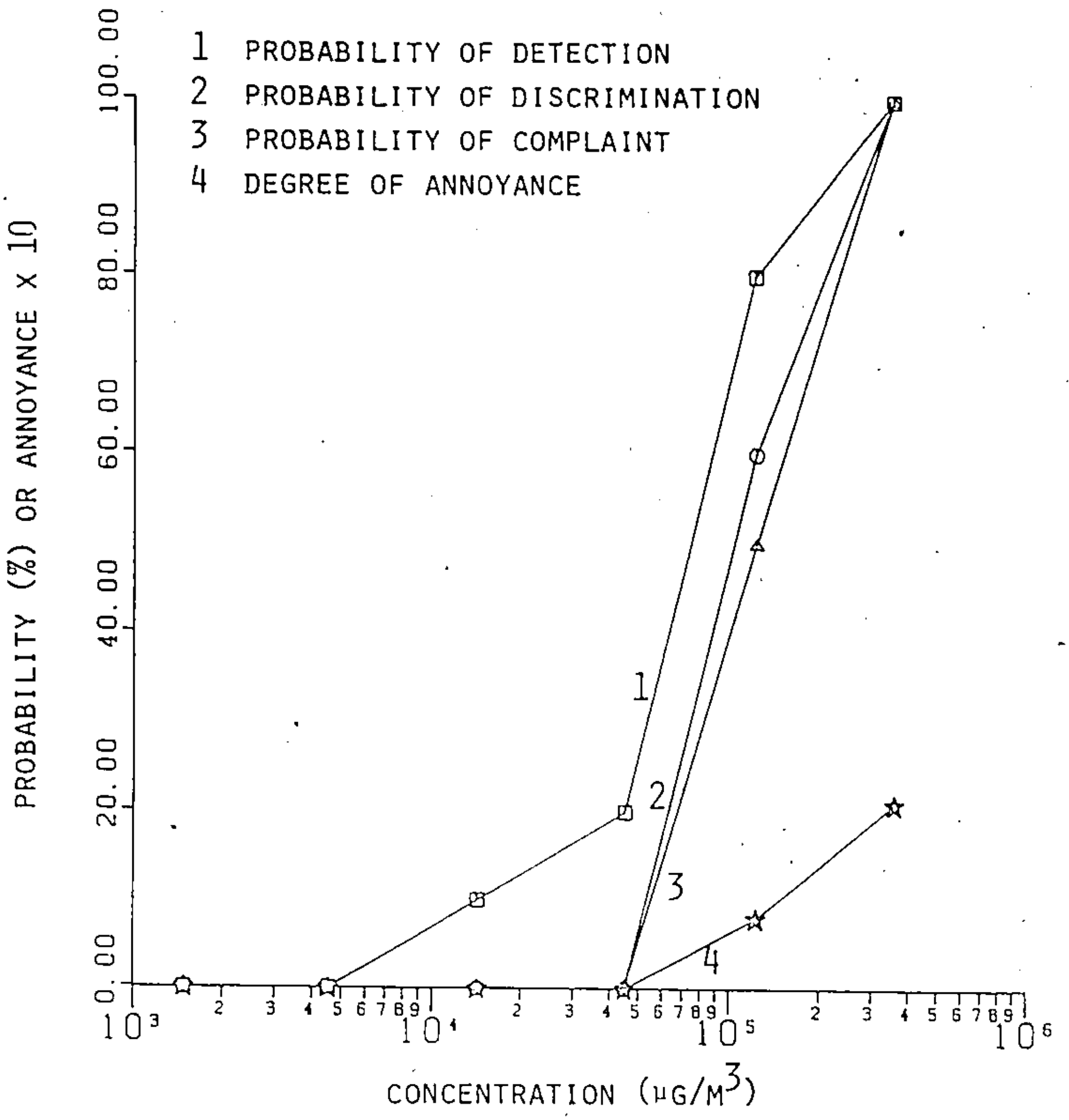


FIGURE XI.3: Panel Three Odour Impact Model.

TABLE XI.7: Panelists' Indication of Odourous Tubes for Panel Four.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	2	1	1	2	3	2
2	3	1	3	3	3	2
3	2	2	3	1	3	2
4	1	2	2	1	3	2
5	2	1	3	2	3	2
6	2	1	2	1	3	2
7	1	3	1	3	3	2
8	3	3	2	1	3	2
9	2	2	1	1	3	2
10	3	2	2	2	3	2
Odourant Concentration = 2.48×10^6 $\mu g/M^3$						

TABLE XI.8: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Four.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	3	3	3	3	3	4	5
2	0	0	0	0	0	1	6
3	0	0	0	1	2	3	4
4	0	0	0	0	0	3	6
5	0	0	0	0	0	2	6
6	0	0	0	0	1	4	4
7	0	0	0	0	1	2	5
8	0	0	0	0	1	2	5
9	0	0	0	0	1	1	5
10	0	0	0	0	0	1	6

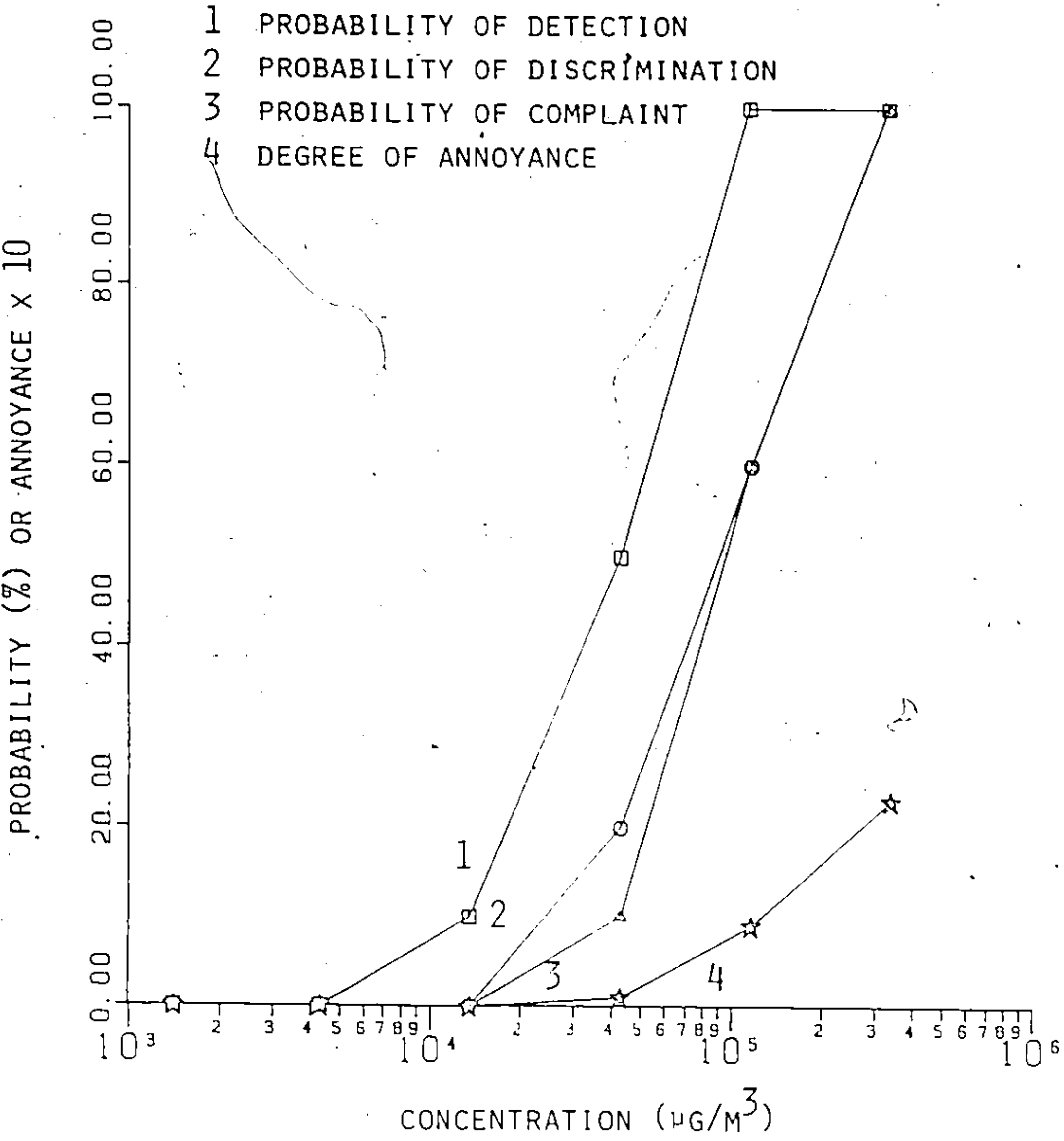


FIGURE XI.4: Panel Four Odour Impact Model.

TABLE XI.9: Panelists' Indication of Odourous Tubes for Panel Five.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	2	3	1	1	3	2
	Dilution Factor					
	1765.	575.8	182.9	57.9	21.3	7.3
1	1	1	2	1	3	2
2	3	2	1	2	3	2
3	2	1	3	2	3	2
4	1	3	2	1	3	2
5	1	1	3	2	3	2
6	2	2	2	2	3	2
7	2	3	3	1	3	2
8	1	3	3	1	3	2
9	2	2	3	2	2	2
10	2	1	2	3	3	2
Odourant Concentration = 2.48×10^6 $\mu g/M^3$						

TABLE XI.10: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Five.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	1	2	5
2	0	0	0	0	0	1	6
3	0	0	0	0	1	1	5
4	0	0	0	0	0	1	6
5	0	0	0	0	1	2	5
6	0	0	0	0	2	4	5
7	0	0	0	0	2	5	5
8	0	0	0	0	0	2	5
9	0	0	0	0	0	1	6
10	0	0	0	0	0	2	6

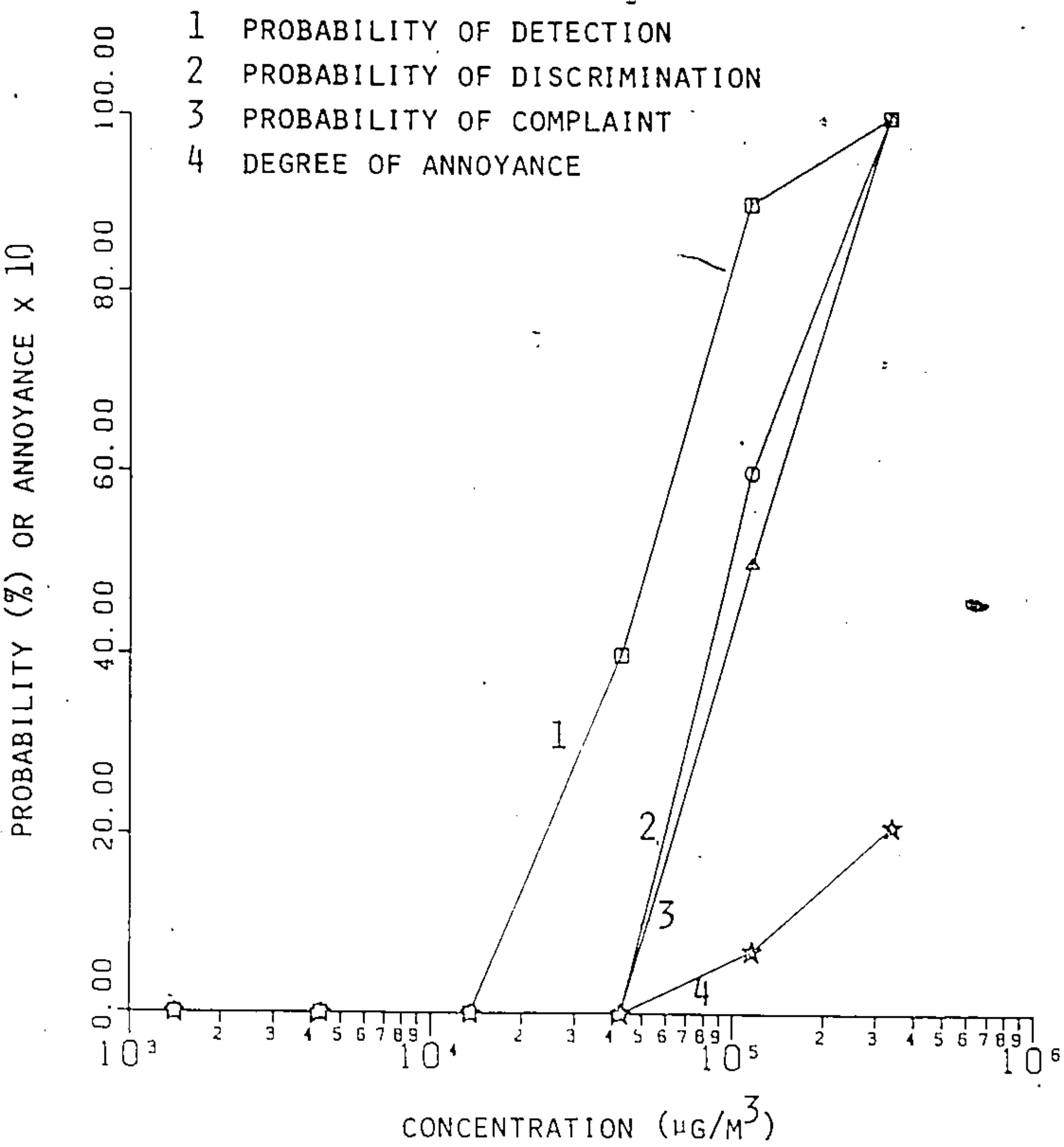


FIGURE XI.5: Panel Five Odour Impact Model.

TABLE XI.11: Panelists' Indication of Odourous Tubes for Panel Six.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	3	3	3	3	1	3
2	2	2	2	2	1	3
3	1	3	2	1	2	3
4	1	3	2	1	2	3
5	3	3	2	1	2	3
6	2	1	3	2	2	3
7	3	2	1	1	1	3
8	2	3	1	1	2	3
9	2	3	2	2	2	3
10	2	1	1	1	2	3
Odourant Concentration = 2.63×10^6 $\mu g/M^3$						

TABLE XI.12: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Six.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	2	6
2	0	0	0	0	0	0	7
3	0	0	0	0	0	1	5
4	0	0	0	0	1	2	5
5	0	0	0	0	0	1	6
6	0	0	0	0	0	1	6
7	0	0	0	0	0	3	6
8	0	0	0	0	0	2	6
9	0	0	0	0	2	4	5
10	0	0	0	0	0	2	6

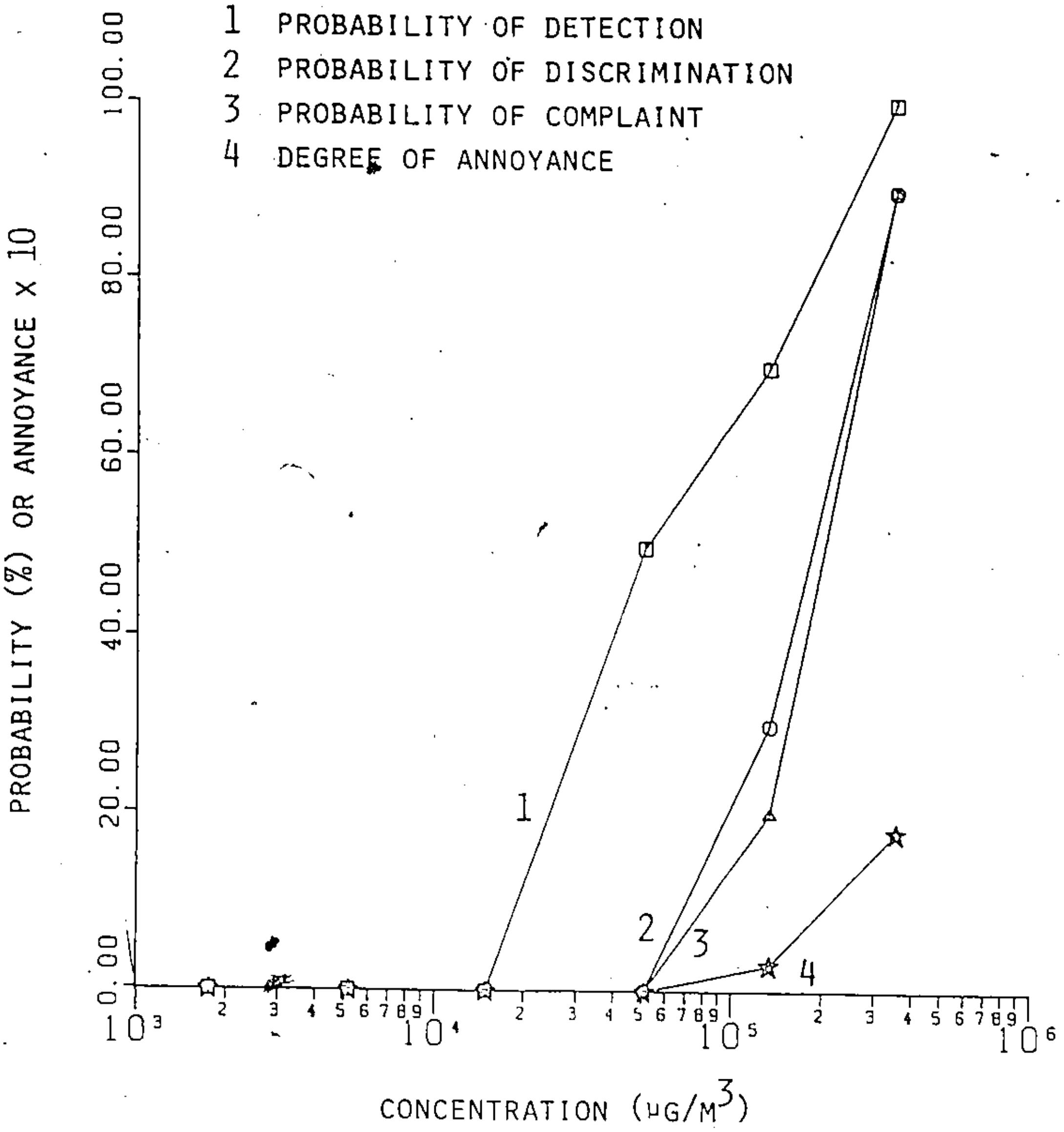


FIGURE XI.6: Panel Six Odour Impact Model.

TABLE XI.13: Panelists' Indication of Odourous Tubes for Panel Seven.

Panelist	Dilution Level No.					
	1	2	3	4	5	6
	Correct Tube Choice					
	1	2	3	1	2	3
	Dilution Factor					
	1497.	506.2	176.2	51.5	19.7	7.4
1	2	1	1	2	3	3
2	1	1	2	1	2	3
3	1	1	2	2	2	3
4	2	2	3	3	2	3
5	3	2	1	3	2	3
6	2	3	2	3	2	3
7	3	3	2	1	2	3
8	1	1	3	1	1	3
9	3	1	3	2	2	3
10	3	2	1	1	2	3
Odourant Concentration = 2.63×10^6 $\mu g/M^3$						

TABLE XI.14: Panelists' Degree of Annoyance and Dilution Level of Discrimination for Panel Seven.

Panelist	Dilution Level No.						Discriminate at Dilution Level No.
	1	2	3	4	5	6	
	Degree of Annoyance (0-10)						
1	0	0	0	0	0	1	6
2	0	0	0	0	0	1	5
3	0	0	0	1	3	3	5
4	0	0	0	1	2	4	4
5	0	0	0	0	1	2	5
6	0	0	0	0	0	1	6
7	0	0	0	0	0	1	6
8	0	0	0	0	0	0	6
9	0	0	0	0	0	1	6
10	0	0	0	0	0	3	6

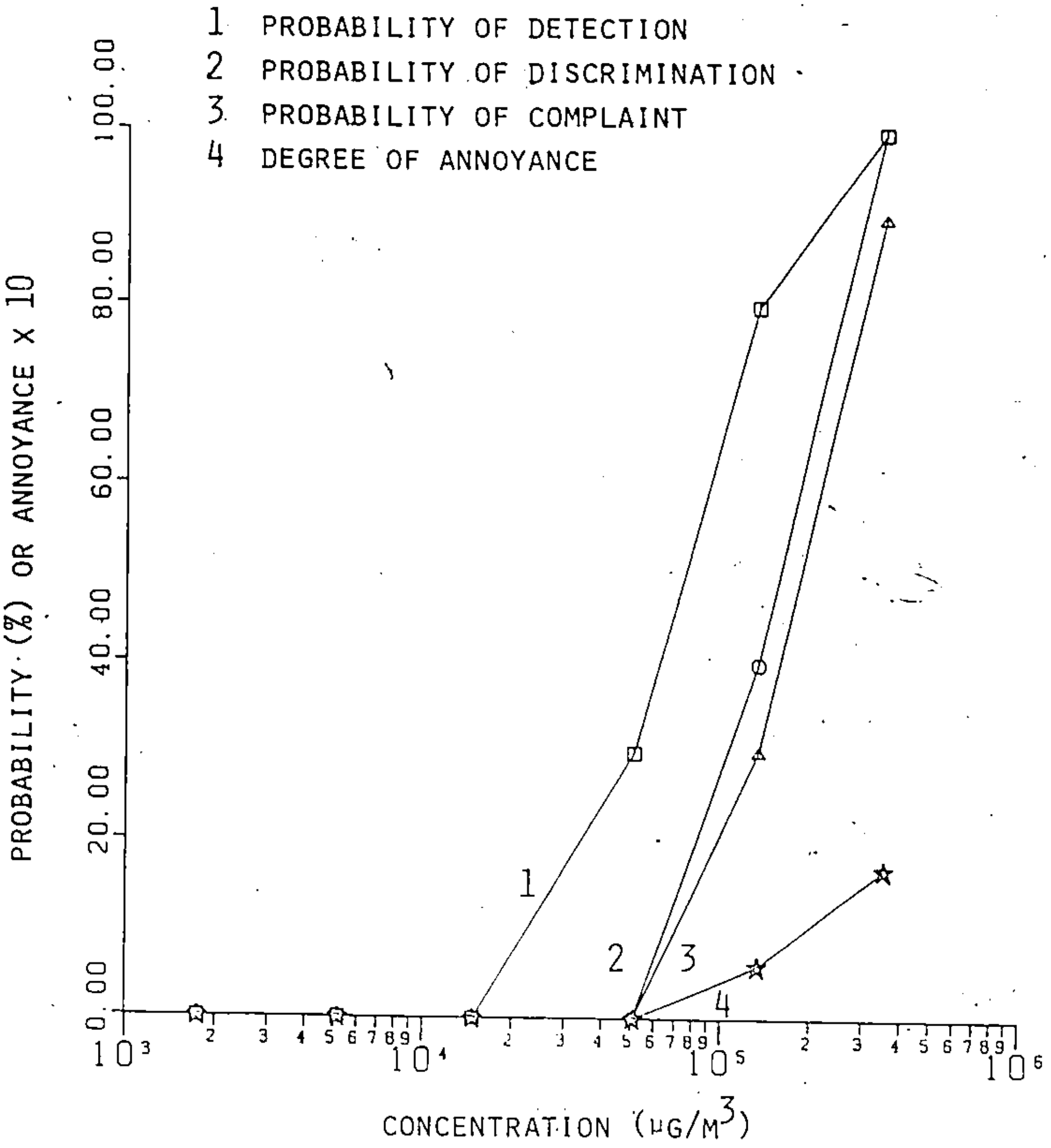


FIGURE XI.7: Panel Seven Odour Impact Model.

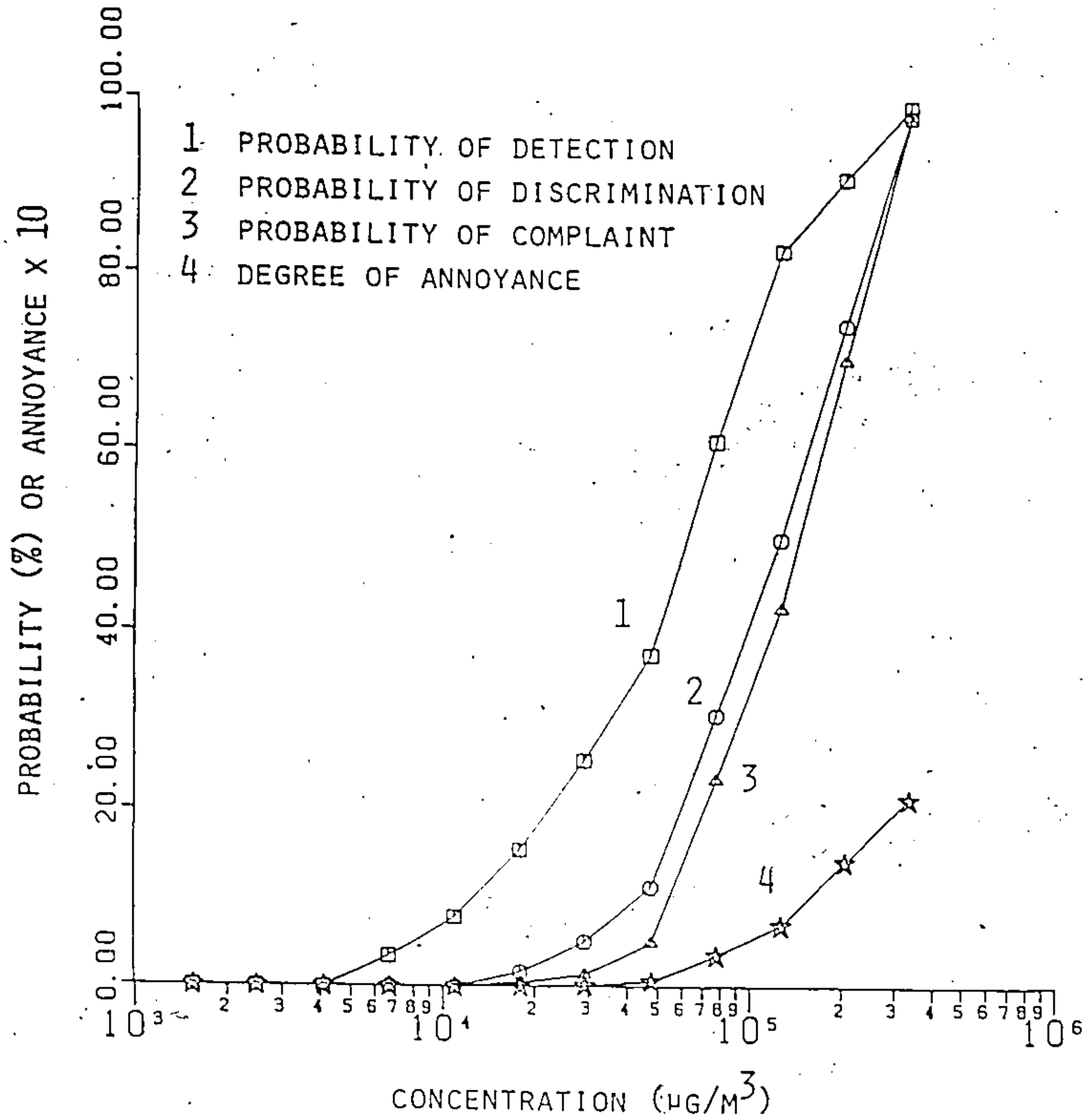


FIGURE XI.8: Odour Impact Model for Octane.

Appendix XII

Major Equipment Components

Major Equipment Components

1. Six Level Dynamic Triangle Olfactometer
   IIT Research Institute
   USA Patent No. 3,902,851

2. Dilution Air Pump
   Thomas Industries
   1419 Illinois Ave., Sheboygan, Wisconsin
   53081
   Catalogue No. 907CA18-TEF

3. Odour Pump
   Masterflex Peristaltic Pump (60-600 RPM)
   Cole Parmer
   Catalogue No. 7553-20

   Masterflex Pump Head
   Model 7017-21
   Patent No. 3,358,609

   Tygon Food Grade Tubing
   Catalogue No. 6419-17
   1/4 inch ID

4. Dry Test Meter
   Rockwell International
   M & U Div. Guelph, Ont.
   RC-415 Meter
   No. EG-171824
   Temperature compensated to 25 °C

5. U-Type Manometer
   The Meriam Instrument Co.
   Cleveland, Ohio, USA.
   Model 20BA10WM

6. Weighing Balance
   Sartorius 2474
   Sartorius
   Germany
   Precision - 0.01 mg
   Range - 160.0 g
   Type 2474S0008

VITA AUCTORIS

1963	Born in Montreal, Quebec, Canada, on July 28.
1980	Awarded High School Diploma from Pierrefonds Comprehensive High School, Montreal, Quebec, Canada.
1981	Awarded Secondary School Diploma from Vincent Massey Secondary School, Windsor, Ontario, Canada.
1985	Completed the Degree of Bachelor of Applied Science in Chemical Engineering at the University of Windsor, Windsor, Ontario, Canada.
1986	Candidate for the Degree of Master of Applied Science in Chemical Engineering at the University of Windsor, Windsor, Ontario, Canada.