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A statistical description of aerosol deposition in nose and mouth for inspiration and expiration has been presented based upon a comprehensive analysis of pertinent experimental data reported in the literature. Due to inherent intersubject and intrasubject variabilities, randomness exists in the deposition data. This randomness has been accounted for in developing predictive relationships for deposition.

Statistical analysis of aerosol deposition in nose and mouth

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introduction

Inhaled particles will deposit along the air passages between the point of entry at lips or nares and larynx. The amount of particles entering the lung thus depends upon the route of entry in the head. Normally, the nasal route collects more particles than the oral because it has nasal hairs and more complex air passages.

Information on nasal deposition has been obtained mostly from experimental work. The usual technique for measuring inspiratory deposition is to draw the aerosol through the nose and out of the mouth while the subject holds his breath.(1-6) The aerosol concentration is measured before it enters the nose and after it leaves the mouth. Neglecting mouth deposition during expiration, inspiratory nasal deposition can be calculated from the concentration difference.

Experimental data show that inspiratory nasal efficiency is best described as a function of the parameter ($\rho d^2 Q$) where ρ is the particle mass density, d the particle diameter and Q the air flow rate. Since this parameter is equivalent to the particle Stokes number, deposition is largely contributed by particle inertia.

Using the data of Landahl and Black,(1) Landahl and Tracewell(2) and Pattle,(3) an empirical relationship was adopted by the Task Group on Lung Dynamics(7) to calculate the inspiratory nasal deposition. This relationship is

$$\eta_{NI} = -1.200 + 0.475 \log \frac{\rho d^2 Q}{(\mathrm{g}\ \mu\mathrm{m}^2\ \mathrm{sec}^{-1})} \qquad (1)$$

Later data obtained by Lippmann(6) using radioactive aerosols also support this relationship. However, relatively scattered and lower nasal depositions were reported by Hounam *et al.*(4,5) using the similar inspiration technique. Hounam's results further show that inspiratory nasal efficiency fits better using a new parameter ($\rho d^2 \Delta P$), where ΔP is the pressure difference across the nose and mouth. Hounam's relationship is

$$\eta_{NI} = 4.331 + 0.660 \log \frac{\rho d^2 \Delta P}{(\mathrm{kg\ m}^{-1}\ \mathrm{Pa})} \qquad (2)$$

Inhalation through nose and out of mouth with breath-holding cannot be regarded as normal breathing. A different breathing method to measure nasal deposition was employed by Giacomelli-Maltoni *et al.*(8,9) and improved by Heyder and Rudolf.(10,11) In this method, the lung (tracheobronchial tree and pulmonary region) is also considered a part of the experimental system. The deposition of particles in the nose is calculated from total deposition of particles in the entire respiratory tract for mouth, nose, mouth-nose and nose-mouth breathing. Because mouth deposition is not significant under the experimental condition, this method allows the determination of nasal deposition for both inspiration and expiration. The experimental correlations of Heyder and Rudolf are as follows:

$$\eta_{NI} = -1.15 + 0.47 \log \frac{\rho d^2 Q}{(\mathrm{g}\ \mu\mathrm{m}^2\ \mathrm{sec}^{-1})} \qquad (3)$$

for inspiration, and

$$\eta_{NE} = -1.01 + 0.43 \log \frac{\rho d^2 Q}{(\mathrm{g}\ \mu\mathrm{m}^2\ \mathrm{sec}^{-1})} \qquad (4)$$

for expiration.

Fry(12) measured nasal deposition of 4.06 μm particles using the methods and apparatus developed by Hounam *et al.* The particle carries on the average 62 unit charges as produced and 11 unit charges as the particle passing through a bipolar ion field for charge reduction. It was found that the difference between average particle charge has no effect on nasal deposition.

There are very limited amounts of data available for mouth deposition. Deposition in the mouth for expiration is normally assumed to be negligible under the experimental condition. For inspiration, deposition of particles in the mouth was measured by Lippmann,(13) Foord *et al.*,(14) Stahlhofen *et al.*(15) and Chan and Lippmann(16) using radioactive aerosols. In these experiments, the subject breathes through a large bore tube in the mouth. The amount of deposition is obtained from the difference of activity measurements, one immediately after the exposure and the other after the deposited particles are removed with mouthwash or by other means. Using their own data, Foord *et al.* obtained a relationship for inspiratory mouth deposition in the form

$$\eta_{MI} = -0.651 + 0.2 \log \frac{\rho d^2 Q}{(\mathrm{g}\ \mu\mathrm{m}^2\ \mathrm{sec}^{-1})} \qquad (5)$$

However, a different relationship was derived by Chan and Lippmann based upon the data of Lippmann, Stahlhofen *et al.* and Chan and Lippmann. It gives

$$\eta_{MI} = 4.14 \times 10^{-2} + 1.02 \times 10^{-5} \frac{\rho d^2 Q}{(g\ \mu m^2\ sec^{-1})} \qquad \textbf{(6)}$$

For $\rho d^2 Q > 1.3 \times 10^4$ g $\mu m^2 sec^{-1}$, equation (6) has a higher deposition than that given by equation (5).

Deposition experiment in the mouth by natural mouth breathing without using a mouth-piece was conducted by Dennis.(17) His data was calculated by the Task Group on Lung Dynamics as a linear function of log $\rho d^2 Q$. Comparison of this result with equation (6) shows that natural breathing has a much greater mouth deposition than breathing through a tube. However, as pointed out by the Task Group, mouth deposition by natural breathing is quite sensitive to the degree to which the mouth is opened, it is inadvisable to apply Dennis' result to mouth deposition in general.

Equations (1) (3)-(6) imply that deposition in the nose and mouth is mainly caused by impaction, since $\rho d^2 Q$ corresponds to the particle Stokes number which is a measure of particle inertia. For small particles at low flowrate, dependence on other parameters is possible. But this has not been studied experimentally.

Theoretical deposition studies in the nose and mouth are scarce because our present knowledge on the anatomical structure and flow field is limited. There have been only two studies on nasal deposition for inspiration. Landahl(18) used a four-region model to calculate deposition by considering inertial and settling effect of particles. His results show less deposition than the experimental data. Scott *et al.*(19) adopted a more accurate nose model consisting of five regions: (I) the region filled with nasal hair, (II) the nasal valve, (III) the expansion region, (IV) the turbinate region,

TABLE I
Source of Deposition Data in Nose and Mouth

Source	Aerosol	Particle Diameter (μm)	Flowrate Q (Lpm)	Number of Subjects	Type of Breathing
		Inspiratory Nasal Deposition			
Landahl & Black (1947)	polydisperse clouds (sampled by Cascade Impactor)				
Landahl & Tracewell (1949)	methylene blue, bismuth subcarbonate, tyrosine, corn oil, Na_2SO_4 $NaHCO_3$, $Ca_3(PO_4)_2$	aerodynamic dia. (0.5 - 23)	constant Q (17.4 - 17.8)	5	nose-in mouth-out with breath holding
Pattle (1961)	monodisperse methylene blue	geometric dia. (1.0 - 9.0)	constant Q (10, 20, 30)	1	
Hounam *et al.* (1969, 1971)	monodisperse radioactive polystyrene	aerodynamic (1.78 - 7.96)	constant Q (5 - 37)	3	
Lippmann (1970)	monodisperse Fe_2O_3 (sizable charged)	geometric dia. (0.8 - 2.4)	average Q (20 - 30)	2	
Giacomelli-Maltoni (1972)	monodisperse Carnauba wax	aerodynamic dia. (0.25 - 1.8)	average Q (~ 24)	15	nose-in mouth-out vs mouth-in mouth-out
Martens & Jacobi (1974)	monidisperse polystrene latex	geometric dia. (0.3 - 1.9)	average Q (~ 30)	1	
Hyder & Rudolf (1974, 1977)	monodisperse di-2-ethyl-hexyl sebacate	geometric dia. (0.5 - 3.5)	constant Q (5 - 37)	4	
		Expiratory Nasal Deposition			
Hyder & Rudolf (1974, 1977)	monodisperse di-2-ethyl-hexyl sebacate	geometric dia. (0.5 - 3.5)	constant Q (5 - 37)	4	mouth-in nose-out vs mouth-in mouth-out
		Inspiratory Mouth Deposition			
Lippmann (1977)	monodisperse radioactive Fe_2O_3	aerodynamic dia. (2 - 10)	average Q (22 - 39)	22	mouth breathing through a tube
Foord *et al.* (1978)	monodisperse polystyrene labelled with $99m_{TC}$	aerodynamic dia. (2.5 - 7.5)	average Q (15 - 60)	19	
Chan & Lippmann (1980)	monodisperse radioactive Fe_2O_3	aerodynamic dia. (0.2 - 7)	average Q (~ 28)	26	
Stahlhofen *et al.* (1980)	monodisperse radioactive Fe_2O_3	aerodynamic dia. (1 - 10)	constant Q (45)	3	

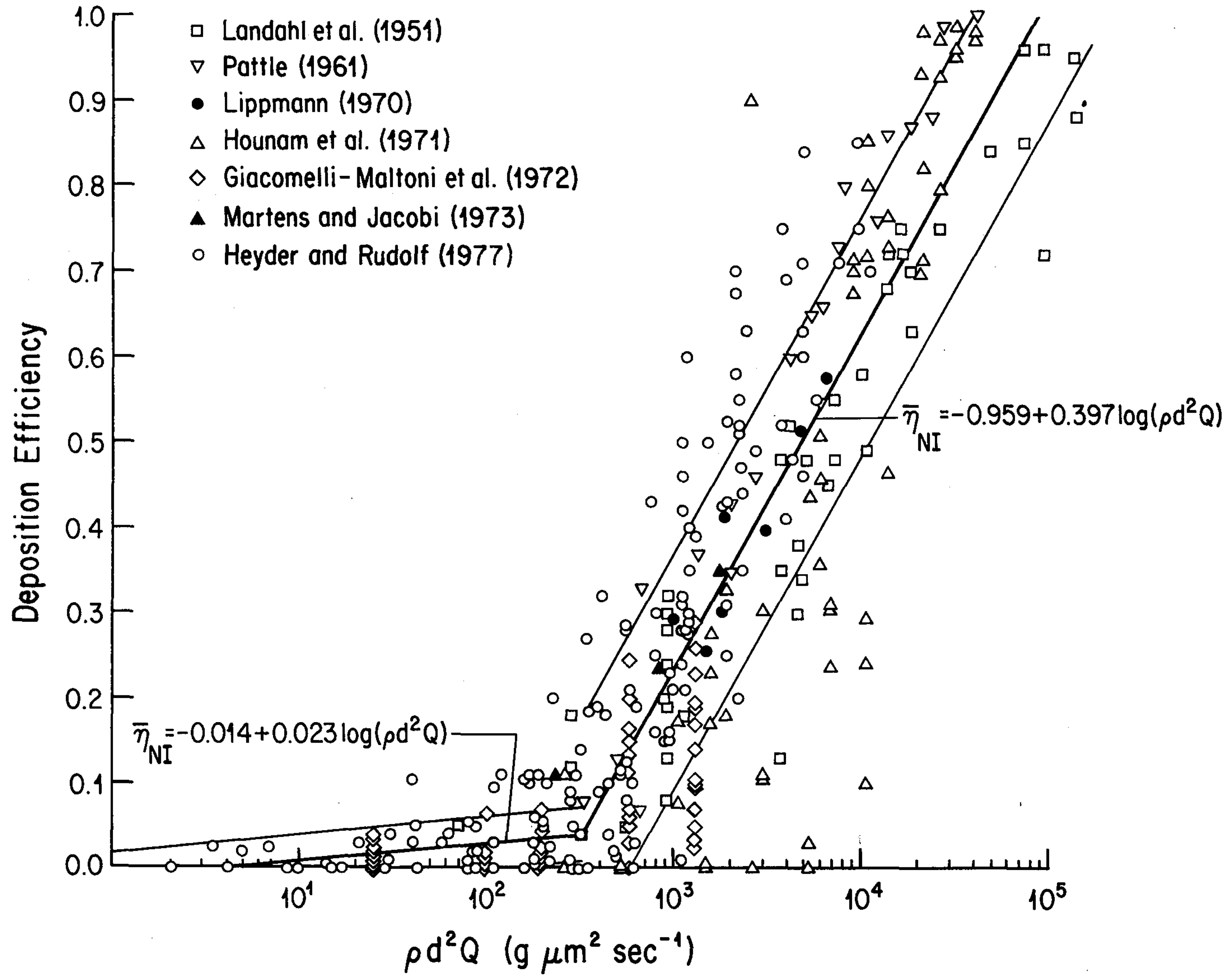

Figure 1 — Deposition of particles in the head for nasal inspiration as a function of ρd^2Q. The equations of $\bar{\eta}_{NI}$ and their σ_{NI} are given by solid lines.

and (V) the posterior bend. Additional to direct impaction, they considered deposition due to secondary flows in the expansion region. This secondary flow is thought to be generated by the air jet from the nasal valve. Calculated depositions using this model show reasonably good agreement with data for both total and regional deposition in the nose.

Deposition data in the nose and mouth by various workers that we previously reported always exhibit a very large amount of scatter. In addition to uncertainties in measurement technique, one major source of this scatter comes from intersubject and intrasubject variabilities. The intersubject variability may arise from the difference in anatomical structure and dimensions, number of nasal hair, breathing pattern, etc. while the intrasubject may be caused partly by the nasal cycle in which flow may be distributed equally side to side or as much as 80% -20%.

The empirical relationships (1) to (6) and the theoretical results by Landahl and Scott *et al.* do not provide the statistical characteristics of deposition. This information is important in the consideration of establishing exposure standards. Furthermore, deposition variabilities in the tracheobronchial and alveolar regions of the lung are known to exist.(13) Because inhaled aerosols reach these regions after they pass through the nose or mouth, it is possible that deposition variations in the tracheobronchial and alveolar region are caused by those which occur in the nose or mouth.

In this paper, a statistical analysis is performed on the deposition data in order to derive more consistent formulas for predicting nasal and mouth deposition at inspiration and expiration. Their associated statistical properties are also presented.

data collection and analysis

The experimental work that we have reviewed above provides accurate and reliable deposition data for nose and mouth to date. These data are used as the basis of our analysis. Table I lists the sources of all experimental data that we used in our analysis together with other pertinent

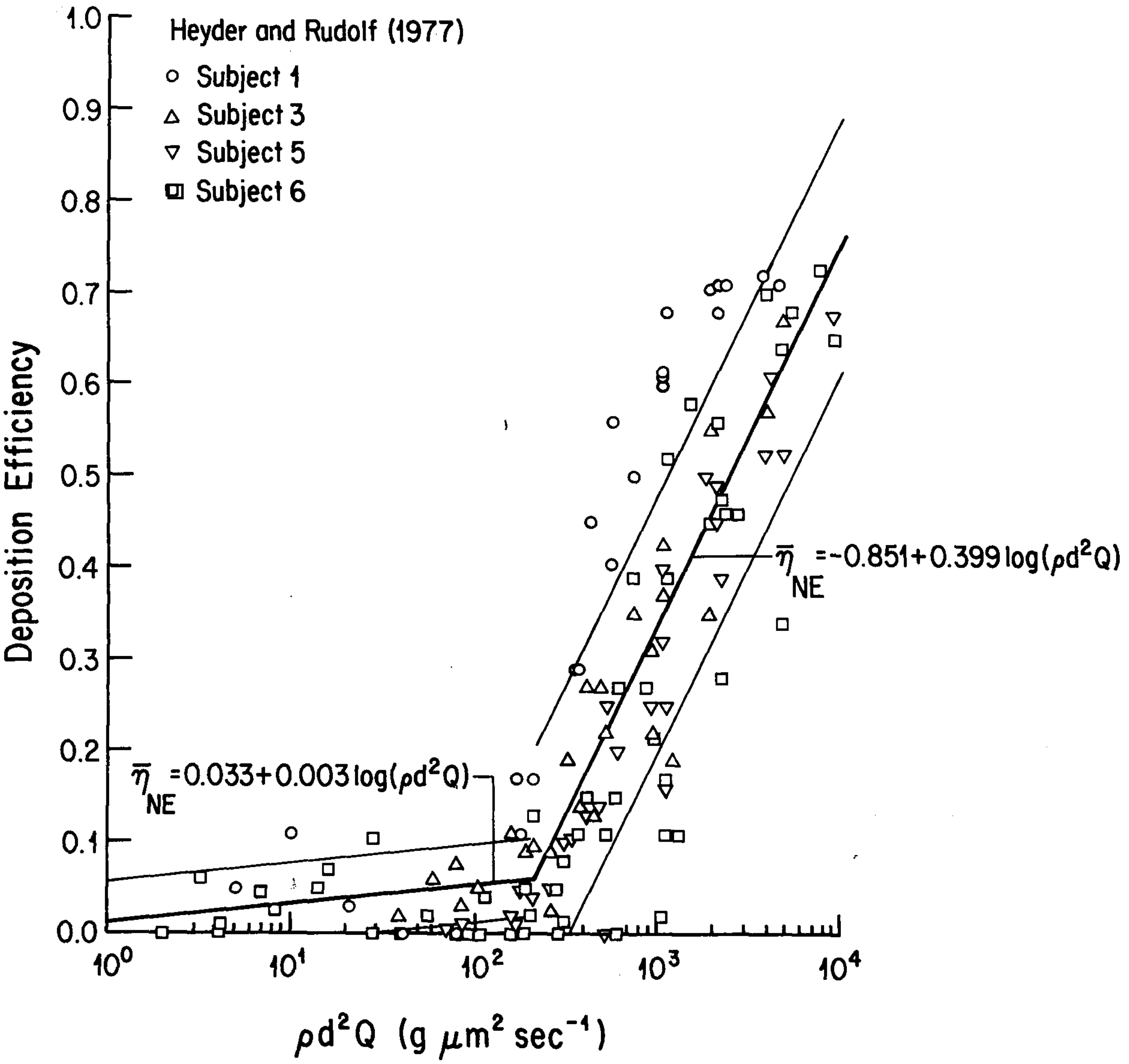

Figure 2 — Deposition of particles in the head for nasal expiration as a function of ρd^2Q. The equations of $\bar{\eta}_{NE}$ and their σ_{NE} are given by solid lines.

information concerning the experiments. These data are presented in Figures 1 to 3 for the cases of inspiratory nasal deposition, expiratory nasal deposition and inspiratory mouth deposition respectively. All data points with negative efficiency in the nasal deposition experiment of Heyder and Rudolf have been replaced by zero deposition.

An observation of Figures 1 and 2 shows that the data points can fit well into two linear relationships in terms of log ρd^2Q, one for small ρd^2Q and the other for large ρd^2Q, with a smaller slope for small ρd^2Q. This is expected on physical grounds that small ρd^2Q in the experiment corresponds to submicron particles, for which diffusional effect becomes increasingly important, resulting in a weaker dependence on particle inertia. The breakpoint of these two relationships is found in the following manner. We first chose a breakpoint for the deposition data at ρd^2Q = 250 g $\mu m^2 sec^{-1}$. Two linear regressions were derived separately from the data for $\rho d^2Q < 250$ g $\mu m^2 sec^{-1}$ and $\rho d^2Q > 250$ g $\mu m^2 sec^{-1}$. The two linear regressions meet at a new breakpoint which was used as the breakpoint of our formulae. The linear relationships for nasal deposition we obtained are as follows:

Inspiratory nasal mean efficiency

$$\bar{\eta}_{NI} = -0.014 + 0.023 \log \frac{\rho d^2Q}{(g\ \mu m^2 sec^{-1})} \quad \textbf{(7a)}$$

for $\rho d^2Q < 337$ g $\mu m^2 sec^{-1}$

and

$$\bar{\eta}_{NI} = -0.959 + 0.397 \log \frac{\rho d^2Q}{(g\ \mu m^2 sec^{-1})} \quad \textbf{(7b)}$$

for $\rho d^2Q > 337$ g $\mu m^2 sec^{-1}$

Expiratory nasal mean efficiency

$$\bar{\eta}_{NE} = 0.033 + 0.003 \log \frac{\rho d^2Q}{(g\ \mu m^2 sec^{-1})} \quad \textbf{(8a)}$$

for $\rho d^2Q < 215$ g $\mu m^2 sec^{-1}$

and

$$\bar{\eta}_{NE} = -0.851 + 0.399 \log \frac{\rho d^2 Q}{(g\ \mu m^2 sec^{-1})} \qquad \textbf{(8b)}$$

$$\text{for } \rho d^2 Q > 215 \text{ g } \mu m^2 sec^{-1}$$

For mouth deposition, Figure 3 shows that all data points for $\rho d^2Q < 1000$ g $\mu m^2 sec^{-1}$ are nearly zero. We, therefore, neglected these points in the calculation. For $\rho d^2Q > 1000$ g $\mu m^2 sec^{-1}$, a single relationship was derived from the data. The result is

$$\bar{\eta}_{MI} = -1.117 + 0.324 \log \frac{\rho d^2 Q}{(g\ \mu m^2 sec^{-1})} \qquad \textbf{(9a)}$$

$$\text{for } \rho d^2 Q > 3000 \text{ g } \mu m^2 sec^{-1}$$

and

$$\bar{\eta}_{MI} = 0 \qquad \textbf{(9b)}$$

$$\text{for } \rho d^2 Q < 3000 \text{ g } \mu m^2 sec^{-1}$$

Equations (7)-(9) are plotted in Figures 1 to 3 for the use of predicting mean depositions. To account for intersubject and intrasubject variabilities, we may write, for a given ρd^2Q,

$$\eta_i = E(\eta_i) + \epsilon_i = \bar{\eta}_i + \epsilon_i \qquad \textbf{(10)}$$

where η_i is the deposition efficiency for occurrence i, $E(\eta_i)$ is the expected value of η_i, and ϵ_i is a random variable such that

$$E(\epsilon_i) = 0 \qquad \textbf{(11)}$$

An observation of the data in Figures 1 to 3 shows that ϵ_i does not vary significantly with ρd^2Q. The variance of ϵ_i is therefore assumed to be constant for each case. Thus,

$$Var(\epsilon_i) = E(\epsilon_i^2) = \sigma^2 \qquad \textbf{(12)}$$

where σ is the standard deviation. Based on the data points, the values of σ are obtained for nose and mouth deposition in various ranges of ρd^2Q. The results are tabulated in Table II.

It is natural to assume that the distribution of ϵ_i in equation (9) is normal due to the fact that many random sources exist in problems of this type. To check the validity of this assumption, Chi-square tests were performed based upon the data points for inspiratory nasal, expiratory nasal and inspiratory mouth depositions. In all cases the assumed distributions are accepted at 5% significance level. The validity of the normal distribution for each ϵ_i was also verified

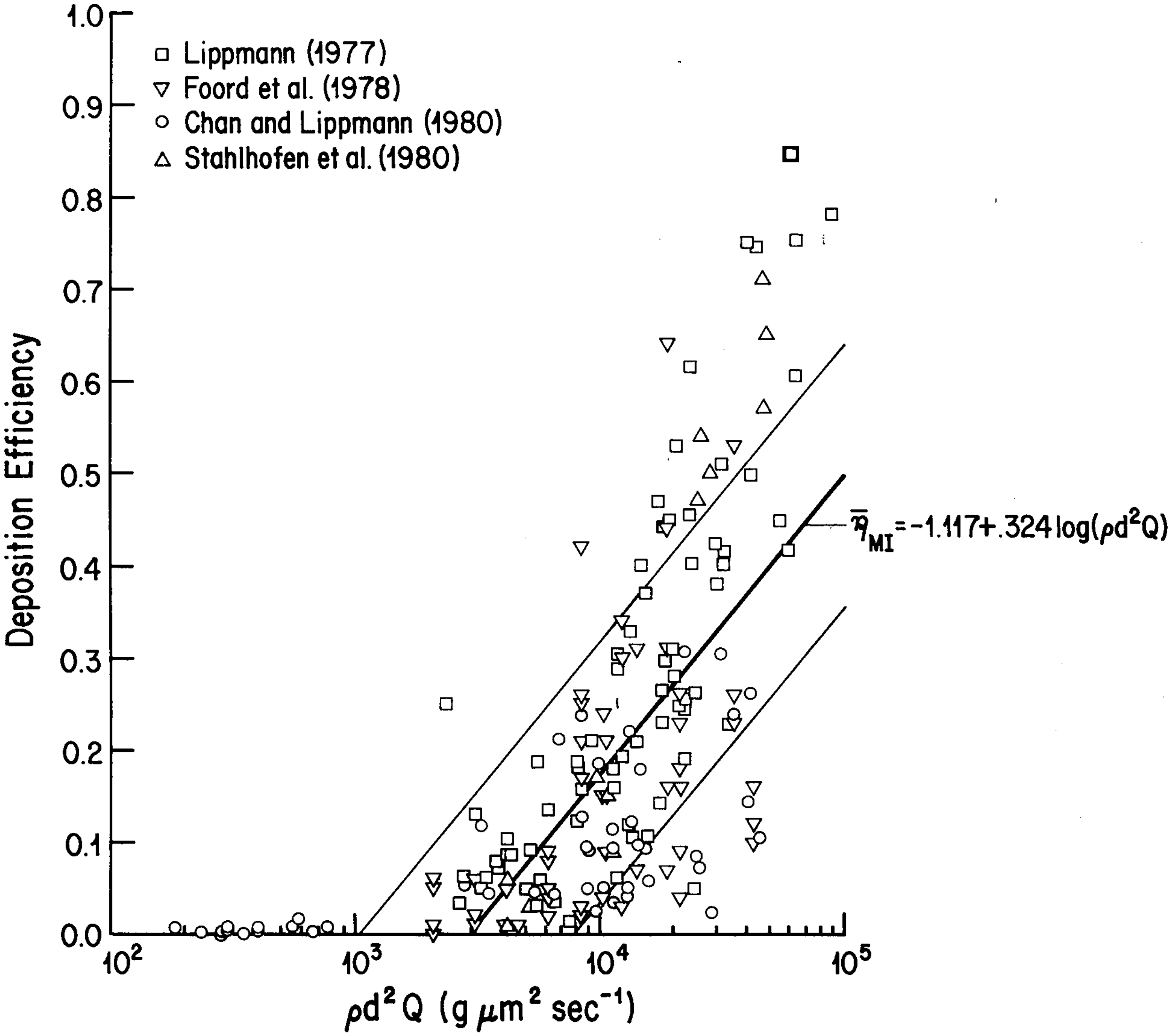

Figure 3 — Deposition of particles in the head for mouth inspiration as a function of ρd^2Q. The equation of $\bar{\eta}_{MI}$ and its σ_{MI} is given by solid lines.

TABLE II
Values of σ_{NI}, σ_{NE} and σ_{MI}

Inspiratory nasal efficiency	$\rho d^2Q < 337$ g $\mu m^2 sec^{-1}$	$\rho d^2Q > 337$ g $\mu m^2 sec^{-1}$
σ_{NI}	0.034	0.145
Expiratory nasal efficiency	$\rho d^2Q < 215$ g $\mu m^2 sec^{-1}$	$\rho d^2Q > 215$ g $\mu m^2 sec^{-1}$
σ_{NE}	0.046	0.140
Inspiratory mouth efficiency	$\rho d^2Q < 3000$ g $\mu m^2 sec^{-1}$	$\rho d^2Q > 3000$ g $\mu m^2 sec^{-1}$
σ_{MI}	0	0.144

using normal probability papers, and these are presented in Figures 4 to 6. It is seen that cumulative relative frequencies provided by the data closely follow straight lines in all cases.

combined nose and mouth breathing

Normal breathing is usually accomplished by a combination of nose and mouth breathing, though the exact proportion of air breathed through the nose and the mouth is not well established. Some measurements have recently been made be Camner and Bakke.[(20)] Let the fraction of air breathed through the nose be α_I for inspiration and α_E for expiration. Then particle deposition in the head may be written in the form.

$$\eta_{HI} = \alpha_I \eta_{NI} + (1-\alpha_I)\eta_{MI} \quad (13)$$

for inspiration, and

$$\eta_{HE} = \alpha_E \eta_{NE} \quad (14)$$

for expiration.

Assuming α_I and α_E are deterministic, the mean and variance of the combined breathing are given by

$$\bar{\eta}_{HI} = \alpha_I \bar{\eta}_{NI} + (1-\alpha_I)\bar{\eta}_{MI} \quad (15)$$

$$\bar{\eta}_{HE} = \alpha_E \bar{\eta}_{NE} \quad (16)$$

$$\mathrm{Var}(\eta_{HI}) = \alpha_I^2 \mathrm{Var}(\eta_{NI}) + (1-\alpha_I)^2 \mathrm{Var}(\eta_{MI}) = \alpha_I^2 \sigma_{NI}^2 + (1-\alpha_I)^2 \sigma_{MI}^2 \quad (17)$$

and

$$\mathrm{Var}(\eta_{HE}) = \alpha_E^2 \mathrm{Var}(\eta_{NE}) = \alpha_E^2 \sigma_{NE}^2 \quad (18)$$

If α_I and α_E are probabilistic, with their mean values equal to $\bar{\alpha}_I$ and $\bar{\alpha}_E$ and standard deviations to be σ_i and σ_e respectively, we may obtain

$$\bar{\eta}_{HI} = \bar{\alpha}_I \bar{\eta}_{NI} + (1-\bar{\alpha}_I)\bar{\eta}_{MI} \quad (19)$$

$$\bar{\eta}_{HE} = \bar{\alpha}_E \bar{\eta}_{NE} \quad (20)$$

$$\mathrm{Var}(\eta_{HI}) = \sigma_i^2 [\sigma_{NI}^2 + \sigma_{MI}^2 + (\bar{\eta}_{NI} + \bar{\eta}_{MI})^2] + (1-\bar{\alpha}_I)^2 \sigma_{MI}^2 + \bar{\alpha}_I^2 \sigma_{NI}^2 \quad (21)$$

and

$$\mathrm{Var}(\eta_{HE}) = \sigma_e^2 \sigma_{NE}^2 + \sigma_e^2 \bar{\eta}_{NE}^2 + \sigma_{NE}^2 \bar{\alpha}_E^2 \quad (22)$$

In the derivation of above equations, it is assumed that η_{NI}, η_{MI}, α_I and α_E are statistically independent.

concluding remarks

A statistical description of aerosol deposition in nose and mouth has been presented based upon a comprehensive analysis of pertinent experimental data available. Due to inherent intersubject and intrasubject variabilities, randomness exists in the deposition relationships and the results presented here permit one to make probabilistic statements concerning aerosol deposition in various regions. Equations (7)-(9), which give the mean deposition information, together with standard deviations given in Table II and normal distribution results, completely characterize the statistical behavior of deposition efficiencies, and various probabilities of interest can be easily calculated.

By way of illustration, consider η_{NI}, inspiratory nasal efficiency, at $\rho d^2Q = 500$ g $\mu m^2 sec^{-1}$. Equation (7b) and Table II show that it is a normally distributed random variable with mean $\bar{\eta}_{NI} = 0.113$ and standard deviation $\sigma_{NI} = 0.145$. The probability of η_{NI} taking values in an arbitrary interval (a,b) is then given by (see, for example, Soong[(21)])

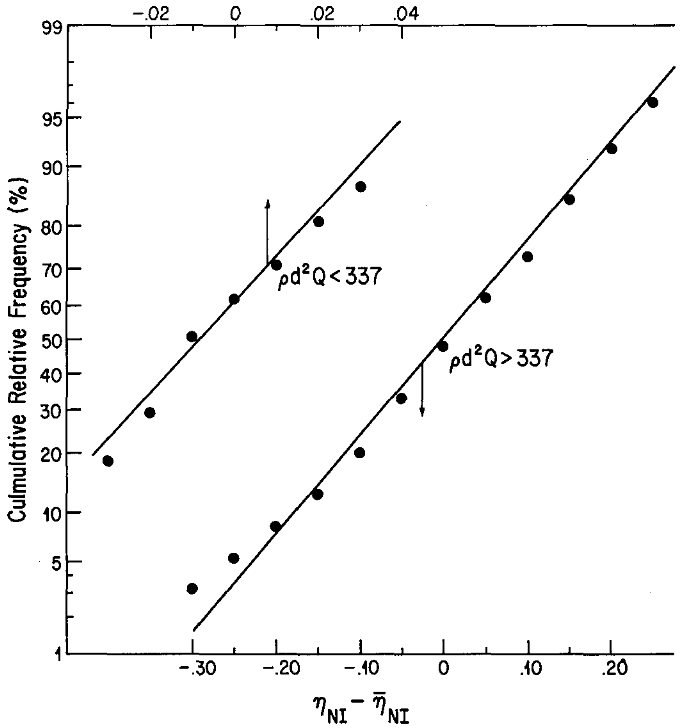

Figure 4 — Cumulative relative frequency diagram for (η_{NI} -$\bar{\eta}_{NI}$).

$$P\left(a \leq \eta_{NI} \geq b \right) = F_U\left(\frac{b - 0.113}{0.145} \right) - F_U\left(\frac{a - 0.113}{0.145} \right) \quad (23)$$

where $F_U(u)$ is the probability distribution function of the standardized normal random variable, i.e., a normal random variable with zero mean and unit standard deviation, and is widely tabulated. Let $a = 0.2$ and $b = 0.4$, for example. Table A.3 in Soong[(21)] gives

$$P(0.2 \leq \eta_{NI} \leq 0.4) = F_U(1.98) - F_U(0.60) = 0.976 - 0.726 = 0.25 \quad (24)$$

If $a = 0.2$ and $b = +\infty$,

$$P(\eta_{NI} \geq 0.2) = F_U(1) - F_U(0.60) = 1 - 0.726 = 0.274. \quad (25)$$

Similar calculations can be made for η_{NI} at other values of ρd^2Q and for efficiencies in other regions. It is noted that, as represented by Equations (13) and (14), the combined efficiencies η_{HI} and η_{HE} (with α_I and α_E being deterministic), being linear combinations of normal random variables, are also normal. Same types of calculations can also be performed with respect to these quantities.

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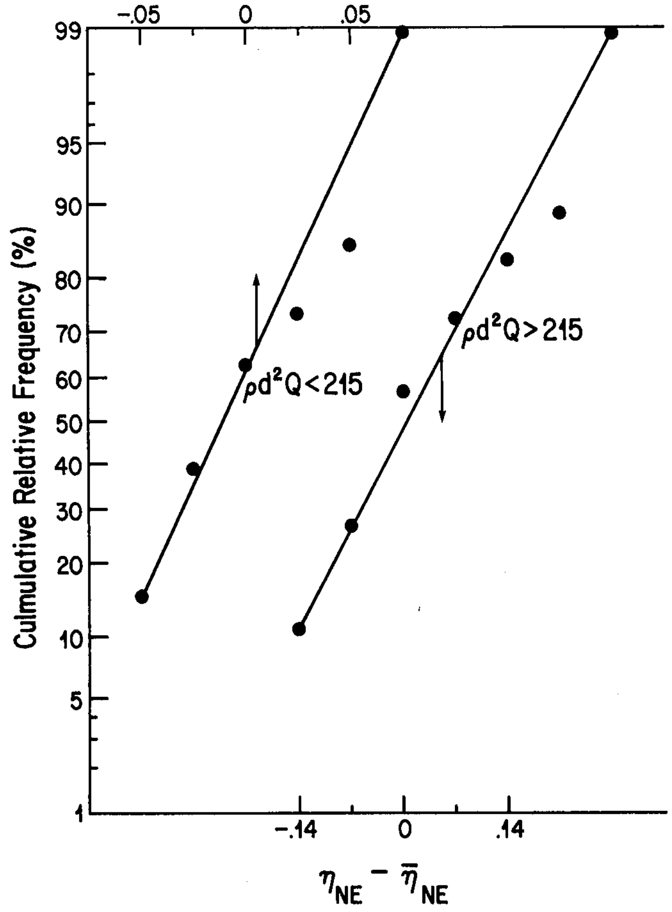

Figure 5 — Cumulative relative frequency diagram for $(\eta_{NE} - \bar{\eta}_{NE})$.

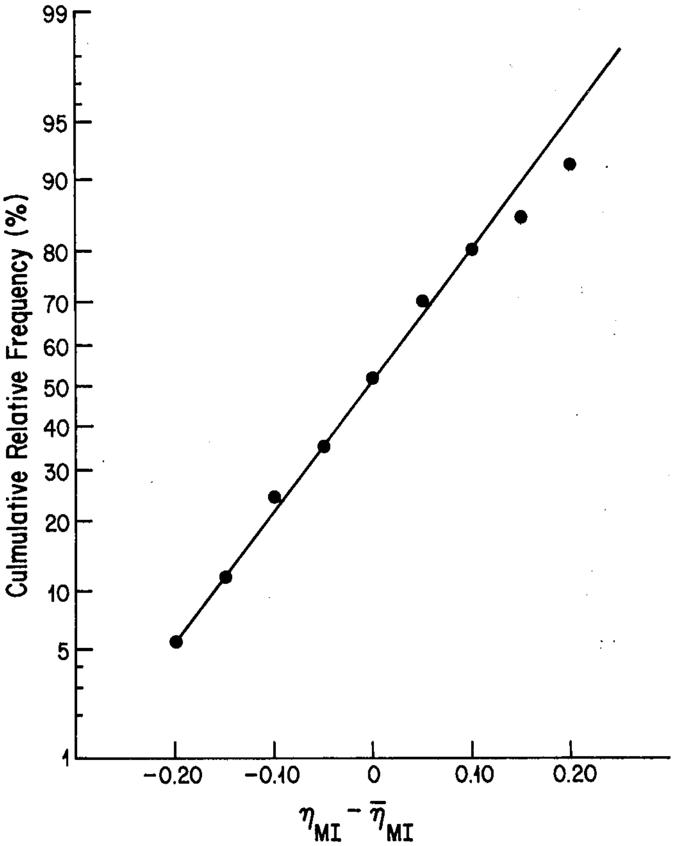

Figure 6 — Cumulative relative frequency diagram for $(\eta_{MI} - \bar{\eta}_{MI})$.

references

1. **Landahl, H.D. and S. Black:** Penetration of Airborne Particulates through the Human Nose. *J. Industr. Hyg. Toxicol. 29*:269-277 (1947).
2. **Landahl, H.D. and T. Tracewell:** Penetration of Airborne Particulates through the Human Nose: II. *J. Industr. Hyg. Toxicol. 31*:55-59 (1949).
3. **Pattle, R.E.:** The Retention of Gases and Particles in the Human Nose. Inhaled Particles and Vapours (edited by C.N. Davies), pp. 301-311. Pergamon Press, Oxford & New York (1961).
4. **Hounam, R.F., A. Black and M. Walsh:** Deposition of Aerosol Particles in the Nasopharyngeal Region of the Human Respiratory Tract. *Nature 211*:1254-1255 (1969).
5. **Hounam, R.F., A. Black and M. Walsh:** The Deposition of Aerosol Particles in the Nasopharyngeal Region of the Human Respiratory Tract. *J. Aerosol Sci. 2*:341-352 (1971).
6. **Lippmann, M.:** Deposition and Clearance of Inhaled Particles in the Human Nose. *Ann. Otol. Rhinol. Laryngol. 79*:519-528 (1970).
7. **Task Group on Lung Dynamics:** Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract. *Health Phys. 12*:173-207 (1966).
8. **Giacomelli-Maltoni, G., C. Melandri, V. Prodi and G. Tarroni:** Deposition Efficiency of Monodispersed Particles in

Human Respiratory Tract. *Am. Ind. Hyg. Assoc. J. 33*:603-610 (1972).

9. **Märtens, A. and W. Jacobi:** Die in-vivo Bestimmung der Aerosolteilchendeposition in Atemtrakt bei Mund-bzw. Nasenatmung. In: *Aerosol in Physik, Medizin and Technik.* Bad Soden, W. Germany: Gesellschaft für Aerosolforschung, pp. 117-121 (1974).
10. **Heyder, J. and G. Rudolph:** Deposition of Aerosol in the Human Nose. Paper presented at the Fourth International Symposium on Inhaled Particles and Vapors, Edinburgh (1975).
11. **Heyder, J. and G. Rudolph:** Deposition of Aerosol Particles in the Human Nose. Inhaled Particles IV, Part I (edited by W.H. Walton) pp. 107-125. Pergamon Press, Oxford & New York (1977).
12. **Fry, F.A.:** Charge Distribution on Polystyrene Aerosols and Deposition in the Human Nose. *J. Aerosol Sci. 1*:135-146 (1971).
13. **Lippmann, M.** Regional Deposition of Particles in the Human Respiratory Tract. In: *Handbook of Physiology — Reaction to Environmental Agents* (D.H.K. Lee, *et al.* Ed.) pp. 212-232. The American Physiological Society, Bethesda, MD (1977).
14. **Foord, N., A. Black and M. Walsh:** Regional Deposition of 2.5-7.5 μm Diameter Inhaled Particles in the Healthy Male Nonsmokers. *J. Aerosol Sci. 9*:343-357 (1978).
15. **Stahlhofen, W., J. Gebhart and J. Heyder:** Experimental Determination of the Regional Deposition of Aerosol Particles in the Human Respiratory Tract. *Am. Ind. Hyg. Assoc. J. 41*:385-398 (1980).
16. **Chan, T.L. and M. Lippmann:** Experimental Measurements and Empirical Modeling of the Regional Deposition of Inhaled Particles in Humans. *Am. Ind. Hyg. Assoc. J. 41*:379-409 (1980).
17. **Dennis, W.L.:** The Discussion of Paper by C.N. Davies: A Formalized Anatomy of the Human Respiratory Tract, in Inhaled Particles and Vapors (edited by C.N. Davies) p. 88-94. Permagon Press, Oxford & New York (1961).
18. **Landahl, H.D.:** On the Removal of Airborne Droplets by the Human Respiratory Tract: II. The Nasal Passages. *Bull. Math. Biophys. 12*:161-169 (1950).
19. **Scott, W.R., D.B. Taulbee and C.P. Yu:** Theoretical Study of Nasal Deposition. *Bull. of Math. Biology 40*:581-603 (1978).
20. **Camner, P. and B. Bakke:** Nose or Mouth Breathing. *Environ. Res. 21*:398 (1980).
21. **Soong, T.T.:** Probabilistic Modeling and Analysis in Science and Engineering, Chapter VII, Wiley, New York (1981).

NIOSH CURRENT INTELLIGENCE BULLETIN: #35

Ethylene Oxide (EtO): Evidence of Carcinogenicity

May 22, 1981

The National Institute for Occupational Safety and Health (NIOSH) recommends that ethylene oxide be regarded in the workplace as a potential occupational carcinogen, and that appropriate controls be used to reduce worker exposure. These recommendations are based primarily on an industry-sponsored study demonstrating that ethylene oxide is carcinogenic in experimental animals. In this study, ethylene oxide was associated with increases in leukemia in female rats and peritoneal mesotheliomas (malignant tumors) in male rats. There has been widespread recognition of the mutagenic potential of ethylene oxide, and recent evidence demonstrates adverse reproductive effects in mammals, which also are of public health concern. In addition, limited epidemiologic investigations at two worksites provide evidence that excess risk of cancer mortality may exist for the ethylene oxide workers studied. Some workers are on occasion exposed to relatively high concentrations of ethylene oxide, particularly where it is used for fumigation and sterilization. On the basis of this information, NIOSH requests that producers, dustributors, and users of ethylene oxide, and of substances and materials containing ethylene oxide, give information to their workers and customers, and that professional and trade associations and unions inform their members.

CIB #35 is available from the U.S. Department of Health and Human Services, Public Health Service Centers for Disease Control, National Institute for Occupational Safety and Health, Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, OH 45226.