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LACK OF CORRELATION BETWEEN PM_{10} MEASUREMENTS AND UPPER RESPIRATORY TRACT DOSE

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INTRODUCTION

A size-selective air intake that has a 50% cut point at 10 μm (PM_{10}) was developed to monitor those ambient air particulate concentrations that might cause lung disease. The underlying assumption in establishing the current U.S. ambient air monitoring system was that PM_{10} samples would provide equal protection regardless of the size distribution of the particulate matter. The size fraction, PM_{10}, is based on the aerodynamic diameter of particles that are capable of penetrating to, but not necessarily depositing in, the thoracic region of the respiratory system. Epidemiologic studies suggest that exposure to particulate air pollution may cause increased mortality and morbidity from respiratory and cardiovascular disease (Pope *et al*, 1996). Epidemiological studies seek a dose–response relationship to understand the etiology of disease. These analyses seek to find the relationship between particulate air pollution and mortality. However, questions about the usefulness of the PM_{10} estimates have emerged. Previous results suggested that there was a questionable relationship between particulate dose and the PM_{10} measurement.

For occupational environments, McCawley (1993) showed that there is a bias in the relationship between exposure (penetration) and dose (deposition) due to the variations in size distribution in occupational environments. The amount of bias associated with the use of the penetration criteria is dependent upon the particle size distribution. Since deposition is a measurement of dose and as such is the quantity of particulate crossing the physical boundaries of the person and entering the tissue, deposition should relate more directly to response than should measurements such as PM_{10} which only measure penetration.

A high percentage of particulate mass in the atmosphere can occur in particle sizes below 1 μm in diameter (Fig. 1). These submicrometer dusts can be metal or organic fumes, many of which are suspected carcinogens. Not only does the submicrometer fraction contain carcinogens but, the likelihood of finding a correlation between penetration and deposition criteria is severely decreased when there is a substantial submicrometer contribution to the overall mass. The PM_{10} technique when used to estimate submicrometer particulate levels is, for all practical purposes, collecting 100% of the particles.

Diseases such as asthma, chronic bronchitis or bronchial carcinomas are examples of responses initiated by an effective dose, presumably at the critical site in the

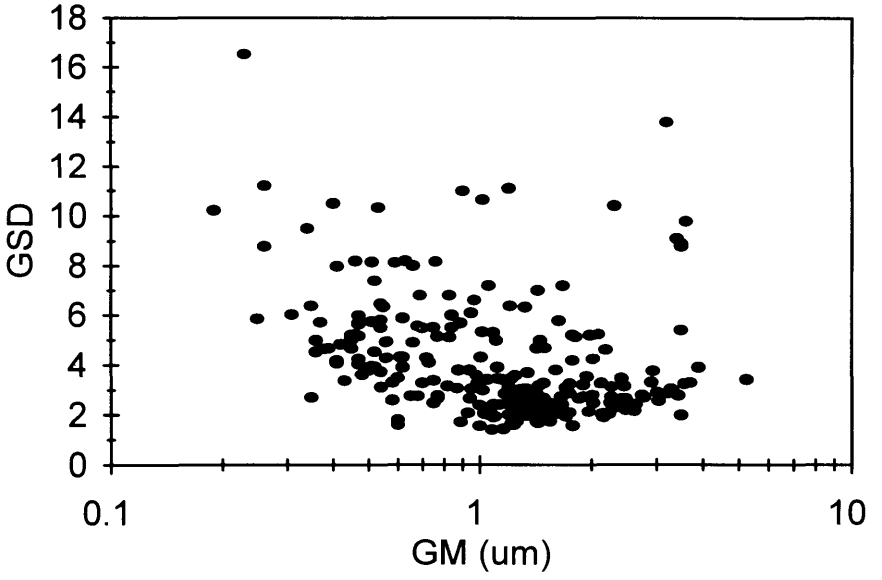

Fig. 1. A plot of all 250 size distributions' geometric means (GM) and geometric standard deviations (GSD) used for the meta analysis, showing 126 GMs less than 1 μm.

upper respiratory tract, that is, the tracheobronchial region. However, PM_{10}, which is similar to the thoracic particulate mass fraction, is that particulate that represents exposure for the whole lung (Boubel *et al.*, 1994). Depending on the particle size, the tracheobronchial fraction may be only a small and variable component of that measurement.

The question raised here is whether the PM_{10} criterion is a good indicator of the dose of particulate responsible for diseases associated with the tracheobronchial region regardless of the size distribution from which the sample is drawn. The hypothesis to be tested is that the slope of the regression line for measurements of tracheobronchial dose vs PM_{10} penetration is not significantly different than zero at a confidence level of 95%. The question being addressed is—"does the same lack of correlation between penetration and deposition, resulting from varying particle size distributions in occupational environments, exist for ambient air?" This paper will assess this relationship by analysing data on size distributions of ambient air particles from published studies.

METHODS

From articles on ambient air studies, a variety of particle size distributions was found. A meta analysis of eight studies (Kadowaki, 1976; Lee and Patterson, 1969; Lee and Goranson, 1970; Lee *et al.*, 1972; Lee and Smith, 1972; Lundgren, 1970; Mainwaring and Harsha, 1976; Patterson and Wagman, 1977) with 250 particle size distributions was performed. For each of the size distributions, the geometric mean (GM) and geometric standard deviation (GSD) was used as given or as estimated from figures to calculate the penetration and deposition. The PM_{10} criterion was used to calculate the percentage of the distribution that contributes to penetration.

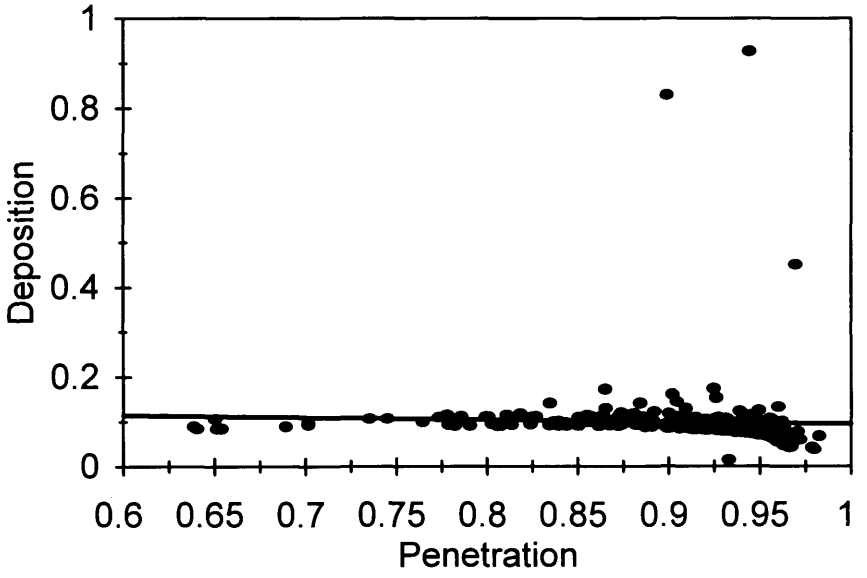

Fig. 2. Two-hundred and fifty data points derived from all the size distributions, comparing estimates of the fraction of the total distribution equivalent to the PM_{10} (penetration) and the fraction of the same distribution that would deposit in the tracheobronchial region of the lung. The slope of the regression line was found to not be significantly different than 0 ($\alpha = 0.05$) indicating that there would be no functional relationship between the two measures.

Deposition was estimated using Stahlhofen *et al.* (1989), for a breathing rate of seven breaths per minute and a minute volume of 3500 ml. Results of studies in which the size distributions of the mass fraction of particular chemical constituents were given are also included. As noted above, the toxic properties of the particulate may relate more to the chemical constituents, the organics or metals content for example. Thus the size distribution of those mass fractions may be relevant, if mass can be assumed to be relevant at all.

RESULTS AND DISCUSSION

Figure 2 shows the regression line for all the calculated values of deposition and penetration in those studies. It should be noted that the slope (−0.05) was not significantly different than 0 ($\alpha = 0.05$), indicating a lack of any measurable correlation. PM_{10}, therefore, does not by itself well represent dose to the upper respiratory tract as was previously seen in occupational environments. However subtraction of the $PM_{2.5}$ fraction (which is a parallel criterion to the PM_{10}, but with the 50% collection point at 2.5 μm) did not improve the correlation for ambient air even though a similar technique had worked to improve correlations for occupational environments.

If there is not a good relationship between the penetration and deposition, then additional variability will be introduced into the dose–response analysis. This lessens the chance of observing a statistically significant exposure–response relationship and calls into question the general applicability of the PM_{10} sampling network. It is vital that a relationship between measurement and dose be closely

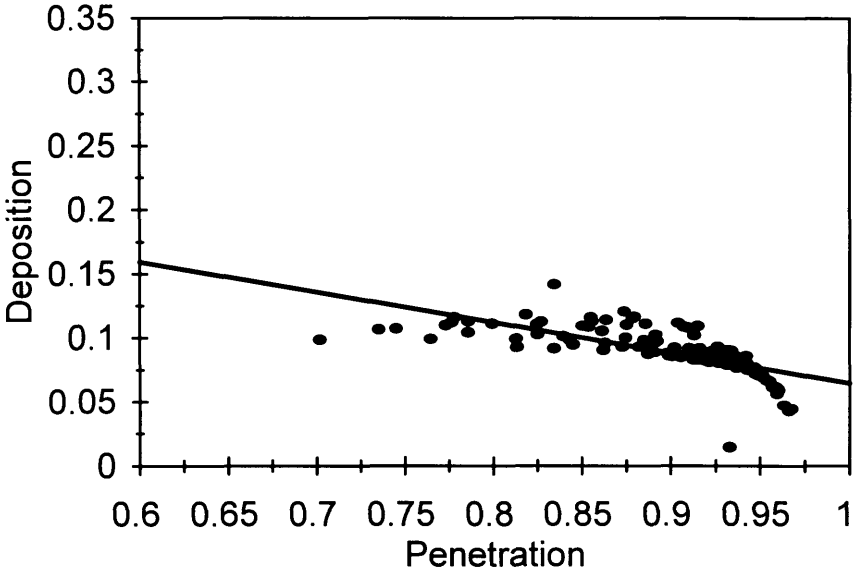

Fig. 3. One hundred and twenty-four data points for only those size distributions with GM > 1.0 μm and GSD < 4.5. As in Fig. 2, there was no positive functional relationship found between PM_{10} (penetration) and tracheobronchial deposition.

correlated in order to set standards that are applicable regardless of the particle size distribution. At the same time, it is acknowledged that PM_{10} is not meant to represent the dose to the lung of submicrometer aerosols.

All the size distributions with GMs greater than 1 μm and having a GSD less than 4.5 were examined. This was done to eliminate those distributions that might have substantial amounts of submicrometer particle mass, since there would be no association between deposition and penetration in that region for PM_{10}. When the PM_{10} is compared with the tracheobronchial deposition a negative slope is seen (Fig. 3). This implies improbably that as the exposure increases the dose decreases. However, using the subtraction method (PM_{10} minus $PM_{2.5}$), increased the correlation. Figure 4 shows the results of the regression calculation for this data, which had a correlation coefficient of 0.81.

CONCLUSION

Interpretation of size distribution information noted here indicates that PM_{10} is not a good measure of dose to the upper respiratory tract. While there could be temporal stability to the size distributions the spatial differences make it difficult to support any finding that the PM_{10} offers equal protection at all locations for a mass dose to the upper respiratory tract. This offers an explanation for some of the lack of observed correlation between exposure measurement and health effects seen in epidemiology studies.

It has been demonstrated in an occupational and now in an ambient air study that there can exist a lack of a consistent relationship between penetration measurement and dose due to the variations in size distribution. The PM_{10} criterion and the

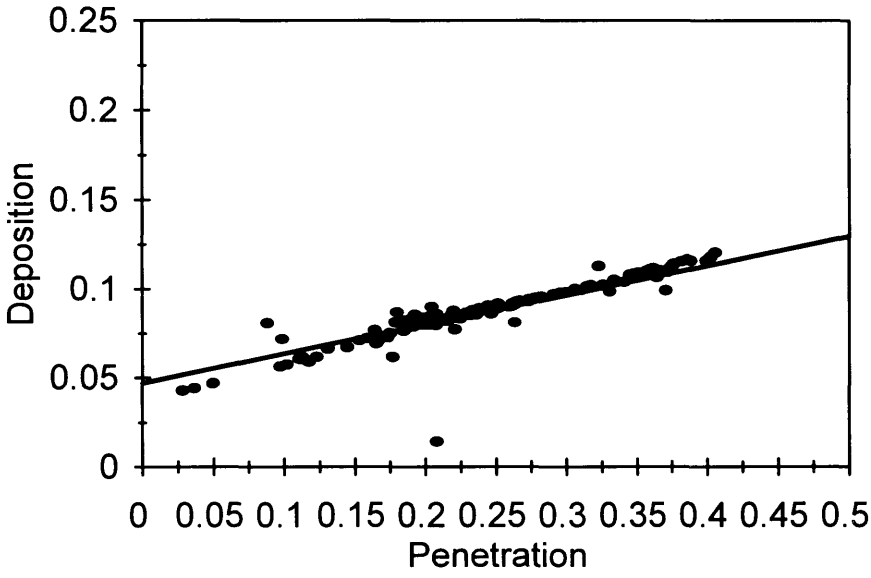

Fig. 4. The same 124 size distributions used in Fig. 3, but the measure of penetration is now PM_{10}–$PM_{2.5}$ compared with tracheobronchial deposition. The statistically significant positive relationship between the two measures is lessened if the submicrometer size distribution are included in the analysis.

thoracic criterion because of its similarity, are poor indicators of dose to the tracheobronchial region.

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