# Chapter 7: The Health Effects of Particulate Matter

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# The Health Effects of PM: Scientific Issues

- Is there evidence of health effects when ambient PM10 concentrations are at or below the current CA standards?
- What is the weight of evidence?
- Is the evidence consistent and coherent?
- Is there evidence of causality?

# 1. Is there evidence of health effects at or below the current CA standards?

- In Oct 2000, AQAC endorsed recommendations of OEHHA/ARB staff that current PM standards may not be protective of public health, including that of infants and children, with an adequate margin of safety.

- In Dec 2000, Air Resources Board approved these recommendations and asked for formal review of standard.

# 2. What is the weight of evidence?

- Hundreds of epidemiological, toxicological and clinical studies examine PM and health effects.
- Recent epi reviews by US EPA, WHO, EU, UK, Canada as basis for standard-setting.
- OEHHA/ARB highlight major studies, but do not provide encyclopedic assessment.

# Existing and Proposed Standards for PM

| Institution | PM measure | Averaging time | Concentration ($\mu g/m^3$) | Attainment Date |
|---|---|---|---|---|
| | | | | |
| U.S.EPA | PM10 | Annual | 50 | |
| California | PM10 | Annual | 30 | |
| **California (prop)** | **PM10** | **Annual** | **20** | |
| European Union | PM10 | Annual | 40 | 1/1/05 |
| European Union | PM10 | Annual | 20 | 1/1/10 |
| | | | | |
| U.S. EPA (prop) | PM2.5 | Annual | 15 (12.5 – 20) | |
| **California (prop)** | **PM2.5** | **Annual** | **12** | |
| | | | | |
| U.S. EPA | PM10 | 24-hour | 150 | |
| **California** | **PM10** | **24-hour** | **50** | |
| European Union | PM10 | 24-hour | 50 (35x) | 1/1/05 |
| European Union | PM10 | 24-hour | 50 (7x) | 1/1/10 |
| | | | | |
| U.S. EPA (prop) | PM2.5 | 24-hour | 65 (20 –65) | |
| Canada | PM2.5 | 24-hour | 30 (7x) | 1/1/10 |

# Use of Epidemiological Studies. I

- Involve real-world exposures (short- and long-term over wide range of conditions) and health responses
- Can examine different segments of the population (e.g., elderly, asthmatics, children)
- Imprecise measurement of exposure
- Need to consider potential confounders

# Use of Epidemiological Studies. II

- Typically analysis relies on multiple regression models:

***Health = f(pollution, weather, season, time, day of week, other pollutants, individual risk factors)***

- Recent developments in statistical techniques and computer software and memory provide new methods (e.g., smoothing techniques, simulation) to address potential confounders autocorrelation, meta-analytical approaches.

# Use of Epidemiological Studies. III

Results from five continents link PM to:

- Mortality
- Cardiovascular and respiratory hospitalization
- Emergency room visits
- Worsening of asthma
- Bronchitis
- Work loss, school absenteeism
- Respiratory symptoms
- Lung function decrements

# Use of Epidemiological Studies. IV

Studies conducted and associations reported for a wide range of:

- Climates and seasonal patterns
- PM concentrations and mixtures
- Co-pollutants and weather covariations
- Population characteristics
- Housing stock, etc

# Results of PM Epidemiology Studies -- Short Term Exposure

- Studies conducted for over 200 cities worldwide, in the U.S.
- Using many years of data per city, examine relation between daily concentrations of PM10 and daily counts of mortality.
- Studies account for factors that might explain daily changes in mortality, such as weather, seasonal effects, and day of week.
- Individual-level factors are constant.

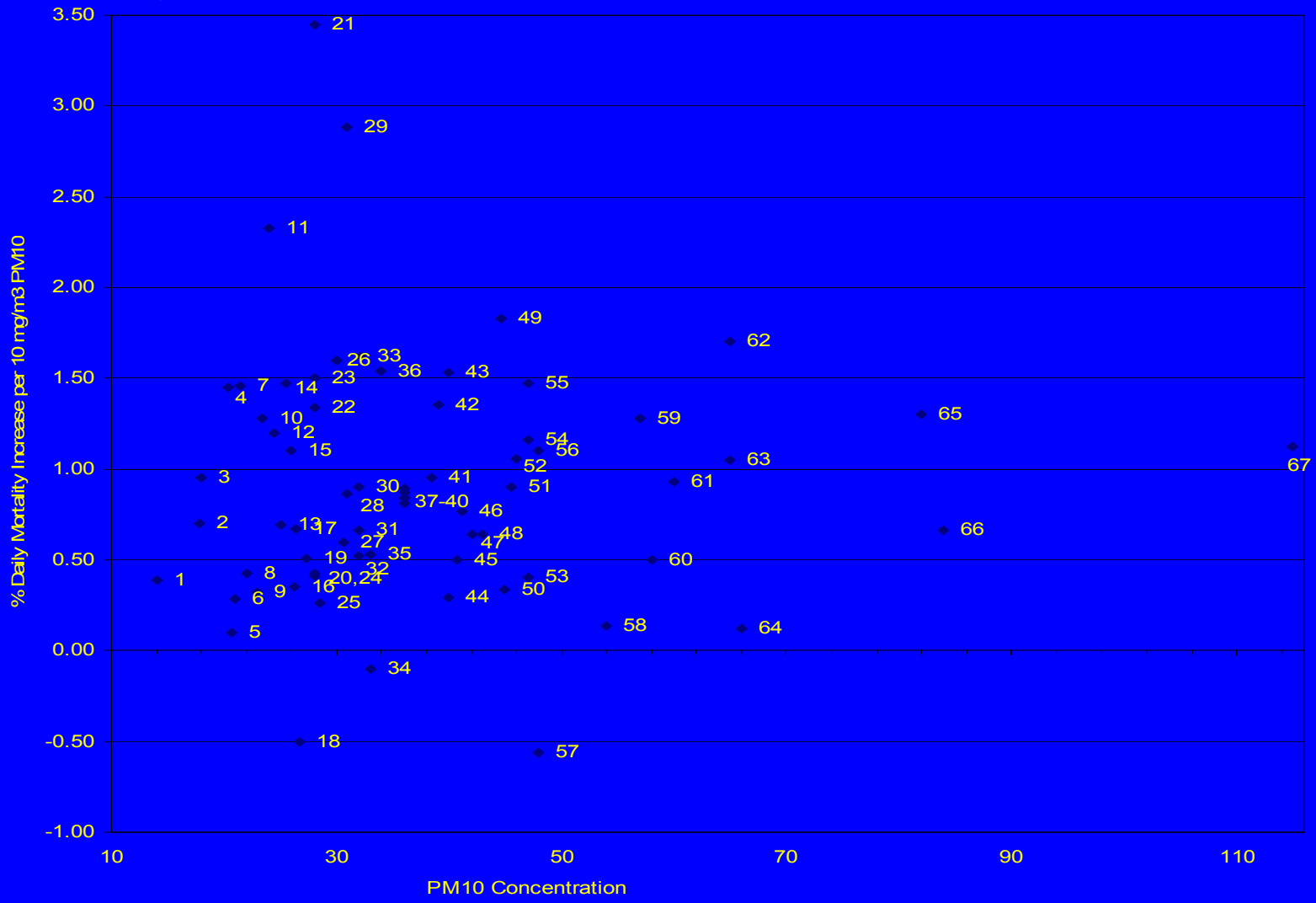
# Results of PM Epidemiology Studies -- Short Term Exposure (cont.)

- Most show associations between daily or multi-day averages of PM and **all-cause** mortality, **respiratory** and **cardiovascular** mortality, and mortality for those **> 65 years of age.**
- Document cites 64 single-city studies using PM10; other PM metrics used include PM2.5, coarse particles, black smoke, COH, and extinction coefficient.

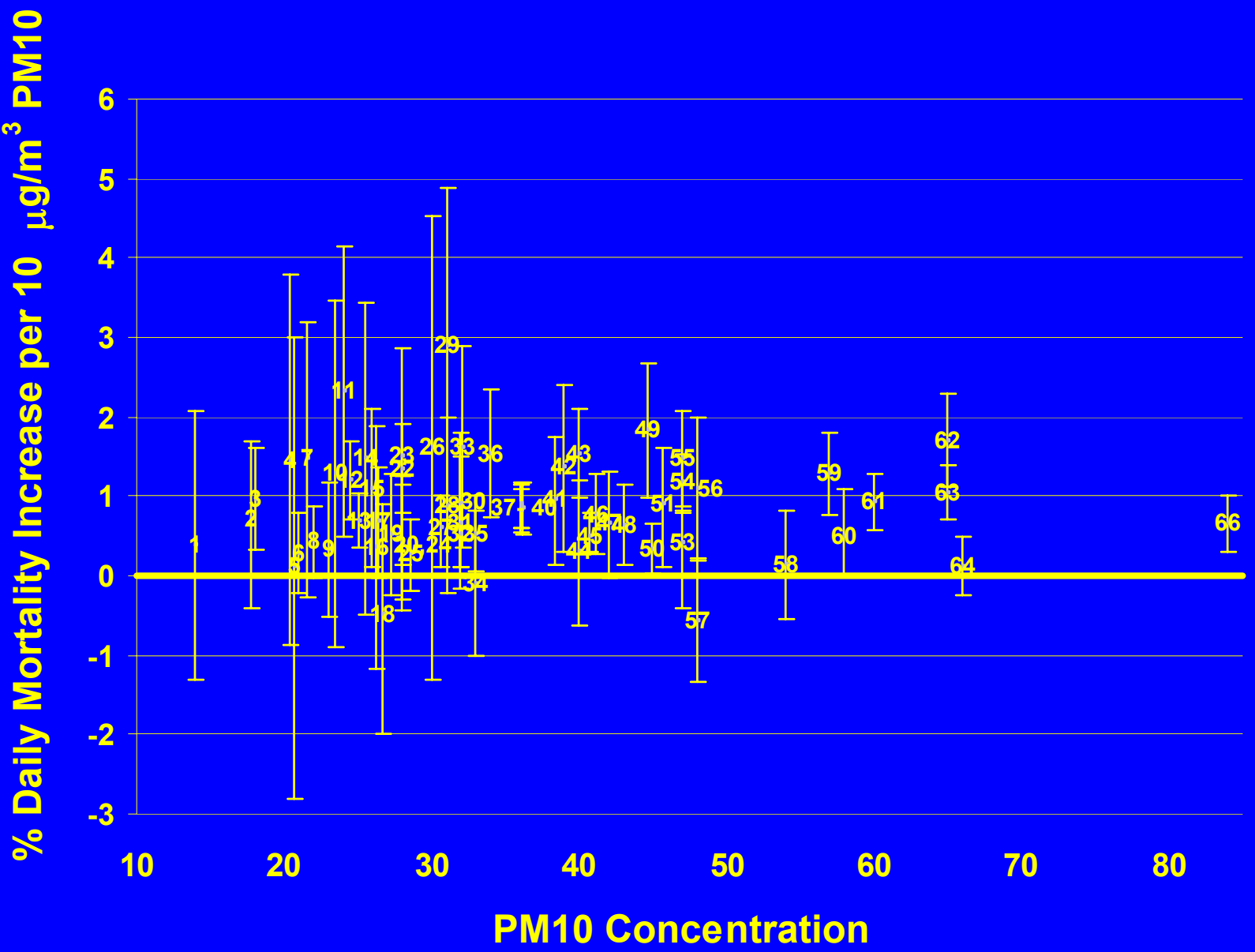
# Consistency, I

- Most studies of PM10 and mortality show increments in daily deaths of between 0.5 and 1.5% per 10 $\mu g/m^3$ PM10
- Greater uncertainty about the association among studies conducted at lower concentrations

# PM10 Study Average and Percent Increase in Mortality



# Confidence Intervals Associated with Studies of Mortality and PM10 Exposure



# Multi-city studies, I

- HEI-sponsored study (NMMAPS) of 20 and 88 largest cities in U.S.
- To address concerns, uses consistent approaches, years, data, models, and sensitivity analyses; also addresses issue of publication bias and adds statistical power.
- Statistically significant associations between PM and several mortality categories. Results consistent with previous studies.
- Northeast and Southern California show largest associations.

# Consistency, II

- "We found consistent evidence that the level of PM10 is associated with the rates of death from all causes and from cardiovascular and respiratory causes. The association of PM10 was not affected by the inclusion of other pollutants…Our findings strongly support the findings of prior studies of PM and mortality." (Samet et al., NEJM 2000)
- "The [Review] Panel also concluded that the evidence for PM10 effects on both the number of deaths and hospitalizations can be regarded as compelling and consistent." (HEI Review Panel)

# Multi-city studies, II

Other studies include:

- Harvard six cities
- 10 U.S. cities (Schwartz 2000)
- 8 largest Canadian cities (Burnett et al. 2000)
- 29 European cities (Katsouyanni et al. 2001)

# Coherence

Using similar methodology, associations observed between daily PM10 and:

- Hospitalization for cardiovascular disease
- Hospitalization for respiratory disease
- Urgent care visits
- Asthma attacks and medication use
- Acute bronchitis, wheeze (longer-term exposure)
- Respiratory symptoms
- Decrements in lung function
- School absenteeism and work loss

# Results of PM Epidemiology Studies -- Long Term Exposure

- Several studies (Harvard 6-city, ACS, AHSMOG, EPRI) have examined the effects of long-term exposure to PM10, sulfates and/or PM2.5.
- These 'prospective cohort' studies follow individuals for 7 to 15 years.
- Largest uses ACS cohort of roughly 500,000 individuals in 151 cities, followed for 7 years.
- Analysis controls for individual-level factors that may influence risk of mortality (e.g., smoking, weight, alcohol, occupational exposure, gender, and age)

# Results of PM Epidemiology Studies -- Long Term

- Several studies report association between longer term exposure to PM10, PM2.5 and/or sulfates and survival or life expectancy.
- Effects estimates of ≈ 4 to 7% per 10 $\mu g/m^3$ of PM10
- Between the least and most polluted cities in the U.S., the average life expectancy reduction estimated at about 1.5 years.

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# Results of PM Epidemiology Studies: Long Term Exposure

- HEI-sponsored reanalysis of Harvard 6 cites and ACS studies replicated original results
- Extensive sensitivity analysis confirmed associations with PM after considering:

(1) alternative statistical models

(2) individual-level variables (physical activity, education, body mass, smoking status, marital status, alcohol consumption and occupational exposure)

(3) ecologic variables (population growth, income, weather, number of hospital beds and water hardness)

(4) non-linear specifications in the dose-response function that would allow for the possibility of a threshold

(5) co-pollutants including ozone, sulfur dioxide and nitrogen dioxide

(6) alternative PM exposure estimates, including different years

(7) underlying variation from city to city

(8) spatial clustering of cities

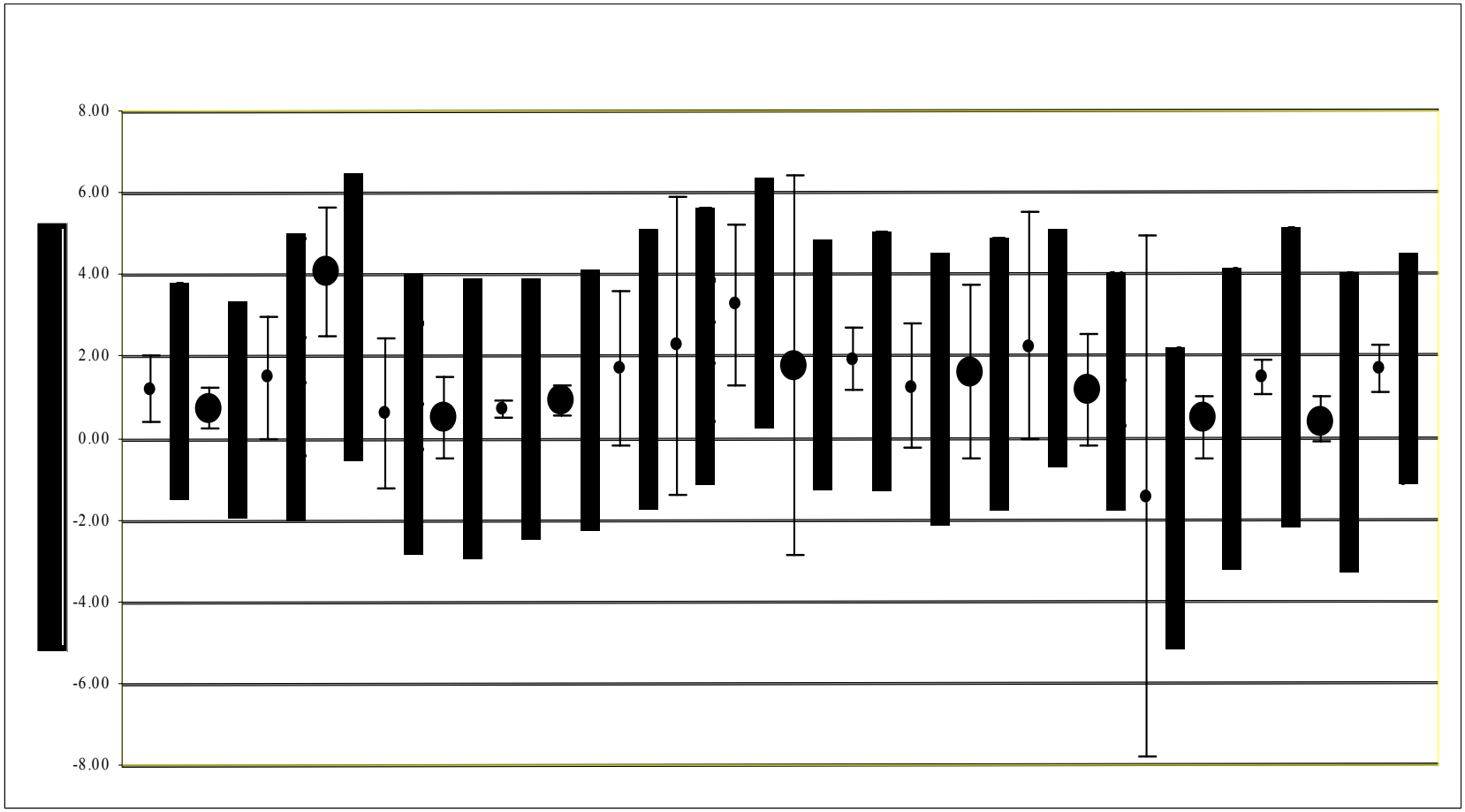
# Latest ACS cohort results

- Recently presented but unpublished results (Pope et al., 2002) doubled follow-up to 16 years
- Added more extensive controls for smoking, occupational exposure, and new variables for dietary factors
- Results generally similar to previous analysis.
- After corrections for spatial correlations (Burnett et al., 2001) associations still apparent.

# Other Notable Results from Short and Long-Term Exposure Studies I

- The nine available time-series short-term exposure studies on FP/CP indicate mixed results.
- Most analyses fails to detect threshold in response:
  - Many studies conducted at low concentrations
  - Statistical approaches using flexible models
  - Smoothers used to determine shape

# Daily Mortality Increases Associated with Fine and Coarse Particles




Note: Bar represents 95% confidence interval; small and large dots represent fine and coarse particles respectively.

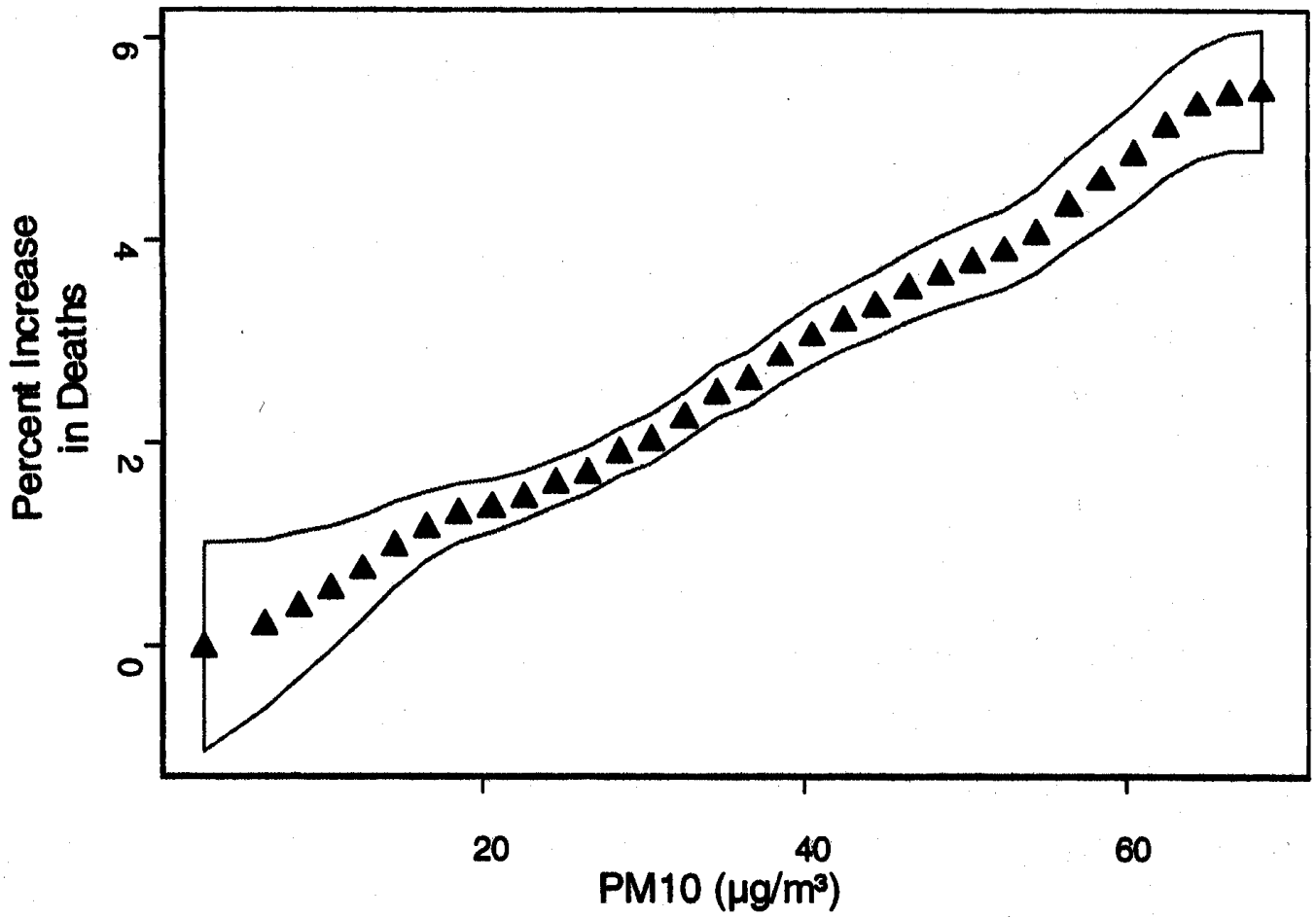
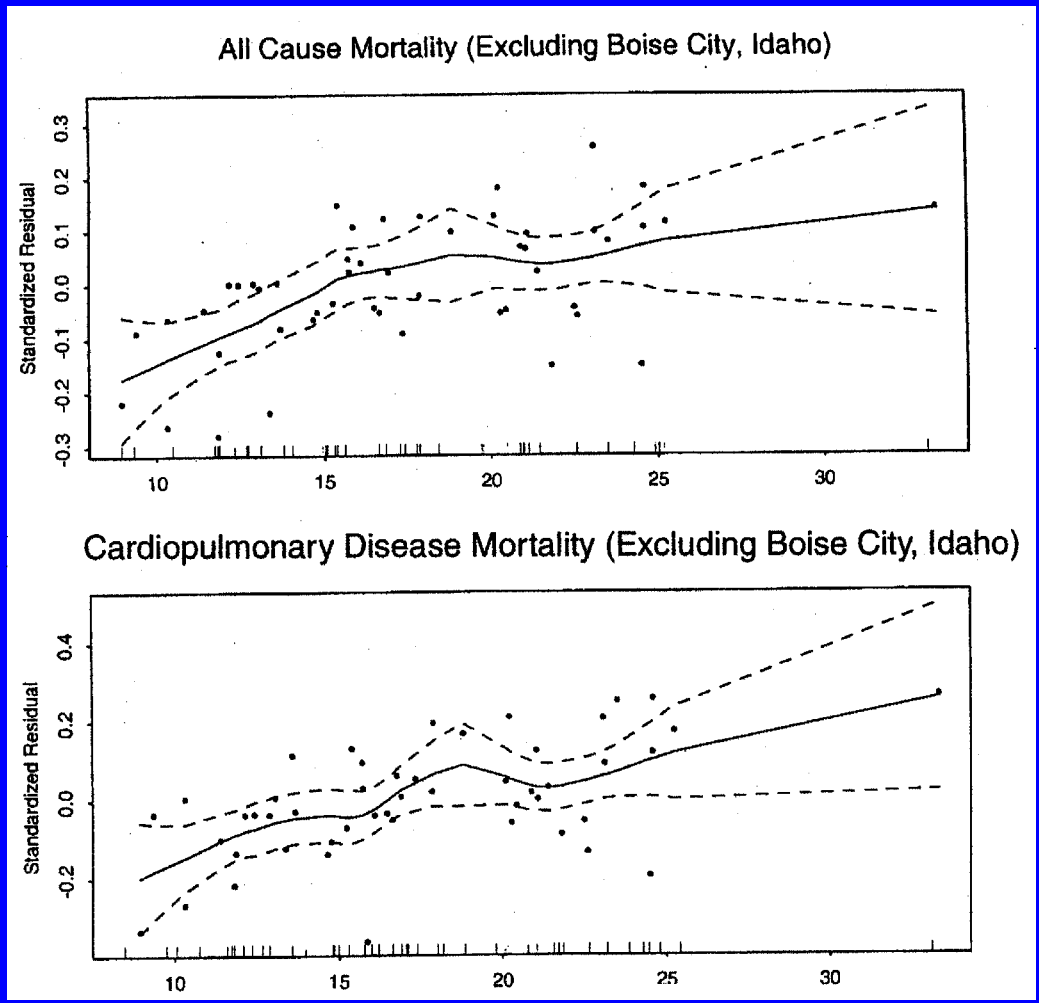



FIGURE 2. Dose response between $PM_{10}$ and daily deaths in ten U.S. cities.

Schwartz and Zanobetti, 2000, p 670




Krewski et al, 2000 p 162

# Other Notable Results II

- Mortality displacement appears minor
- Composition-specific studies suggest combustion-related PM is most toxic. PM may serve as surrogate.
- Careful control for weather and other and potential confounders
  - Linear or smoothed variables included for temp, humidity, dewpoint
  - Extremes in weather also modeled
  - Influence of seasonal cycles factored out

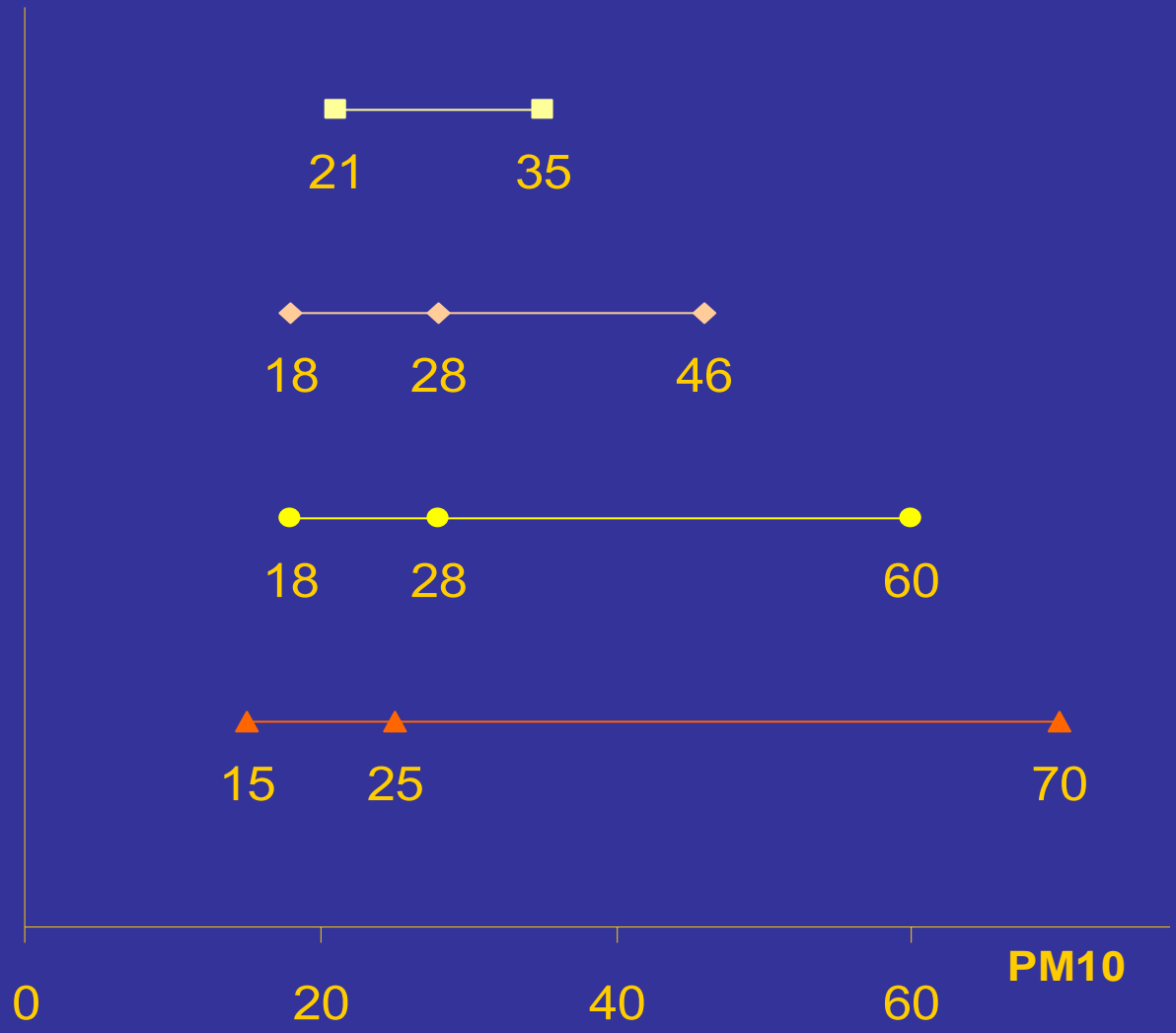
# General Rationale for New PM Standards

- PM10 standards introduced in California in 1983
- Hundreds of studies published since then, confirming linkages with mortality and other adverse health effects at current ambient levels
- Recent studies suggest effects from both fine and coarse particles

# Rationale for Annual Average Standards

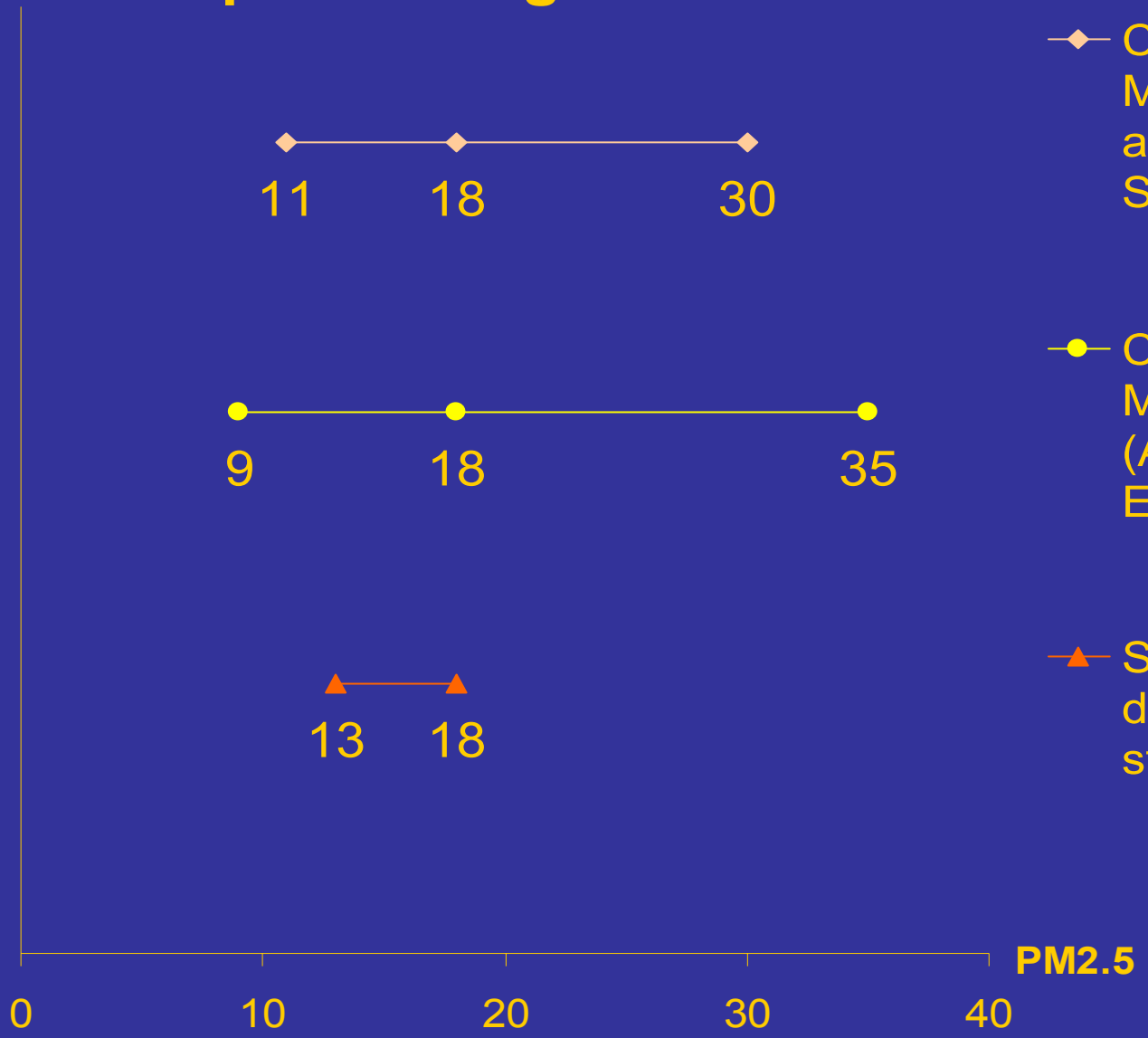
- Greatest impact on mortality associated with chronic rather than acute exposure
- Primary focus on reducing entire PM distribution and long-term exposures by lowering annual PM10 average and adding standard for PM2.5 annual average
- PM2.5 has different sources, indoor penetration, lung deposition and long-term effects than PM10

# Range of PM10 Observed in Epidemiologic Studies




- Chronic Exposure Morbidity: Dockery et al 1986; LA Children's Health Studies
- Chronic Exposure Mortality: Dockery et al 1993 (6-City Study)
- Chronic Exposure Mortality: Pope 1995 (ACS), PM10 Equivalent
- Study means of daily mortality studies

# Range of PM2.5 Observed in Epidemiologic Studies




Chronic Exposure Mortality: Dockery et al 1993 (6-City Study)

Chronic Exposure Mortality: Pope 1995 (ACS), PM10 Equivalent

Study means of daily mortality studies

# Rationale for 24-hr standard

- Some areas attaining annual standard will still have episodic PM elevations – need for short-term standard.
- Therefore, retain 24-hr standard for PM10.
- However, difficult to disentangle effects of chronic exposure from acute effects, and to determine effects of single exposure.

# Rationale for 24-hr standard II

- Brightline for PM2.5 difficult to determine

# Rationale for Sulfate Standard

- Health evidence for sulfates less consistent than that for PM10 and PM2.5
- Sulfate concentrations in California far lower than current standard
- Strongly acidic sulfates associated with health effects are uncommon in California

# EXPECTED HEALTH BENEFITS FROM ATTAINING ANNUAL AVERAGE STANDARDS

Change to proposed annual average PM10 standard estimated to prevent about :

- 6,500 (95% C.I. = 3,200 – 9,800) deaths/year
- 3,100 cardiovascular hospitalizations among those > 65 yr

389,000 lower respiratory symptoms among children aged 7 – 14