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Original Contributions

LUNG CANCER AND AIR POLLUTION IN SOUTHCENTRAL LOS ANGELES COUNTY[1]

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Henderson, B. E. (U. of S. California. School of Medicine. tor Angeles, CA 90033), R. J. Gordon. H. Menck, J. SooHoo, S. P. Martin and M. C. Pike. Lung cancer and air pollution in southcentral Los Angeles County. *Am J Epidemiol* 101:477–488, 1975.—An increased rate of lung cancer has been consistently observed from 1968–1972 among males in southcentral Los Angeles. This excess risk occurs across several social classes end occupational categories. No differential excess of oral cavity, pancreatic, laryngeal end bladder cancer was observed in the same area. lessening the possibility that regional variations in smoking habits accounted for the excess lung cancer. Air sampling has indicated an excess of certain polynuclear aromatic hydrocarbons (PAH) in southcentral Lor Angeles. There was a correlation between the geographic distribution of lung cancer cases and the general location of industries which have emitted these PAH. A case-controlled study of smoking, occupational end residential history in the southcentral area is underway.

air pollution; cancer, lung; carcinogens; hydrocarbons; lung neoplasms

INTRODUCTION

We have reported an escess of lung cancer in an area of southcentral Los Angeles County (1) baaed on death certificate information for the two years 1968–1969. We have also reported that there was a distinctive pattern of air pollution at one particular location within this area in 1972 which was unlike that found at other county locations (2). Several polynuclear aromatic hydrocarbons (PAH), including some known carcinogens, in the suspended airborne particulate matter occurred at much higher concentrations at that one location than elsewhere.

The possibility that the excess in lung cancer may be due tu the local air pollution prompted us to do a further analysis as mortality figures from 1970 and the results of the first year, 1972, of the Los Angeles County Cancer Surveillance Program became available (3). The Cancer Surveillance Program attempts to collect all incident cancer cases (excluding skin and cervix in situ) from Los Angeles County. These additional data have enabled us to analyze in some detail the possibly confounding effects of social class and occupation, as well as to consider the different histological types of tung cancer in the different areas.

In addition. we designed a study to determine the extent of the area surrounding the previous sampling point which would show the distinctive PAH air poilution pattern. so that we might delineate its sources.

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Abbreviation: PAH, polynuclear aromatic hydrocarbons.

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Materials and Methods

Cancer statistics. The 1586 census tracts of Los Angeles County were aggregated into 14 study areas based on reasonably homogeneous air pollution profiles as previously described (figure 1) (1). One of those areas, No. 2 in the report, has since been subdivided to make two areas, now Nos. 2 and 14. The populations of these tracts were derived from the 1970 Census data (4). The analysis was limited to whites, including Mexican-Americans, as the black and Oriental populations are not widely distributed throughout Los Angeles County. The lung cancer cases from the 1968–1970 Los Angeles County death certificates (kindly supplied on computer tapes by Mr. Martin Donabedian of the Los Angeles County Department of Health), and the incident cases for 1972, collected by the Cancer Surveillance Program, were simply added together to provide an average annual lung cancer rate. This makes use of all the data available and would seem unlike to produce any artifacts since lung cancer has such a high mortality rate. All age standardizations were done to the United States 1970 Census Population (5) using the age groupings of the Third National Cancer Survey (6). The cancer rates ate given per 100,000 population at risk.

A "social class" index, 1 (high) through 5 (low). was assigned to each census tract based on the average educational level and average family income level of the inhabitants as calculated &om the 1970 C—— (7), using a modification ot the Hollingshead Index (8). This was done for each tract as follows:

1) For each person over age 25 in the tract, an educational level from 6 to 1 was assigned: level 6 = elementary school only, 5 = up to 3 years of high school, 4 = 4 years of high school (high school graduate), 3 = up to 3 years of college, 2 = 4 years of college (college graduate), 1 = 5+ years of college. Using this scale, an average educational level far the tract was calculated.

2) For each family in the tract, an income level from 5 to 1 was assigned: level 5 = up to $4000 per year, 4 = $4000 up to $8000, 3 = $8000 up to $12,000, 2 = $12,000 up to $15,000. I = $15,000+. Using this scale, an average family income level for the tract was calculated.

3) Finally a value was calculated as 4 × (average educational level) plus 7 × (average family income level) and this value was assigned a social class from 5 to 1: group 5 = lowest 5 per cent of the county, 4 = next

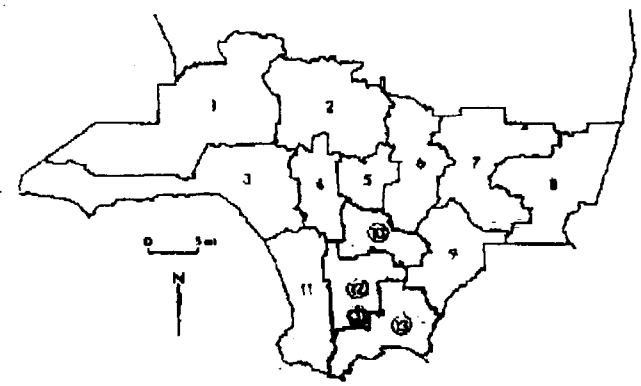

FIGURE 1. Los Angeles County divided into 14 areas. Shaded areas show higher lung cancer rates (data based on white males only). Location 3 (circled) is original air sampling trailer site.

31 per cent, 3 = next 27 per cent, 2 = next 27 per cent, 1 = last 10 per cent.

Of the 7997 cases available (6022 cases in 1968–1970; 1975 cases in 1972), we lacked accurate address information for 147, race was unknown for 105, and 23 resided in one or other of the two census tracts that did not have sufficient income or education census data to enable us to calculate social class. These 275 subjects have been omitted from all analyses, leaving 7722 subjects, 5841 male and 1881 female.

Using the 1972 Cancer Surveillance Program data it was possible to analyze to some extent the relationship between the observed excess of lung cancer in the youth-central area and occupation. (Occupation is not coded on the death certificate computer tapes.) The expected numbers of lung cancer cases by occupation were calculated using the age-specific distribution of non-lung cancer cases as representative of the distribution of the population. For example, among craftsmen aged 55–64 there were 49 non-lung cancer cases in the remainder of the county. The lung cancers were respectively 23 and 79. The expected number of lung cancer cases in this age group in the southcentral area was thus calculated as $49 \times 79/169 = 22.9$. The observed and expected numbers in the two age groups 45–54 and 55-64 were added to give the results shown in table 4.

Environmental sampling. Operation of the large-scale trailer-mounted air sampler has been described (2). At radii varying up to 15 km for the original trailer site (location 3) in the southcentral area, eight smaller individual samplers were located. (figure 2). These were equipped with either Unico 500, Bendix 550 or Staplex TFIA air samplers, all similar to those described by the Intersociety Committee (9). All were [illegible] before use and after any service by means of a Merriam 50MC-2 laminar flow element and a set of resistance orifice plates. The samplers were loaded with 20 × 25 cm glass fiber filters (Gelman type A, all from the same lot). They were run for approximately 24 hours with each filter. The sampling locations shown in figure 2 were all at fire stations except for one at a hospital (MLK). Samplers at Stations 53, MLK and 11 were on one story roofs, the remainder on the ground. Each morning during operation a technician visited all eight locations, in the same order, reading the gauge before and after loading a fresh tared filter. The filters, folded once after exposure, were transported in manila envelopes. The circuit to all stations required an average of about three hours to complete. (Station 94 proved to be an inconvenient location and the sampler there was moved after one week to Station 19.) The samplers were operated one week at a time on alternate weeks during the period of June 13 to August 1 1973. The large trailer sampler was operated on the same schedule but filters were changed after each two weeks of actual sampling time.

At a downtown location (area No. 1 in

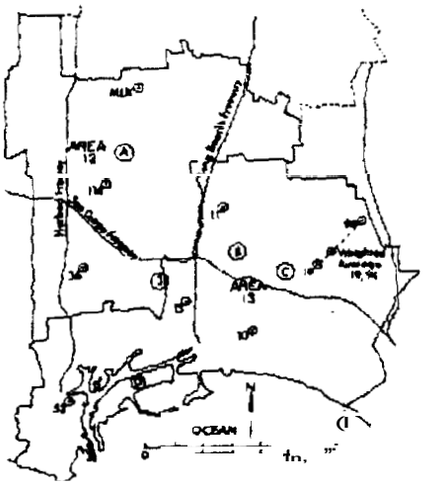

FIGURE 2. Areas 12 sod 13 showing survey air sampling sites Location 3 (circled) is original air sampling trailer sire. Circled letters are wind monitor locations.

reference 2) a comparison test was run by operating the large trailer sampler continuously for 16 days, and simultaneously running one of the small samplers a few feet away. The latter was likewise run continuously except for about five minutes every two days needed to change filters. and one period of breakdown estimated at about one day. The eight 20 × 25 cm fitters were combined into a composite for extraction and analysis.

Chemical analysis. The 20 *x 25* cm filters were kept in a desiccator over saturated calcium nitrate solution for 24 hours before *weighing,* both before and after sampling. The trailer filters were similarly *kept three to lour* days in a two-chambered air-tight *box* with a small blower in the partition to circulate air in the box through the filter and over a tray of saturated calcium nitrate solution. The large filters were weighed to the nearest gram before and after sampling. After weighing, the small filters from each week's operation at any one location were combined into a composite for extraction with benzene in a Soxhlet apparatus. After this the bundle was air dried and several discs were cut with a cork-borer from ell the filters in the bundle, for analysis of inorganic components. The benzene extract was dried to constant weight at 40 *C* on a rotary vacuum evaporator, then made up io 10 ml in *chloroform. An aliquot Of this was taken for* PAH analysis by methods described earlier (2), *except* that *the chromatographic* system was changed to incorporate the gradient elution device of Jewell et al. (10). Some *of* the filter discs were used for a Soxhlet extraction with water for determination of nonmetallic ions. Ammonium was determined with a specific ammonia electrode, nitrate was determined by the xylenol method (11), sulfate was measured by a turbidimetric method (12), and chloride was determined by titration with mercuric nitrate (13). The rest of the filter discs were ashed with RF-excited oxygen, extracted with nitric-hydrochloric ac mixture. and analyzed for selected meu by atomic absorption spectrometry, usi the spectrometer manufacturer's reco mended *conditions.* Blanks for the 20 × cm filter analyses were run on an unus filter *from* the Same batch lot. Five rep cate portions of each large trailer filt along with *an unexposed segment* blank, were analyaed for inorganics w the same *procedures.* Extract weights a inorganics concentrations were correct for *the* small blank filter contributions. PAH were observed in the blanks.

Air *pollution statistics.* Since air pall ant concentrations tend to follow a log-n mal distribution, they were expressed log concentrations for all analysis p poses. The data were fitted to the mod log concentration = constant + time eff + location effect.

The *time* effect was for four separ weeks. The Same model was used for to suspended particulate matter with time effect being for 28 separate days.

Using the above model, the mean values at each station were calcula using the standard Least squares two-v analysis of variance method (14), allow for missing observations. *The* antilogs these mean values are given in tables 7 a 8. *The significance* of *variation over tir* allowing for possible station differenc *and vice-versa, was* calculated by th same standard methods and the relevan values are included in the tables.

RESULTS

The average annual rates of lung can for white males and females by geograp area are given in table 1, As previou reported (1), the rates for males w highest in areas 10, 12, and 13, thi contiguous geographic areas of southe tral Los Angeles County (figure 1). 7 increased rate in these three areas present among both those younger a those older than 65. Among females

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TABLE 1

Average annual age-adjusted lung cancer rates per 100,000 by area in Los Angeles County. 1968–1970, 1972*

Area	Males				Females			
	No.	Age group 35–64†	65+‡	Total§	No.	Age group 35–64†	65+‡	Total§
1	496	70.5	335.6	55.9	192	27.3	66.7	15.4
2	613	71.9	313.3	54.1	190	23.5	49.2	12.5
3	500	61.9	293.4	48.8	222	30.5	63.7	16.1
4	516	66.6	280.6	48.8	220	22.0	65.6	13.9
5	422	90.6	302.0	58.8	113	n.7	56.1	13.1
6	465	56.5	276.3	45.4	162	18.7	49.6	11 0
7	325	71.1	302.2	52.6	113	28.0	505	13.9
a	193	70.7	290.4	51.8	53	21.4	38.5	10.7
9	338	76.9	333.1	58.0	85	21.3	42.4	11.1
10	412	90.8	420.7	70.9	100	27.2	50.6	13.7
11	474	68.6	3753	59.1	164	26.5	52.8	13.7
12	318	90.9	415.7	70.2	71	23.8	45.8	12.3
13	666	97.3	382.3	69.2	177	27.1	50.3	14.0
14	103	56.5	365.2	56.2	27	2C.2	64.0	12.8
Total	5941	73.5	325.2	55.8	1881	24.7	54.7	13.4

* Death certificate cases from 1968–1970, and Cancer Surveillance Program cases in 1972 combined. White only.

†Standardized to the US 1970 Census population using age groupings 35–44, 45–54 and 55–64.

‡Standardized to the US 1970 Census papulation using age groupings 66–76 and 75+.

§Standardized to the US 1970 Census population using age groupings 0–14, 15-24. 25–34. 35-44. 45–54. 55–64, 65–74, and 75+.

rates in areas 10, 12 and 13 were similar to the rate for the entire county. The male excess in the southcentral area was 33 per cent or approximately 87 deaths per year. Forty-six of these excess deaths occurred in those under 65 years of age.

Among males, but not females. the rate of lung cancer varied by social class. The increased rate of lung cancer among males in the southcentral area was seen in each social class except social class 1 (table 2); the social. class 1 population of the southcentral area is, however, small and the addition of only two lung cancer cases to the five in this social class in this area would make the increase uniform across all social classes.

Table 3 shows that the excess in the southcentral area held essentially inde-Pendent of histological type although it was more pronounced lor adenocarcinoma than for squamous cell carcinoma.

TABLE 2

Average annual age-adjusted lung cancer rates per 100,000 for white males by social class in Los Angeles County. 1968–1970, 1972

Social class	Southcentral area		Remainder of County		Ratio of
	No.	Rate*	No.	Rate*	
1 (high)	5	37.4	307	45.0	0.83
2	153	63.0	997	4a.9	1.29
3	246	65.8	1130	520	1.27
4	792	72.7	1612	58.5	124
5 (low)	200	76 a	399	53.7	1.43
All	1396	69.8	4445	52.5	1.33

* Standardized as in last footnote to table 1.

For ail of Loa Angeles County, transport workers and operatives appeared at greatest risk to lung cancer as shown by the lung to non-lung ratios of table 4. The excess of observed lung cancer in the southcentral area wag distributed over six of the nine

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relevant occupational categories of the census (table 4). The greatest relative excess occurred in service workers; this appears to be largely due to an elevated lung cancer risk in janitors, guards, and watchmen in that area.

The geographic distribution of several other cancers which have been linked to smoking (15) is shown in table 5. There was a 20 per cent excess of esophageal cancer in the southcentral area, but there was little variation at the other sites.

TABLE 3

1972 incidence rates of different histological types of lung cancer in white males by area in Los Angeles County

	Southcentral area		Remainder of County		
	No.	Rate*	No.	Rate*	Ratio
Adenocarcinoma	61	12.0	176	6.2	1.9
Squamous cell	106	21.3	350	10.2	1.3
Carcinoma NOS†	131	25.3	436	20.6	1.3
Other histologies	25	5.2	115	3.4	1.0
Histologically undetermined	45	9.8	147	7.2	1.1
Total	370	75.6	1185	55.6	1.1

* Standardized as in last footnote to table 1
† Not otherwise specified

The results of the sampler comparison run are shown in table 6. The large filter yielded more benzene-solubles, but the remaining values were in fairly good agreement except for the more volatile tetracyclic varieties of PAH (i.e., pyrene (PYR), fluoranthene (FLT) and benz(a) anthracene (BAA). We decided therefore to exclude all tetracyclic varieties of PAH (i.e., PYR, FLT, BAA and chrysene (CHY) from further consideration.

Some analytical chemical results for the sampling locations are shown as calculated means in tables 7 and 8. Other components, not showing significant variation over time or location, and their mean concentration values were: Mg(0.96) $\mu g/m^3$, Na(4.1 $\mu g/m^3$), Cd(1.2 ng/m^3) Co(1.3 ng/m^3), Cr(7.2 ng/m^3), Mn(42 ng/m^3), Ni(26 ng/m^3), and NO_3 (0.8 $\mu g/m^3$). Three PAH varieties measured showed variation over time but not location, their mean concentrations were: benzo(k)fluoranthene (BKF) (0.08 ng/m^3), anthanthrene (ANT) (0.07 ng/m^3), perylene (PER) (0.08 ng/m^3).

TABLE 4

1972 ratio of lung to non lung cancers in Los Angeles County and observed vs. expected lung cancer cases in white males for the southcentral area by occupational category (ages 35–64)

Code*	Occupation	Lung:non lung ratio in county	Observed cases in southcentral area (O)	Expected cases in southcentral area (E)	Ratio O/E
1–196	Professional, technical	0.27	7	8.3	0.8
201–245	Managers	0.30	17	12.8	1.3
260–285	Salesworkers	0.18	5	3.8	1.3
301–395	Clerical	0.12	7	5.9	1.2
401–580	Craftsman	0.33	35	30.8	1.1
601–695	Operatives	0.45	27	20.0	1.4
701–715	Transport workers	0.86	9	12.2	0.8
740–785	Laborers	0.49	8	9.2	0.9
800–824	Farm workers	0.14	0	0.0	
901–984	Service workers	0.37	22	8.5	2.6
	Retired	0.12	1	1.8	0.6
	Unknown	0.19	16	21.2	0.7
	Total	0.35	152	130.6	1.2

* *1970 Census of Population Alphabetical Index of Industries and Occupations* (20)
† Standardized to the US 1970 Census population using age groupings 35–54, 55–64
‡ Calculated using same age groupings as in footnote above.

TABLE 5

Average annual age-adjusted cancer rate per 100,000 in white males for pancreas, larynx, lung, bladder and all cancers by area in Los Angeles County, 1968–1970, 1972*

ICD†	Site	Southcentral area		Remainder of County		Ratio of rates
		No.	Rate‡	No.	Rate‡	
140–148	Oral cavity	146	7.0	582	6.6	*1.06*
150	Esophagus	92	4.7	324	3.9	1.21
157	Pancreas	198	10.3	876	10.7	0.96
161	Larynx	73	3.5	315	3.7	0.95
162	Lung	1396	69.8	4445	*62.5*	1.33
181	Bladder	206	11.1	969	*12.5*	0.89
140–208	All cancer	4497	228.0	17819	213.0	*1.07*

* Death certificate cases from 1968–1970, and Cancer Surveillance Program cases in 1972 combined.
† *International Classification of Diseases*. (Seventh Revision.)
‡ Standardized as in last footnote to table 1.

TABLE 6

*Comparison of large and small air samplers over a 14-day sampling period, June 6, 1970 to June 26, 1970**

	Single large filter sample	Composite of eight 2-day 20 × 25 cm (small) filters
BSPM, $\mu g/m^3$	17.0	11.9
Pb, $\mu g/m^3$	5.2	5.1
Fe, $\mu g/m^3$	3.0	3.1
PAH, ng/m^3:		
PYR	0.9	4.7
FLT	0.4	1.8
BAA	*0.7*	*0.3*
CHY	1.1	0.9
BEP	1.7	1.6
BAP	0.5, 0.6†	0.6, 0.8†
BKF	0.7	0.6
PER	0.2	*0.2*
ANT	0.1	*0.3*
GEE	4.4	*5.8*
COR	3.3	3.4

* BSPM: benzene-soluble particulate matter; PAH: polynuclear aromatic hydrocarbon; PYR: pyrene; FLT: fluoranthene; BAA; benz(a) anthracene; CHY: chrysene; BEP: benzo(e)pyrene; BAP: benzo (a) pyrene; BKF: benzo(k)fluoranthene; PER: perylene; ANT; anthanthrene; GEE: benzo(ghi)perylene; COR: coronene.
† Second value by fluorescence in H_2SO_4.

TABLE 7

Polynuclear aromatic hydrocarbons (PAH) in suspended particulate matter. fitted mean values of four weekly sample composites

Station	BSPM* $\mu g/m^3$	Component: PAH*, ng/m^3			
		BEP	BAP	GEE	COR
53	3.78	0.31	0.15	0.74	0.74
36	3.30	0.48	*0.26*	1.26	1.03
116	3.90	0.40	0.18	0.99	0.99
MLK	4.94	0.37	0.21	0.98	0.90
11	5.54	0.47	0.29	1.26	1.17
94/19	4.16	0.45	0.23	1.04	1.00
10	3.68	0.36	0.25	0.94	0.80
13	4.65	9.64	0.34	1.32	1.07
Mean all stations	4.21	0.44	0.24	1.7	0.98
P values for significant variation:					
Over time, after allowing for location differences,		<.01	<.01	<.05	<.01	<.01
Over location, after allowing for time differences,		<.05	<.01	<.05	<.05	<.05
Trailer data, not fitted	8.00	1.08	1.19	1.42	0.57

* See table *6* for identifications.

The four varieties of PAH showing significant variation among sampling locations are listed *in* table 9, normalized to the mean for all stations. Most of the normalized values for these four agree well for each station. The station averages of the four normalized values are plotted in figure 3. It is possible to estimate visually a contour approximating the normalized station mean (1.0), with values above 1.0 enclosed, and those below 1.0 outside the

TABLE 8

Constituents in suspended particulate matter, fitted mean values (ug/m³) of four weekly sample composites

Station	Component						
	SPM*	Ca	Fe	Pb	Cl_2	NH_4^+	$SO_4^=$
[illegible]	87.6	1.56	1.91	0.99	2.2	[illegible]	[illegible]
36	83.7	1.29	1.46	1.11	1.9	0.56	14.7
116	106.5	1.44	2.21	1.17	1.6	[illegible]	[illegible]
MLK	91.6	2.26	1.56	0.93	1.6	0.80	13.4
41	109.6	2.15	2.47	1.32	1.4	0.96	15.5
94-19		1.45	1.91	1.26	1.6	0.48	13.4
40	96.4	1.60	2.21	0.85	1.8	[illegible]	12.9
43	116.4	1.99	2.48	1.19	2.6	[illegible]	16.0
Mean	98.7	1.64	2.00	1.10	1.76	0.60	13.7
P values for significant variation							
Over time, after allowing for location differences							
	.01	.01	.05	.01	.01	.01	.01
Over location, after allowing for time differences							
	< .01		.05				
Trailer data, not fitted	189.0	2.51	2.56	0.62	1.11	1.9	[illegible]

* Suspended particulate matter

contour, as indicated on the map. The contour resembles a distorted ellipse with the high trailer sample value near one focus, and the northeastern edge falling roughly along the boundaries of areas 12 and 13. (Similar contours may be estimated for the four individual PAH.)

The lung cancer rates of the "higher PAH" group inside the 1.00 normalized station mean are slightly higher than those of the "lower PAH" group, the remainder of areas 12 and 13 outside the mean contour line as shown in table 10. The rates for both areas are substantially higher than those for the remainder of the county.

In figure 2 the circled letters designate locations for which data were available on wind direction and velocity. For the total sampling period this information was summarized into the wind roses shown in figure 4. The length of any radial bar represents the percentage of the total survey period during which wind came from the direction of the bar, and the thicknesses indicate the four specified velocity ranges shown in the figure. The strongest and most frequent winds were seen to come from directions between northwest and south.

An estimate of the long-term levels of emission of suspended particulate matter from motor vehicle exhaust and from industrial sources is shown, summed, over two mile (3.2 km) grid squares, in figure 5. The vehicle emissions were obtained by combining traffic density data (16) with a particle emission factor of 0.012 lb per gallon (5.1 gm per 3.79 liters) of gasoline consumed (17), assuming an average of 17 miles (24.2 km) per gallon. The total particulate emissions for petroleum refineries and chemical plants in Los Angeles County were obtained from recent estimates (18). They were added to the vehicle emissions according to grid location. This study area includes over half the petroleum refining capacity in the county.

DISCUSSION

The increased rate of lung cancer among males in southcentral Los Angeles County which was previously reported from death certificate data from 1968–1969 (1), contin

ued to be observed with additional mortality data from 1970 and morbidity data from 1972.

The increased risk was apparent across social class as well as in six of the eight relevant occupational categories of the US Census. The presence of the excess in the non-factory occupational categories lessens the possibility that the difference can be explained *by* exposure to chemicals, *dust.* fumes. or other direct. occupational sources of carcinogens. For the *entire* county, occupation was an important determinant of a man's lung cancer risk. but within the limits of proportional incidence statistics it did not explain the excess male risk in the southcentral area. These observations suggest that occupational risk may not explain the excess lung cancer in southcentral Los Angeles. However, current occupation is not necessarily a good indicator of occupational history and until such detailed histories are available, we cannot exclude the possibility that the excess is related to occupational risk.

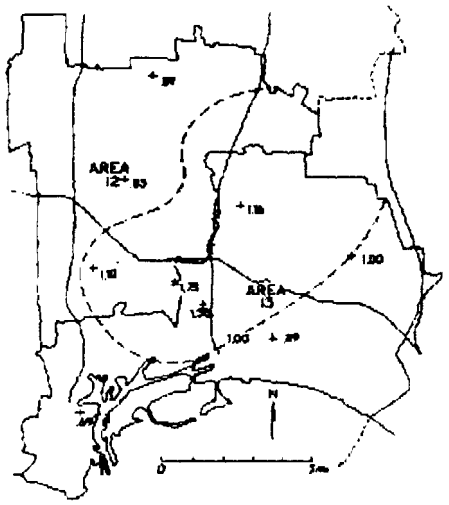

FIGURE 3. Average normalized PAH values from table 3 at sampling locations, with mean (1.00) contour sketched in. (At starred location 1.75 is corresponding trailer value. not fitted data).

TABLE 9

Variation of four different PAH by location

	Component*				Geometric mean of 4 normalized values
	BEP	BAP	CEE	COR	
Mean concentration, 8 stations-ng/m³	0.44	0.24	1.07	0.98	
Concentration at station, normalized to 8-station mean					
53	.69	.62	.69	.75	.69
36	1.09	1.08	1.18	1.05	1.10
116	.90	.75	.83	.91	.85
MLK	.84	.89	.92	.92	.89
11	1.05	1.22	1.17	1.20	1.16
94/19	1.02	.98	.98	1.03	1.00
10	.80	1.06	.88	.82	.89
13	1.46	1.42	1.24	1.10	1.30
Trailer data, not fitted	2.44	4.96	1.33	.58	1.75

*See table 6 for identifications.

The increased risk of lung cancer associated with cigarette consumption has been well documented (15, 19. 20). One possible explanation for the regional excess of lung cancer was that the residents of the southcentral area bad different smoking habits. However, oral cavity, esophageal. pancreatic. laryngeal. and bladder cancer also have been related *to* cigarette consumption (15) and of these only esophageal cancer was in excess in the southcentral area. It is possible that since the esophagus is also a directly exposed site that the supposed same non-smoking "cause" of the increased risk of lung cancer may be partially-responsible for the esophageal excess also. Furthermore, the greatest excess rate was of adenocarcinoma of the lung. the histological type which some studies suggest is not related to smoking habits (21).

The expansion of our sampling in the southcentral area further allows us to de-

TABLE 10

Average annual age-adjusted lung cancer rate per 100,000 for white males by area by social class in Los A County, 1969–1970, 1972

Area*	Social classes 1-3		Social classes 4-5		All classes	
	No.	Rate†	No.	Rate†	No.	R
Inside contour ("higher PAH" group)	129	65.4	281	75.7	410	
Remainder of areas 12 + 13 ("lower PAH" group)	181	58.8	393	74.0	574	
Remainder of County	2528	50.0	2329	59.0	4857	

* See figure 3.

† Standardized as in last footnote to table 1.

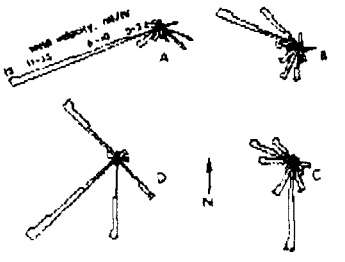

FIGURE 4. Wind roses for locations from figure 2 during the air sampling periods. Lengths of bars represent percentages of total survey time. thicknesses represent velocity ranges as shown.

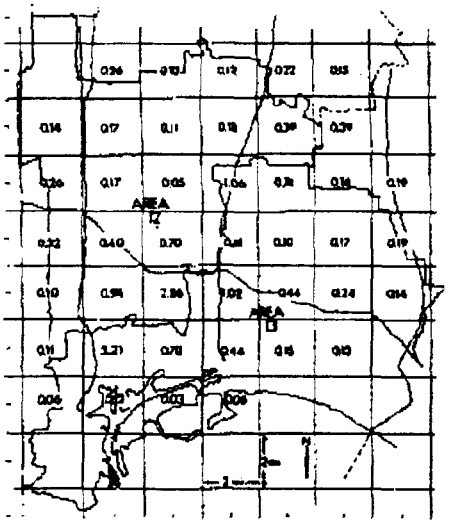

FIGURE 5. Particulate emissions in tons/day, summed over 2-mile (3.2 km) grid squares from automotive, petroleum refining and major chemical sources.

fine the increase of air pollution in area.

The sampling period occurred during summer, which is the season of l concentration for primary, non-p chemical pollutants. The analytica sampling precision is therefore less t might be for the higher winter poll levels. The wind effects observed c the four weekly sampling interval! may not include all variations *that* occur over longer periods of a year or which would affect the area distribut PAH shown in figure 3. Neverthele wind patterns given in figure 4 seem characteristic of the area, based on extensive studies (21). From such stu appears that air masses in the southc study area move to and from the no parts of the county a relatively smal of the time. Not infrequently, a slow ing vortex or eddy will oscillate ab the vicinity of the study area for hours before moving on. Thus, locall erated air pollution may remain in th for prolonged periods. Comparison of 3 (PAH concentrations in air) with fi (emission) shows that during this there was displacement towards the east from the center of density for en to that for concentration in air T consistent *with* the wind pattern played in figure 4.

The four PAH found to show sign variation by location form a reas

coherent geographic pattern which permitted making an estimate of an area of relatively higher PAH and determining the census tracts lying mostly within this area. The rates of lung cancer for the population in these tracts were then compared with the remainder in areas 12 and 13 and with the rest of Los Angeles County (table 10).

The boundaries of a "higher PAH" area are obviously fluid, varying from one time to another. The contour sketched in figure 3 represents an average of conditions *aver* a two-month period. Within the study area covered by the air samplers the PAH levels inside the contour are higher than those outside, and the still higher value (not from fitted data) at the trailer location (No. 3) falls near the center of density one would estimate from the contour. The cancer incidence rates for the areas covered by the air sampling survey are only slightly higher for census tracts inside the contour than outside. The difference for all social classes combined is 6.2 per cent. This effect is more pronounced for the higher social classes 1-3, although the actual rate for classes *1-3* are *always* lower than for classes 4-5 in a given area (or county-wide).

Several factors bear on such a comparison. The air pollution measurements ere recent and of limited duration. In occupational studies of lung cancer the latent interval between exposure to a carcinogen and the appearance of the disease ranged from 10 to more than 30 years (23). The air pollution levels at earlier times were certainly much higher than they are now (2) because of the imposition of control regulations. The major industrial plants in the study area were nearly all in the same locations 30 years ago, and average weather conditions have not changed. The exposures to airborne PAH at earlier times were probably greater than at present, and may have extended over larger areas than suggested by figure 3. Moreover, *additional* major industrial emission sources lying in area 11, to the west of the study *area,* may contribute to present and past pollution in the high rate areas.

The mobility of the papulation must also be considered. Latecomers to the area have not been exposed to the local pollution for as long a time, and those who were *exposed* but left the area may be on the wrong side of the comparison.

We believe the excess of lung cancer in this area could be due to a regional excess *of* carcinogenic air pollution. We do not have an explanation for the restriction of the excess to males. In fact, this finding might suggest that we have failed to uncover an occupational explanation for the excess lung cancer. *An* increased risk of lung cancer in males associated with air pollution has been previously documented by several investigators (24-28), but there are many problems of interpretation in all these studies. If the increased lung cancer risk were confined to long-term residents, it would support the hypothesis that regional air pollution might be a causative factor. To study thia problem in greater detail we are currently undertaking *a* case-control study of smoking, occupational and residential *history* in *the* southcentral mea

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from radicals; previously, Lieberman *et al.* (*22*) described the generation of ethylene from methional or methionine mediated by ascorbate plus cupric ion in a model system.

Our studies have shown that ethane production is a characteristic of spontaneously peroxidizing mouse tissue in vitro and that ethane formation from mice in vivo can be provoked by CCl_4. The amounts of ethane evolved in vivo were correlated with conditions that either increased (phenobarbital pretreatment) or decreased (α-tocopherol pretreatment) the susceptibility of liver to lipid peroxidation. These data suggest that the study of evolved ethane may provide a means to detect and, perhaps, to monitor ongoing pathological lipid peroxidation changes in vivo.

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6. The use of a needle with a side vent (22 gauge, Becton-Dickinson) prevented clogging of the orifice on repeated penetration through rubber.
7. Two gas chromatographs were used, a Becton-Dickinson GC-5 equipped with a 12-foot (3.6-m) alumina, carbon rod and a Hewlett-Packard 5750 equipped with a 6-foot (1.8-m) Porapak N column, both with flame ionization detectors. Ethane was observed both in vitro and in vivo with both instruments. Retention times for methane, ethane, and ethylene were 1.0, 1.7, and 2.1 minutes, respectively (alumina, 150°C); 0.3, 1.4, and 1.2 minutes, respectively (Porapak, 50°C); and 0.3, 0.7, and 0.7 minutes, respectively (Porapak, 150°C). For the in vivo experiments presented in Fig. 2 (Porapak N), analysis was carried out at the highest instrumental sensitivity setting, which yielded a 50 percent deflection of the recorder for an ethane concentration of 15 ppmv/ml. The unknown substance present in room air and traveling with the same retention time as ethane was distinguished from ethane by passing gas samples through a 13-cm length of Tygon tubing packed with molecular sieve (1/12 mesh, Supelco, Bellefonte, Pa.). This procedure trapped the ethane but passed the unknown substance, which was present in amounts that were constant in any experiment (as determined by zero time, final, and selected midpoint readings), but varied from day to day in the range of 1 to 6 ppmv/ml of ethane equivalents per milliliter.
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24. A preliminary report of part of this has been presented (*35*). We thank Nannos and *T. Colvill* for expert assistance. Supported in part by PH HE-01065 and NS-07194 and by the Monitoring Fund, Medical Service, terian Hospital, New York. Reprints to G.C.

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Industrial Air Pollution: Possible Effect on Lung Cancer

Abstract. *Higher lung cancer mortality rates occurred in males living in heavily industrialized areas of Los Angeles County, California. These areas characterized by elevated concentrations of benzo[a]pyrene and other polycyclic aromatic hydrocarbons of primarily industrial origin in the soil and air.*

Because of the increasingly large number of deaths due to lung cancer, there has been continued interest in the etiology of this disease. During the 1960's several epidemiologic studies (*1*) showed a strong relation between lung cancer and cigarette smoking. The effects of other forms of air pollution on the incidence of lung cancer were also investigated. Occupational studies incriminated specific airborne pollutants (*2*). Urban and rural studies implicated air pollution in general (*3*, *4*). Hammond and Selikoff (*5*) suggested that a synergistic interaction of smoking and industrial, neighborhood community air pollution was mental in causing lung cancer.

Interest in the possible neighborhood air pollution on cer mortality led us to investigate geographic distribution of this in Los Angeles County. Ba analysis of the mortality data health districts within the cou grouped into 13 study areas sonably homogeneous air pollu files, as defined by the Los An Pollution Control District (*6*) lations at risk for these 13 s

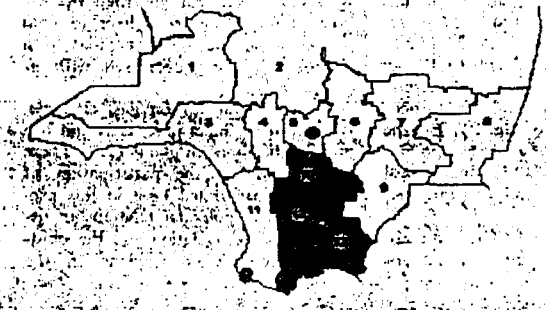

Fig. 1. Los Angel ty showing areas) the dignosis o the lung c tality rat and 196 70 per numbers study are port), the lation pa tions (*12*).

determined from the 1970 census data (7). Caucasians comprised the majority of the Los Angeles County population and were widely dispersed through all 13 study areas. To minimize racial differences the analysis was performed on Caucasian deaths only. The percentage of Mexican-Americans, included in the Caucasian subpopulations, varied by 10 to 35 percent between study areas. The age-adjusted lung cancer mortality rates for Caucasian males and females were calculated for the 13 areas from the Los Angeles County death certificates (8). The age-adjusted rates were standardized to the U.S. 1970 census population (9) by the direct method. A socioeconomic class index from 1 to 5, calculated from the average income and education level, was assigned to each census tract by using a modification of the six-factor Hollingshead index (10). Socioeconomic classes 1 to 5 contained 7, 27, 29, 32, and 5 percent, respectively, of the Los Angeles County population of male whites.

The age-adjusted lung cancer rates for 1968 and 1969 for male Caucasians in the 13 study areas ranged from 43 to 75 per 100,000 (Table 1). In areas 10, 12, and 13 the mortality rate was 70 per 100,000 or greater. These three areas are contiguous, are located in south-central Los Angeles County (see Fig. 1), and are populated predominantly by those in the middle and lower socioeconomic classes. The lung cancer mortality rates for Los Angeles County were 1.73 times higher in the lower than the upper socioeconomic classes. However, the excess of lung cancer still remained in the three geographic study areas when all areas were compared for only socioeconomic classes 1 to 5 (Table 1), or for socioeconomic class 4 alone. The percentages of Mexican-Americans living in areas 10, 12, and 13 were close to the Los Angeles County mean. Thus, lower lung cancer rates in Latin males, as reported elsewhere (11), could not have explained the excess of lung cancer in these study areas. Analyses of the 13 study areas for age-adjusted mortality rates of all other cancers combined and for all causes of death showed no similar clustering. Age-adjusted mortality rates for esophageal, stomach, colon, pancreatic, bladder, and prostatic cancers, leukemia, and Hodgkin's disease also failed to show clustering. Lung cancer mortality rates for female Caucasians did not show any clustering.

The Caucasian male population of areas 10, 12, and 13 was 499,609. There were 667 lung cancers in these males in the 2-year period under study. If the populations of these three areas had experienced age-specific rates similar to those in the other ten areas in Los Angeles County, approximately 476 lung cancers, or 95 fewer per year, would have been observed. Thus, there was an apparent 40 percent excess of male lung cancers in these three study areas for 1968 and 1969.

Table 1. Lung cancer mortalities (N) and age-adjusted lung cancer mortality rates (R/100,000) (1968 to 1969) by geographic area for male Caucasians in Los Angeles County.

Area	All socioeconomic classes		Socioeconomic classes 3, 4, and 5	
	N	R/100,000	N	R/100,000
1	239	48	129	51
2	289	50	201	57
3	252	49	144	54
4	216	44	196	50
5	281	63	269	63
6	225	43	168	45
7	177	56	138	63
8	97	52	53	71
9	192	53	148	55
10	210	70	191	71
11	231	57	149	64
12	173	75	162	72
13	284	70	257	73
All	2886	55	2205	59

The elevated lung cancer rates in the south-central area of Los Angeles County seem to correlate with results of air and soil sampling measurements taken during 1971 and 1972 by Gordon and Bryan (12). They found that concentrations of polynuclear aromatic hydrocarbons in the air and soil differed widely between four sampling stations (A, B, C, and D) in different parts of the county (Fig. 1). The highest concentration of benzo[*a*]pyrene in air and soil was found at station C, situated in the center of the three study areas showing increased lung cancer mortality. The benzo[*a*]pyrene concentration of 3.5 ng/m³ at station C was approximately five times greater than would have been expected from automotive exhausts alone (12). Gordon and Bryan (12) suggested that the benzo[*a*]pyrene excess was the result of effluents from the petroleum and chemical industries concentrated in the area. This possible relation between lung cancer and atmospheric benzo[*a*]pyrene is consistent with earlier findings from England (3). Any effect of neighborhood air pollution on lung cancer mortality would probably have to reflect the result of many years of exposure. While the air sampling measurements in 1971 and 1972 from these areas may have been representative of the previous decades, measurements from earlier periods were not available.

It is possible that more smoking or occupational exposure may be related to the excess of lung cancer. Since smoking and occupational history data were not available from the mortality records, the effect of these two factors could not be directly analyzed. Cigarette smoking is inversely related to social class, those in the lower classes smoking more (13). The excess of lung cancer in the same geographic areas persists when only the data for the lower socioeconomic classes are analyzed; this reduces the possibility that the excess can be fully explained by differences in smoking (13). The possibility of geographic differences in smoking was further weakened by the absence of a similar geographic pattern for cancers of the larynx, bladder, esophagus, or pancreas—cancers also related to smoking (1).

It seems unlikely that occupational exposure alone could account for the excess lung cancer deaths. A preliminary review of death certificates for members of the union serving the petrochemical industry did not reveal an excess of lung cancer. We are unaware of any other occupation unique to this area that could be associated with this excess mortality.

The most likely explanation would be a synergistic action between smoking and neighborhood air pollution. The absence of a geographical variation in female lung cancer would be compatible with this hypothesis and similar synergism has been suggested before for smoking and air pollution (3, 14).

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