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AN ASSESSMENT OF THE HEALTH EFFECTS OF COKE OVEN EMISSIONS GERMANE TO LOW-LEVEL EXPOSURES

NOTICE

This document is a preliminary draft. It has been released by EPA for public review and comment and does not necessarily represent Agency policy.

PREFACE

The Environmental Protection Agency has prepared three documents concerning the health effects of coke oven emissions on the general population:

1. A health effects assessment,
2. An environmental exposure assessment, and
3. A population risk assessment based on the data presented in the first two documents.

This report, the health effects document, will be used by the Environmental Protection Agency's Office of Air and Waste Management, and by the Administrator, to determine the scientific basis for possible actions regarding coke oven emissions under the Clean Air Act. The report was prepared under the direction of Criteria Development and Special Studies Division, Office of Health and Ecological Effects, with participation by the following Division personnel:

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Drafts of the three documents were reviewed by the Environmental Protection Agency's Science Advisory Board Subcommittee on Air Quality Criteria for Coke Oven Emissions in public session on May 30-31, 1978. The members of this panel were:

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Review copies of this document were also provided to other government agencies and to industrial and public interest groups, as the result of a notice that appeared in the Federal Register, Vol. 43, No. 76, page 16546, April 19, 1978.

Comments and criticisms received at these meetings and in response to the Federal Register notice have been reviewed and incorporated in the document as deemed appropriate.

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ABBREVIATIONS

A	Aza-arene
AHH	Aryl hydrocarbon hydroxylase
BaP	Benzo(a)pyrene
BeP	Benzo(e)pyrene
BSF	Benzene-soluble fraction
BSO	Benzene-soluble organic
CTPV	Coal tar pitch volatile
DBA	Dibenzanthracene
DMBA	Dimethylbenzanthracene
MCA	Methylcholanthrene
PAH	Polycyclic aromatic hydrocarbon
POM	Polycyclic organic matter
RR	Relative risk
SMR	Standardized mortality ratio
TLV	Threshold limit value
TPM	Total particulate matter
µg	microgram
µm	micrometer
ng	nanogram

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SUMMARY

1. Coke oven emissions consist of a complex mixture of substances that are etiologically implicated in increased mortality from a variety of malignant and nonmalignant diseases among various populations of workers exposed to them for varying lengths of time. These risks include the following:

   a. Elevated risk for cancer of all sites (relative risk [RR] 1.62; $p<0.01$; Redmond, 1976).

   b. Elevated risk for respiratory cancer (RR 15.7; $p<0.01$; Redmond, 1976).

   c. Elevated risk for kidney cancer (RR 5.0; $p<0.01$; Redmond et al, 1976).

   d. Elevated risk for gastrointestinal cancer: large intestine and pancreas (RR 2.93; $p<0.01$ -- intestine; RR 4.55, $p<0.01$ -- pancreas; Redmond et al, 1976).

   e. Elevated risk for pharyngeal and buccal cancer (RR 3.87; $p<0.01$; Redmond et al, 1976).

   f. Elevated risk for nonmalignant respiratory disease (at least 2-fold excess; Redmond, 1976).

Among lightly exposed workers (nonoven workers in coke plants) an increased risk for nonmalignant respiratory disease and cancer of several sites was also observed.

2. Although workers exposed to the emissions develop malignant and respiratory diseases at an elevated rate, they enjoy a favorable overall mortality as a group, in comparison with the general population, a common observation in the study of occupational medicine. Thus the general population, which includes the young, the old, and the infirm, should be considered more susceptible than the work force, especially for development of chronic bronchitis, since they are generally in poorer health.

3. Coke oven emissions contain an array of identified carcinogens, irritants, particulate matter, trace elements, and other chemicals. The toxic effects observed in both humans and animals are greater than the effects that can be attributable to any individual component. This fact suggests an interplay of factors such as cocarcinogenesis, tumor initiation, and tumor promotion that are involved in exposure to "coke oven emissions" as a whole. Thus the emissions as a whole should be considered the toxic agents, and it is inappropriate simply to attribute toxicity of the emissions to any particular component such as benzo(a)pyrene (BaP), although BaP may serve as a useful chemical tool for approximating overall exposure.

4. Extrapolations and approximations derived from occupational data afford the crude estimate that there is an exposure difference of about 3 orders of magnitude between lightly exposed workers and people living in the vicinity of a coke plant, as indexed by BaP concentrations (3.32 $\mu g/m^3$; 2 ng/m^3). Since these lightly exposed workers show an elevated risk for cancer and nonmalignant respiratory disease, it is prudent to assume that levels up to one hundredth of those to which lightly exposed workers are subjected could cause an increased risk to the general population.

SECTION 1
INTRODUCTION

A substantial body of evidence, both direct and indirect, indicates that coke oven emissions, a complex mixture of many components, are carcinogenic and toxic. The carcinogenic potential of various fractions of coal-tar-pitch volatiles (CTPV's), which are a major constituent of coke oven emissions, and of benzo(a)pyrene (BaP), a carcinogenic constituent of the volatiles, has been established by laboratory studies. Epidemiological findings among coke oven workers show that coke oven emissions are carcinogenic to humans and also can lead to the development of nonmalignant respiratory disease, such as chronic bronchitis and emphysema. Chronic lung disease is a serious, irreversible condition that is often debilitating and can be fatal.

The epidemiological evidence relating to other coal carbonization processes, such as those involved in commercial gas production, and to cigarette smoke is also relevant here because of congruence between many of the constituents of coke oven emissions and the constituents of gas works effluents, tobacco smoke, and other sources of combusted organic matter (National Academy of Sciences, 1972). All of these effluents contain polycyclic organic matter (POM), as well as a wide variety of other chemicals.

Our evaluation in this study of the evidence relating to health hazards of other combustion products confirms that the array of toxic effects observed in cigarette smokers and gas-industry workers is similar to the effects observed among coke oven workers. In particular, the finding that cigarette smoke and coke oven emissions contain very similar compounds capable of inducing cancer in humans and animals is of significance and can

be considered evidence of the carcinogenicity of coke oven emissions. Additional indirect evidence comes from data that support an association between urban air pollution and incidence of chronic bronchitis and possibly of lung cancer (Goldsmith and Friberg, 1977), since polluted urban air also contains, in addition to other materials, compounds found in cigarette smoke and coke oven emissions.

It is important that the effects described throughout this report be regarded as resulting from the complex mixture that constitutes coke oven emissions and not from any particular components such as BaP or the benzene-soluble fraction (BSF) of total particulate matter, components that often serve as indicators of the emissions. As we will show, there is extensive evidence that the effects observed are greater than the sum of effects that could be attributed to individual components. Further, the mixture is not accurately definable by any particular component.

The purpose of this report is to use the different bodies of available evidence in assessing the magnitude of the health effects of coke oven emissions on the population at large.

SECTION 2
COMPOSITION, PARTICLE SIZE, AND HEALTH EFFECTS

Coke oven emissions include all of the constituents of bituminous coal released into the atmosphere during the process of carbonization. Among these constituents are a number of carcinogens; at least one, B-naphythylamine, is a proven human carcinogen (Mancuso et al, 1967). Toxicity of coke oven emissions also is manifest in respiratory irritation, cocarcinogenesis, tumor promotion, and other toxic effects. Table 1 shows a partial list of the constituents of coke oven effluents, and Table 2 summarizes some noncarcinogenic toxic effects, such as skin irritation and irritation of the upper respiratory tract. Appendix B gives some of the levels of various constituents that have been measured.

In addition to chemical composition, the form in which the various constituents are released into the atmosphere (e.g., aerosols, gases) and the size and density of the particulate matter with which they are associated determine their effects on human health. Most of the particles emitted are in the respirable range, which means that they can penetrate into the lungs past the normal respiratory defense mechanisms. Particles ranging from 0.1 to 2 μm in diameter are the optimum size for such penetration and hence are the most biologically significant. After entering the respiratory tract, they are largely retained in the trachea, bronchi, and alveoli. Particles larger than 2.0 μm are trapped by the mucous membranes and do not enter the lungs. Particles smaller than 0.1 μm are retained in the tracheobronchial tree, but elution does not occur. Particles smaller than 0.04 μm do not come out of suspension in the inhaled air and are exhaled (Falk and Kotin, 1961). In the atmosphere, polycyclic

Table 1. PARTIAL LIST OF CONSTITUENTS OF COKE OVEN EMISSIONS

POLYNUCLEAR AROMATIC HYDROCARBONS[a]

Anthanthrene
Anthracene
Benzidene
Benz (a) anthracene[b]
Benzo (b) fluoranthene[b]
Benzo (ghi) fluoranthene[b]
Benzo (j) fluoranthene
Benzo (k) fluoranthene
Benzofluorene
Benzo (a) fluorene
Benzo (b) fluorene
Benzo (c) fluorene
Benzophenanthrene
Benzo (ghi) perylene
Benzo (a) pyrene[b]
Benzo (e) pyrene[b]
Benzoquinoline
Chrysene
Coronene
Dibenz (ah) anthracene[b]
Dibenzo (ah) pyrene[b]
Dihydroanthracene
Dihydrobenzo (a) fluorene
Dihydrobenzo (b) fluorene
Dihydrobenzo (c) fluorene
Dihydrobenz (a) anthracene
Dihydrochrysene
Dihydrofluoranthene
Dihydrofluorene
Dihydromethylbenz (a) anthracene
Dihydromethlybenzo (k and b) fluoranthenes
Dihydromethylbenzo (a and e) pyrenes
Dihydromethylchrysene
Dihydromethyltriphenylene
Dihydrophenanthrene
Dihydropyrene
Dihydrotriphenylene
Dimethylbenzo (b) fluoranthene
Dimethylbenzo (k) fluoranthene
Dimethylbenzo (a) pyrene
Dimethylchrysene
Dimethyltriphenylene
Ethylanthracene
Ethylphenanthrene
Fluoranthene
Fluorene
Indeno (1,2,3-cd) pyrene
Methylanthracene
Methylbenz (a) anthracene
Methylbenzo (a) pyrene
Methylbenzo (ghi) perylene
Methylchrysene
Methylfluoranthene
Methylfluorene
Methylphenanthrene
Methylpyrene
Methyltriphenylene
Octahydroanthracene
Octahydrofluoranthene
Octahydrophenanthrene
Octahydropyrene
Perylene
Phenanthrene
o-Phenylenepyrene
Pyrene
Triphenylene

POLYNUCLEAR AZA-HETEROCYLIC COMPOUNDS[a]

Acridine
Benz (c) acridine[b]
Dibenz (a,h) acridine
Dibenz (a,j) acridine

AROMATIC AMINES[b]

β-Naphthylamine
α-Naphthylamine

OTHER AROMATIC COMPOUNDS

Benzene[b]
Phenol[c]
Toluene[d]
Xylene[d]

TRACE ELEMENTS[b]

Arsenic
Beryllium
Cadmium
Chromium
Cobalt
Iron
Lead
Nickel
Selenium

OTHER GASES

Ammonia[c]
Carbon disulfide[c]
Carbon monoxide[c]
Hydrogen cyanide[c]
Hydrogen sulfide[c]
Methane[c]
Nitric oxide[d]
Sulfur dioxide[c]

[a] Lao et al (1975), except as noted.
[b] Kornreich (1976).
[c] Smith (1971).
[d] White (1975).

Table 2. SOME TOXIC CONSTITUENTS OF COKE OVEN EMISSIONS AND SOME OF THEIR NONCARCINOGENIC TOXIC PROPERTIES

Constituent	Suggested Threshold Limit Value (TLV)	Potential health effect
Acetone	1000 ppm 2400 mg/m^3	At 300 ppm -- Slight irritation 500 ppm -- Still tolerated 1000 ppm -- Chronic irritation of respiratory tract, dizziness
Ammonia	25 ppm 18 mg/m^3	1 ppm -- Odor detectable 20 ppm -- Discomfort in uninured workers, complaints 100 ppm -- Irritation of respiratory tract and conjuctivae
Acridine		Powerful irritant: eyes Photosensitizer Causes dermatitis
Anthracene		Irritant: eyes, skin, respiratory tract Photosensitizer
Arsenic	0.25 mg/m^3	Contact dermatitis and sensitization Conjuctivitis Ulceration and perforation of nasal septum
Benzene	10 ppm 30 mg/m^3	Narcotic effects Severe exposures cause bone marrow and blood changes Myelotoxic

(continued)

Table 2 (continued)

Constituent	Suggested Threshold Limit Value (TLV)	Potential health effect
		25 ppm -- Exposure for 12 years; very little intoxication reported
		60 ppm -- Blood changes reported
		100-200 ppm -- Deaths reported
Beryllium	0.002 mg/m^3	Dermatitis, tracheobronchitis
		100 µg/m^3 -- pneumonitis
Cadmium dust	0.05 mg/m^3	Distinctive, nonhypertropic emphysema, with or without damage to renal tubes; anemia, eosinophilia, anosmia, chronic rhinitus, yellow ring on teeth, bone changes
		2-15 mg/m^3 -- Anosmia, proteinuria (low molecular weight) pulmonary emphysema, yellow ring on teeth, eosinophilia, anemia
Chromium	0.5 mg/m^3	Dermatitis (salt)
Cobalt	0.01 mg/m^3	Pulmonary involvement, chronic interstitial pneumonitis
		1-2 mg/m^3 -- Serious and occasionally fatal results, hypersensitivity, allergic dermatitis
Formaldehyde	2 ppm	Irritant: eyes, respiratory tract, skin
		1-2 ppm -- Itching eyes, dry and sore throat, disturbed sleep, unusual thirst on awakening
		6 ppm -- Eye irritation
Hydrogen cyanide	10 ppm	20-40 ppm -- Slight intoxication, variety of neurological symptoms

(continued)

Table 2 (continued)

Constituent	Suggested Threshold Limit Value (TLV)	Potential health effect
Hydrogen sulfide	10 ppm ($15\ mg/m^3$)	500-1000 ppm -- Acts primarily as systematic poison causing unconsciousness and death through respiratory paralysis 50-500 ppm -- Acts primarily as a respiratory irritant 250-600 ppm -- Prolonged exposure may lead to pulmonary edema and bronchial pneumonia 5-100 ppm -- Associated with eye irritation
Lead	$0.15\ mg/m^3$	Nerve function disorders, inability to sleep, fatigue, constipation Long-term exposure: anemia, colic, neuritis, headaches, loss of appetite, weakness, double vision Organic lead: mental disturbances, inability to sleep, general anxiety, delerium - acute
Nickel	$1\ mg/m^3$	Increase in incidence of nasal, sinus, and lung cancer in workers in nickel refineries
Pyridine	5 ppm	0.83-2.46 ml -- Was toxic in human therapy with one death from liver and kidney damage; central nervous system affected; stimulates bone marrow to production of blood platelets Vapor - irritating to mucous surfaces

(continued)

Table 2 (continued)

Constituent	Suggested Threshold Limit Value (TLV)	Potential health effect
		15-330 ppm -- Nausea, headache, insomnia and nervousness, low back or abdominal discomfort
Selenium	0.2 mg/m^3	Intense irritation of eyes, nose, and throat, headache Severe exposure: bronchial spasms, asphyxiation, chills, fever, bronchitis
		0.007-0.05 mg/m^3 -- Headache, tracheobronchitis, conjunctivitis 0.2-0.4 mg/m^3 -- Garlic odor of breath, skin rashes, indigestion, metallic taste
Sulfur dioxide	5 ppm 13 mg/m^3	Irritation of the mucous membranes, coughing, eye irritation, increased pulmonary flow resistance; adverse symptoms appear at levels between 5 and 10 ppm.
Toluene	100 ppm 375 mg/m^3	100-1100 ppm -- Enlargement of liver, macrocytosis, moderate decrease in erythrocyte count and absolute lymphocystosis 200 ppm -- Headache, nausea, lassitude 200-500 ppm -- Impairment of coordination, momentary loss of memory, anorexia 500-1500 ppm -- Palpitation, extreme weakness, pronounced loss of coordination and impairment of reaction time; red cell decrease in 2 cases, aplastic anemia (possible benzene impurity)

(continued)

Table 2 (continued)

Constituent	Suggested Threshold Limit Value (TLV)	Potential health effect
		200 ppm -- Slight but definite changes in muscular coordination; 7 hours exposure to 200 ppm cause prolongation of reaction time, decreases in pulse and systolic blood pressure.
Xylene	0.1 mg/m^3	Acute oral and skin irritation, sensitization, gastrointestinal irritant.

Sources: Stellman et al (1973).
American Conference of Governmental Industrial Hygienists (1976).
Patty (1958).

aromatic hydrocarbons (PAH's) are primarily found absorbed on particulate matter, hence the presence of respirable particulate matter increases the likelihood that PAH's will penetrate into the lungs. Table 3 gives the range of particle sizes found in coke oven emissions.

The trapped particles in the mucus that are not exhaled and that also do not enter the lung are either swallowed or spit out. Morgan (1975) hypothesizes that in asbestos exposure it is the swallowing of asbestos-containing mucus that leads to the increased incidence of neoplasia of the digestive organs. Elution of PAH's from swallowed particle-contaminated mucus may also explain the diverse sites of cancer associated with exposure to coke oven emissions.

Elution of the PAH's requires a sufficient period of contact between the soot particles and the respiratory epithelium. The larger the particle (provided that it is respirable), the more readily elution into the lungs takes place. PAH's that are adsorbed onto particles smaller than 0.1 μm are not readily eluted (Falk and Kotin, 1961). Furthermore, mucociliary defense clearance mechanisms that normally may limit the entrance of respirable materials are hampered by some chemical and physical agents present in coke oven emissions.

In addition to evidence of the carcinogenic properties of substances like PAH's and aza-arenes, various substances in coke oven emissions are known to produce noncarcinogenic toxic effects, such as nonmalignant respiratory disease, which is discussed later. Many of the major toxic constituents of coke oven emissions (Table 2) are irritants and cilia-toxic agents; some are thought to be cocarcinogens. Sulfur dioxide and sulfuric acid mist are known to cause irritation of the respiratory tract, interfere with mucous clearance mechanisms, and produce bronchoconstriction, as reflected by increased airway resistance. Sulfur dioxide is readily converted into the more powerful irritant, sulfuric acid, in the presence of humidity and particulate

Table 3. PARTICLE SIZE RANGE AND BIOLOGICAL SIGNIFICANCE OF COKE OVEN EMISSIONS

Size[a]	Site	Process	Reference	Biological significance
0.1-1 μm (tarry droplets)	Retort house		Lawther (1965)	Particles in the 0.1-2.0 μm range are respirable and largely retained in the trachea, bronchi, and alveoli; particles >2.0 μm are trapped in the mucous membranes; particles <0.1 μm are retained but elution does not take place; particles <0.04 μm are exhaled (Falk and Kotin, 1961)
1 μm and up (dust)	Retort house		Lawther (1965)	
1.5 μm	Topside coke oven	General atmosphere (shift change)	White, L.D., et al[b]	
1.8 μm	Topside coke oven	During coking	White, L.D., et al[b]	
2.9 μm	Topside coke oven	Charging	White, L.D., et al[b]	
1 μm-1.27 mm	Coke plant	Quenching	Fullerton, R.W. (1967)	
5 μm-1.27 mm	Coke plant		Masek, V. (1970, 1971)	

[a] For respirable particles, the rate of elution of PAH increases with the size of the particle to which the PAH is adsorbed.

[b] No date.

matter (Amdur, 1969). Hydrogen cyanide is also strongly ciliatoxic and mucus-flow-inhibiting. Most toxicological research on these noncarcinogenic constituents of coke oven emissions has been concerned with exposure to the individual substances alone. We can only guess at the combined toxic potential of the several components as they occur in coke oven emissions.

SECTION 3
EXPERIMENTAL EVIDENCE OF TOXICITY: CARCINOGENESIS

EXPERIMENTS WITH ANIMALS

Over the past few decades, both in vivo and in vitro studies have helped establish the carcinogenicity of particular PAH's. With regard to the potential carcinogenic hazard to humans of PAH's in coke oven effluents, the most pertinent data stem from experiments with animals involving cutaneous application, intratracheal instillation, and inhalation exposure. These methods of administration most resemble the routes by which humans may be exposed to PAH's, and the studies also have helped elucidate the role of synergism among different pollutants in the production of cancers.

Cutaneous application on mouse skin is an important bioassay method used as a model system for studying histological changes associated with precarcinogenic and carcinogenic stages. Carcinogenic activity on mouse skin has been demonstrated for various tars, soots, oils, urban air pollutants, gasoline and diesel engine exhaust "tars," the particulate matter of tobacco mainstream and sidestream smoke, and several other combustion products (Hoffman and Wynder, 1976; Karbe and Park, 1974; Kipling, 1976; Hoffmann and Wynder, 1977). Studies of fractions of environmental inhalants have demonstrated that the major type of carcinogen in organic air particulates is the PAH, and that azaarenes contribute carcinogenic activity to a lesser degree (NAS, 1972).

Laskin et al (1970) showed the importance of synergism between two of the most common pollutants in air, SO_2 and BaP, in respiratory carcinogenesis. When rats were exposed to the irritant SO_2 alone, they developed hyperplastic and metaplastic

aberrations. But when SO_2 exposure was combined with BaP exposure (by inhalation), the rats developed squamous cell carcinomas of the bronchus. It has been postulated that SO_2 synergism slows ciliary action and therefore increases BaP retention and/or causes chronic injury; following injury, the resultant regenerating cells may be more susceptible to the BaP (Scala, 1975).

Synergism has also been demonstrated between carcinogenic chemicals and particulate matter (for example, carbon and iron oxide). In a study by Saffiotti et al (1968), all of the hamsters that were administered a 50:50 mix of BaP and iron oxide developed tumors of the respiratory tract, whereas none of the hamsters given iron oxide or BaP alone developed any lung tumors. The tumors induced in the hamsters were comparable with those found in humans, both in histological type (squamous cell and anaplastic carcinoma were most frequent) and in location in the respiratory tract (largely from the epithelium of the major bronchi or their primary divisions). A sequence of tumor development from hyperplasia to squamous cell metaplasia was observed.

Montesano et al (1970) performed experiments of a similar type, also with Syrian hamsters, using intratracheal instillation of BaP and iron oxide. In a dose-response study, four groups of hamsters were given weekly administrations of different doses of a BaP/iron oxide mixture. The groups received 2.0, 1.0, 0.5, and 0.25 mg of BaP, each with an equal amount of iron oxide. The results showed a definite, positive correlation of dose level and tumor incidence. Also, the greater the dose level, the earlier the tumors appeared. Other studies indicated that a given total quantity of BaP/iron oxide mixture administered in fractions by frequent instillations would produce tumors earlier than a single administration of the total dose. Again, the morphology and topography of these experimentally induced tumors were markedly similar to those in humans.

Crocker et al (1970) have demonstrated that intratracheal instillation of a BaP/iron oxide mixture can induce respiratory tract tumors in a primate, Galago crassicaudatus. Black ink

powder has been used as the carrier for carcinogens in intratracheal instillation studies. L. M. Shabad (1962) induced bronchogenic carcinomas in rats using dimethylbenzanthracene (DMBA) on black ink powder.

Other animal studies, particularly those involving mouse skin, have suggested a two-stage mechanism for tumor induction, in which PAH's act as tumor initiators and phenols, aliphatic hydrocarbons, 3- and 4-ring PAH's, and dihydroxybenzenes act as tumor promoters (Van Duuren, 1969). As in cocarcinogenesis, the initiation-promotion model is based on the combined action of different compounds to produce an effect that no single compound would produce by itself. The indication in laboratory experiments that different components of coke oven emissions interact synergistically lends support to the view that the toxic potential of the complex mixture--coke oven emissions cannot be related to the potential of a single compound.

METABOLISM OF POLYCYCLIC AROMATIC HYDROCARBONS

In recent years much research has been conducted to clarify the metabolism of carcinogenic PAH's. Maximum systemic excretion of BaP and its metabolites is via the liver and biliary system (Heidelberger and Jones, 1948; Kotin et al, 1959). There is a maximum excretion rate into the bile in rats suggestive of numerous storage sites. Adipose tissues, the central nervous system, and the sebaceous glands have been identified as storage sites (Chalmers and Peacock, 1936; Peacock, 1936).

It is the metabolic pathways of PAH's that are of interest. Brookes and Lawley (1964) reported that there is no binding of a PAH to any cellular constituents immediately after application of PAH's to the skin, but rather that the maximum amount of binding occurs only after an interval of 24 to 48 hours. This finding strongly suggests that metabolic activation is a prerequisite for macromolecular binding of PAH's. Gelboin (1969) found that binding of BaP to DNA *in vitro* depended upon the presence of rat liver microsomes, since without the microsomes no binding would

occur. It is hypothesized that the aryl hydrocarbon hydroxylase (AHH) system in the microsome fraction of rat liver cells can "activate" the PAH's (Gelboin and Wiebel, 1971).

Elucidation of metabolic pathways is thus essential, since the parent polycyclic hydrocarbons are largely chemically inert. Current studies are working out in detail the biochemical conversion of BaP to its carcinogenic metabolite(s) (e.g., Levin et al, 1977), which are thought to result from activation by the microsomal monoxygenase system (Miller and Miller, 1974; Jerina and Daly, 1974; Sims and Grover, 1974; Gelboin et al, 1972). The recent evidence suggests that reactive arene oxide intermediates, particularly 7,8 diol-9, 10-epoxide, are powerful carcinogens (Moore et al, 1977) and binding of such intermediates to nucleic acids has been demonstrated (Kinoshita and Gelboin, 1978). There is also evidence that a BaP derivative formed during the enzyme-catalyzed hydrolysis of glucuronide binds to DNA, so that other metabolic intermediates may be possibly carcinogenic as well (Kinoshita and Gelboin, 1978).

Further evidence of the carcinogenic potential of various PAH's is available by use of in vitro techniques, including organ cell culture and microbiological procedures. Berwald and Sachs (1963, 1965) first applied BaP and 3-methylcholanthrene (MCA) to cultured hamster-embryo cells to obtain "transformed" or tumor cells. These cells grew randomly and continuously in criss-crossed, piled-up colonies; the random growth pattern was genetically transmitted. Subcutaneous inoculation of these cells into hamsters resulted in tumor formation (Berwald and Sachs, 1965). Subsequently, by means of quantitative cloning techniques, investigators found a direct relationship between the known carcinogenic potency of a hydrocarbon and the number of clones transformed (NAS, 1972). The ability of known chemical carcinogens to transform cells in culture was confirmed by DiPaolo et al (1969a).

A favored hypothesis for the development of neoplasms is that they arise as a consequence of somatic mutations. It has

been demonstrated that many mutagens are carcinogens and vice versa. Therefore, a rapid, inexpensive procedure, useful for screening potential carcinogens and also for determining carcinogenicity of metabolites of the parent substance would be useful. Microbiological tests that confirm the mutagenicity of various compounds, including PAH's, have been reported.

The recently developed Ames test utilizes different strains of bacterium, Salmonella typhimurium, to detect back-mutations caused by a particular agent. All of these strains have defects in the histidine operon such that they cannot grow in a histidine-free environment. The theory behind the test is that a mutagen will cause a shift "back" to the wild type, a type that can grow in a histidine-free medium. The test measures the number of reversions to growth that arise when the strains are exposed to suspected mutagenic agents and placed in a histidine-free medium (Ames et al, 1975). Several studies have found that epoxides of known polycyclic carcinogens such as benz(a)anthracene, dibenz(a,h)anthracene, and 7-methylbenz(a)anthracene were mutagenic, but that the parent hydrocarbons were not mutagenic. (Levin et al, 1976; Levin et al, 1976a; and Thakker et al, 1977).

SECTION 4
EPIDEMIOLOGICAL STUDIES OF HIGH-LEVEL EXPOSURE

INTRODUCTION

In attempting to assess the health effects of high-level exposure to coal-tar pitch volatiles, investigators have done epidemiological studies involving coke oven workers as well as workers employed in the production of gas for household use ('town-gas') and for industrial use (generator gas).* The inclusion of mortality data relating to these different processes is warranted by the earlier-mentioned similarity of the chemical processes and effluents involved in coal gasification and in coking. The relative proportions of the various constituents in the different processes vary with the temperature of carbonization and with the type of coal used. Epidemiological evidence of greater increases in disease rates among workers exposed to the higher-temperature processes suggests that the higher the temperature of carbonization, the higher the proportion of toxic compounds released (see Table 4).

Exposure data on retort house gas workers and coke oven workers show that the concentrations of pollutants are of the same order of magnitude. Lawther et al (1965) measured the concentrations of BaP and other PAH's (BeP; 1,12 benzperylene; coronene) in gas works retort houses. The representative mean concentrations of BaP in tarry fumes escaping from the retorts for long-period samples (collected with a continuous sampler over periods of 2 to 4 weeks) averaged 3 $\mu g/m^3$. The maximum was in

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* Coke-plant data come mainly from the United States, Russia, and Czechoslovakia; coal gasification plant data come from Europe and Japan.

Table 4. TEMPERATURE RANGE OF CARBONIZING CHAMBERS AND EXCESS OF LUNG CANCER REPORTED

Carbonizing chamber	Temperature range, °C	Reported excess of lung cancer among workers, %
Vertical retorts	400-500	27 (Doll, 1965)
Horizontal retorts	900-1100	83 (Doll, 1965)
Coke ovens	1200-1400	255 (Lloyd, 1971)
Japanese gas generators	$\geq$ 1500	800 (Lloyd, 1971)

the same range as the levels to which coke oven workers are exposed. In samples obtained with personal monitors the average BaP concentration was 2.6 $\mu g/m^3$, which is approximately equivalent to 0.26 mg/m^3 of the benzene-soluble fraction of total particulate matter [taking BaP as 1% of the benzene-soluble organics (BSO), as calculated by Schulte et al, 1975] and is comparable to the threshold limit value (TLV). All particles in the gas retort houses were respirable (within the range of 0.1 to 1.0 μm).

A major difference between the coking process and the coal gasification process appears to be the relative absence of SO_2 in the latter (0.35 ppm) (Lawther et al, 1965). Absence of SO_2 would lead one to expect that rates of lung cancer among gas workers would be lower than those among coke oven workers, since SO_2 is believed to have a synergistic effect on carcinogenesis, as demonstrated experimentally (Laskin et al, 1970). A similar synergistic relationship with SO_2 has been hypothesized for arsenic exposure (Lee and Fraumeni, 1969). Another difference is that more workers labor on or near the top side of coke ovens and hence are heavily exposed to the effluents, whereas only the top man in a horizontal retort house has the highest exposure. The effluent mixture itself varies with temperature of carbonization, the higher temperatures apparently leading to a more carcinogenic mixture. Comparison of the lower relative mortality of gas retort workers reported by Doll (1952, 1965, 1972) with data in an ongoing long-term study (e.g., Lloyd, 1971) of the mortality of steelworkers and coke oven workers seems to bear out these hypotheses.

HISTORICAL PERSPECTIVE

Epidemiological studies in different countries have demonstrated that workers exposed to the products of the combustion and distillation of bituminous coal experience an increased incidence of cancer of several sites (lung, pancreas, kidney,

bladder, skin). These studies are discussed below, and the overall results are summarized in Table 5.

The earliest association of skin cancer with occupations involving exposure to coal-combustion products was that of Percivall Pott, who in 1775 observed the high incidence of scrotal cancer among chimney sweeps exposed to soot. His observation has now become a classic reference of occupational medicine for cancer and for discussions of coal tar products. In the early 20th century several studies established the association (Sladden, 1928; Bridge and Henry, 1928; E.L. Kennaway, 1925). In a later series of reports, Henry, Kennaway, and Kennaway (1931) and Kennaway and Kennaway (1936, 1947) found an increased rate of bladder and lung cancer in occupations involving exposure to coal gas, tar, pitch, and soot. In their study of cancer of the bladder and prostate, Henry, Kennaway, and Kennaway (1931) found that workers in 8 out of 10 occupations involving exposure to coal products showed an increased risk of bladder cancer as compared with the general English male population. For 5 out of 10 occupations the risk was 1-1/2 to 4 times greater. Among 46 occupations examined, the three occupations with the highest risk of bladder cancer were patent-fuel workers, gas works engine and crane drivers, and tar-distiller workers. In a later retrospective study of the incidence of cancer of the lung and larynx in England and Wales from 1921 to 1932, Kennaway and Kennaway (1936) noted an excess lung cancer mortality among British gas workers and other coal carbonization and by-product workers. In this and a follow-up study (1947) covering the period 1921 to 1938, Kennaway and Kennaway noted an excess of lung cancer deaths among gas producermen, chimney sweeps, and certain categories of gasworks employees. Data on "gas stokers and coke oven charges" showed an approximately 3-fold excess. Doll (1952) comments that these findings are "suggestive of a special occupational risk," but are not conclusive "because the numbers of men engaged in the various occupations had to be deduced from the evidence provided by the censuses of 1921 and 1931 and were not known with any

Table 5. SUMMARY OF EPIDEMIOLOGICAL AND CLINICAL EVIDENCE OF CARCINOGENICITY

Investigator	Date of study	Type of study	Site	Results	Characterization of exposure
Kuroda and Kawahata	1936	Historical prospective	Lung	(12 lung cancer deaths out of a total of 15 deaths for all cancers). Relative risks cannot be calculated but there is suggestion of 26-fold excess over general population (Lloyd, 1971)	Producer gas workers
Kawai, Amamoto, and Harada	1967	Historical prospective	Lung	33 times the rate for other steelworkers	Workers in producer gas works
Henry, Kennaway, and Kennaway	1931	Historical prospective	Bladder	1-1/2 to 4-fold increased risk relative to general population	Workers in 5 out of 10 occupations involving exposure to coal products
Kennaway and Kennaway	1936	Historical prospective	Lung	3-fold excess for "gas stokers and coke oven chargers"	British producer gas workers; chimney sweeps and several categories of gas-works employees
Kennaway and Kennaway	1947	Historical prospective	Lung		
Doll	1952	Historical prospective	Lung	81% excess of lung cancer deaths	Former gas retort workers (pensioners)
Doll	1965	8-year prospective	Lung	Those with heavy exposure showed 69% excess relative to those with minimal exposure (by-products workers)	Gas-worker mortality was greatest for those with greatest exposure (retort house workers)
			Bladder	Those with heavy exposure showed 4-fold excess relative to those with minimal exposure	

(continued)

Table 5 (continued)

Investigator	Date of study	Type of study	Site	Results	Characterization of exposure
Doll	1972	4-year follow-up of 8-year prospective	Lung	Heavily exposed workers showed highly significant excess; by-products workers showed no excess	
Reid and Buck	1956	Retrospective study of deaths among coke plant workers during 1949-54	Lung	No excess in number of cancer deaths among coke plant workers as a whole nor of lung cancer for oven workers	Coke plant workers
Bruusgaard	1959	Retrospective study of deaths among employed and retired gas-workers over a 15-year period	Lung Bladder	6.4-fold increase over general population 5 deaths that appeared to be a significant excess	All deaths occurred among gas-workers with at least 5 years experience; most had more than 10 years
Lloyd, Lundin, Redmond, and Geiser	1970	Prospective study of mortality among steel-workers by work-area.	Lung	Coke plant workers had 2-fold excess relative to rate among steelworkers	Coke plant workers
Lloyd	1971	Detailed prospective study of workers in steel-workers cohort	Lung	Coke oven workers showed 2-1/2-fold excess over steelworkers population; top-side workers had 5-fold excess; workers with 5 or more years full-time top-side work had 10-fold excess; nonoven workers may have excess risk of digestive cancer	Coke plant workers

(continued)

Table 5 (continued)

Investigator	Date of study	Type of study	Site	Results	Characterization of exposure
Redmond, Ciocco, Lloyd, and Rush	1972	Follow-up to above	Lung	Coke oven workers had 1.34 excess risk relative to nonoven workers	Coke plant workers
			Kidney	Coke oven workers had a 7.49 excess risk over nonoven workers	
			Prostate	Coke oven workers had 1.64 excess risk over nonoven workers	
Redmond et al	1976	Follow-up to previous studies extended to 1970	Lung	15.72 excess for full-time top-side oven workers	
			Intestine	2.37 excess for non-oven workers	
			Pancreas	4.29 excess for non-oven workers	
Redmond	1976	Follow-up to previous studies	Kidney	5 excess for all coke plant workers;	
			Lung	3.31 excess for oven workers	
			Pancreas	4.95 excess for nonoven workers	
			Intestine	2.93 excess for nonoven workers	
			Buccal and pharyngeal	3.87 excess for nonoven workers	

certainty after the latter date."

Another important report was a study by Kuroda and Kawahata (1936) demonstrating a high incidence of lung cancer among Japanese gas generator workers. Although lung cancer was a relatively rare form of cancer in Japan during the 1930's, accounting for 3.1 percent of all cancer, this study showed that lung cancer accounted for 80 percent of all cancer (12 out of 15 cases) among the gas generator work force who were exposed to extremely high quantities of material similar to coke oven emissions.

RECENT STUDIES

In another study of 504 deaths among former gas workers at a Japanese steel plant, Kawai et al (1967) found 6 deaths from lung cancer in contrast with the expected number, 0.180, for other workers at the same plant with no gas-generator work experience; this value is 33 times the expected rate. Age-standardized mortality from lung cancer in the control group was close to that of the general male population. The large excess of lung cancer deaths among the gas workers could not be attributed to smoking. The authors note that the excess of lung cancer mortality occurred only in the age group of 45 to 54 years. Data for those in this group with 10 to 19 years of gas-generator work experience showed a marked increase in lung cancer risk, whereas data for those under 45 years of age with the same work experience (10 to 19 years) showed no significantly excessive mortality. The implications of this finding are discussed in Section 7.

Bruusgaard (1959) studied 125 deaths among former gas works employees in Norway, all of whom had at least 5 years work experience and most of whom had more than 10 years. The number of respiratory cancers was higher than expected (12, or 9.6% of the total number of deaths, against 1.5% in males for the country as a whole). The proportion of lung cancers to cancers of all sites among the gas workers (29.2%) was also significantly higher than

that in the general population, 9.2 percent. In addition, there were five deaths from cancer of the bladder--12 percent of all cancers. Although Bruusgaard gives no exposure data and occupational histories for most cases are incomplete, he notes that workers with a history of employment in the retort houses had an especially high incidence of respiratory cancer.

Reid and Buck conducted a mortality study in 1956 among 800 coke plant workers randomly selected from a total of 8000 employed over the years 1949-54, inclusive. The study did not show an elevated cancer risk when death rates for all causes and for cancer were compared with age-specific rates prevailing in the period 1950-54 among workers in a large unspecified industrial organization. The cause of death was ascertained either by reference to the union's funeral fund records, which were required to be supported by a copy of the death certificate, or by a special search at the General Register Office. The coke plant workers were categorized by occupation: coke oven workers, those handling by-products, and maintenance workers (further grouped as laborers, workers, and foremen). No total excess in the number of cancer deaths was found among the coke plant workers as a whole, and there was a "complete lack" of any excess of respiratory cancer for men working on the ovens. When occupational history was taken into account, no excessive cancer risk was found for by-product workers and only a small excess was found for men who had at some time worked at the oven.

This study was criticized by Lloyd (1971), who pointed out that Reid and Buck may have underestimated the number of lung cancer deaths since the records included only men dying while still "on the books" during the period 1949-54. Lloyd also states that "the population at risk and the distribution by age and area of prior employment was based on an estimate of figures which excluded retirees and those who had left employment." Although employment history is inadequate and follow-up is incomplete, reanalysis of Reid and Buck's data shows that the only occupational group with an excess for all cancer as cause of

death was the oven-worker group. A higher death rate of the top-side workers probably would be diluted in this study, since Reid and Buck's definition of oven workers includes both top-side and side-oven workers.

In an effort to further quantify the Kennaway and Kennaway data suggesting a correlation between occupational exposure and cancer mortality, Doll (1952) studied the mortality among male pensioners (over age 60) of a large London gas works company for a 10-year period (1939-1948) and compared the data with mortality data for the population of Greater London. Table 6A, which summarizes the results of this study, shows that retired gas workers had a statistically significant excess of lung cancer deaths as compared with the number of deaths expected at the London rates. In this study, data on men who retired early were included when the men reached age 60 so as not to bias the investigation by the exclusion of a particularly unhealthy group who retired early because of health reasons. Age-standardized mortality ratios were calculated by use of mortality rates for England and Wales, which were weighted to approximate higher rates in Greater London. The causes of death recorded by the company had been copied from death certificates. The pensioners' mortality from all causes was close to the expected (840 deaths against 856 expected), but the mortality from cancer was in excess of the expected (156 against 123.5; $p<0.01$). Cancer of the lung accounted for the greatest excess (25 against 10.4; $p<0.001$), which constitutes a significant increase in mortality.

To assess differences in risk among different jobs within the gas works, Doll categorized the pensioners as those employed outside the works and those involved directly in the production of gas or in handling of the waste products, representing a low- and a high-exposure group, respectively. Excess lung cancer among the high-exposure group was significant (17 observed versus 8.6 expected; $0.01<p<0.02$). Incomplete occupational histories did not permit a judgment as to whether the risk was limited to

Table 6. SUMMARY OF MORTALITY DATA IN GAS WORKERS OBSERVED BY DOLL[a]

A. Causes of death of pensioners from 1939 to 1948 compared with the experience of Londoners

Cause of death	Expected deaths at England and Wales rates	London weights[b]	No. of deaths		Test of significance of difference between observed and expected, value of P[c]
			Expected at London rates	Observed	
Cancer and other tumors	123.5	1.10	135.9	156	
Cancer of stomach and duodenum	25.0	0.93	23.3	32	
Cancer of lungs and pleura	10.4	1.33	13.8	25	<0.01
All causes	831.5	1.03	856.4	840	

[a] Table 6A adapted from Doll (1952); 6B adapted from Doll (1972).

[b] Since adequate mortality data for Greater London were not available, Doll initially used mortality data for England and Wales to calculate the expected number of deaths. He then applied a weighting factor to bring the values into conformity with the numbers that would be expected for residents of Greater London.

[c] The values for P are probabilities with which as great or greater differences between the observed and expected deaths might occur by chance. Values of greater than 0.05 are not recorded.

(continued)

Table 6 (continued)

B. Standardized annual death rate per 1000 men: all four original boards grouped together, and England and Wales (number of deaths in parentheses)

Cause of death	1 Sept. 1953 to 31 Aug. 1961			1 Sept. 1961 to 31 Aug. 1965			1 Sept. 1953 to 31 Aug. 1965			
	Class A[a]	Class C_1[b]	E and W	Class A	Class C_1	E and W	Class A	Class C_1	E and W	Significance of difference between observed (Class A) and expected value of P
Cancer of lung	3.39 (55)	1.16 (5)	2.05	4.08 (44)	1.78 (6)	2.24	3.82 (99)	1.59 (11)	2.13	<0.001
Cancer of bladder	0.28 (4)	0.00 (0)	0.17	0.42 (6)	0.29 (1)	0.17	0.40 (10)	0.13 (1)	0.17	
Cancer of skin and scrotum	0.07 (1)	0.00 (0)	0.02	0.19 (2)	0.00 (0)	0.02	0.12 (3)	0.00 (0)	0.02	0.03; 0.02
Other cancer	2.11 (36)	2.41 (9)	2.57	3.02 (34)	2.37 (8)	2.51	2.70 (70)	2.39 (17)	2.55	
Bronchitis	3.53 (51)	2.10 (9)	1.61	2.42 (26)	3.12 (9)	1.64	2.98 (77)	2.57 (18)	1.63	<0.001
All causes	19.68 (304)	15.00 (61)	18.66	21.69 (243)	14.50 (46)	18.69	21.21 (547)	14.91 (107)	18.67	

Standard population--total number of man-years at risk for both occupational classes and all four boards, 1953-65. The one untraced man in Class A is counted as alive at the end of the study.

[a] Class A = heavy exposure, i.e., coal carbonizing process workers.

[b] Class C_1 = exposure only to by-products, i.e., process and maintenance workers in chemical and by-products plant.

those involved in the gasification process or included those handling by-products. Evaluation of relative mortality rates was further complicated because those listed as employed in other sections of the plant may have been employed in the gas works at an earlier time.

In a separate study, Doll (1965) carried out an 8-year prospective analysis of mortality from different causes among several occupational groups of gas workers and retirees covering the years 1953-61. Table 6B, which summarizes the results of this study and of a follow-up study by Doll (1972), shows that heavily exposed gas workers had statistically significant excesses in mortality from lung cancer compared with the numbers of deaths expected on the basis of the rates for England and Wales. This study (1965) also noted an excess in mortality from bronchitis. The study included 11,499 men between 40 and 65 years of age at the start of the study with 5 or more years in the gas works plant. Observed gas worker mortality rates were compared with those expected in populations of England and Wales and regional metropolitan areas.

Information on the cause of death was obtained from death certificates. The workers were grouped into three classes according to their exposure: heavy exposure (A); intermittent exposure (B); minimal exposure, or exposure only to by-products (C). Again, elevated mortality was attributed to respiratory system disease, specifically, cancer of the lung and bronchitis. The lung cancer mortality rate was 69 percent higher for Class A than for Class C. A 4-fold higher rate of bladder cancer was also observed in Class A as compared with Class C. The increase in bladder cancer verged on significance ($p=0.06$) according to Doll, who concluded that the mortality of gas workers varied significantly with the type of work and that mortality was highest among workers with greatest exposure to the products of coal carbonization. A report on an additional 4 years of observation of the cohort (Doll, 1972) provided follow-up information on 2449 coal-carbonizing process workers and 579 maintenance

workers on mortality rates gathered at annual intervals from 1961 to 1965. Additional employees of four other gas boards were also followed over periods of 7 to 8 years.

Heavily exposed workers (Class A) experienced a highly significant elevated mortality from lung cancer ($p<0.001$) and bronchitis ($p<0.001$). Data on by-product workers (Class C) show no excessive mortality and over the 12-year period provide no substantial evidence of increased occupational risk for this group. The additional 4 years of data in this study support the earlier association between exposure to the products of coal carbonization and increased lung cancer and also a risk of bladder cancer ($p=0.06$). However, the increased mortality from bronchitis, noted earlier, was no longer apparent.

An important series of reports on the mortality of coke oven workers is the extensive, ongoing study of steelworkers conducted by Lloyd, Redmond, and their colleagues at the University of Pittsburgh. These reports, the results of which are summarized in Tables 7 and 8, indicated increased relative risks for certain cancers among coke oven and nonoven coke plant workers. In the course of their study of mortality among nearly 60,000 steelworkers, these investigators began to concentrate on coke oven workers as a subgroup within the steelworker population apparently because of the observed elevated mortality of that subgroup from respiratory and other cancers. This work has confirmed and extended the well-established findings that workers exposed to the coal-carbonization process experience a markedly increased cancer risk. The successive phases of this study also show increased cancer response rates with increased exposure and dose. The results of these studies and available cumulative exposure data are discussed in detail below, along with potential health effects at lower-level exposures, which were approximated within the constraints of the data.

The coke plant workers studied by Lloyd were employed in by-product coke plants. In contrast to the older beehive coke oven,

Table 7. SUMMARY OF RELATIVE RISKS OF DEATH FROM CANCER AMONG COKE OVEN WORKERS[a]

Length of employment (1953-1970), yr	Distribution of workers			Deaths and RR's of death from malignant neoplasms						Deaths and RR's of death from respiratory cancer					
	5+	10+	15+	5+		10+		15+		5+		10+		15+	
Work area				Obs.	RR	Obs.	RR	Obs.	RR	Obs.	RR	Obs.	RR	Obs.	RR
Total coke oven	1860	1194	790	166	1.47[b]	136	1.50[b]	108	1.62[b]						
Coke oven	993	574	325	101	1.66[b]	85	1.95[b]	63	2.40[b]	54	3.02[b]	44	3.42[b]	33	4.14[b]
Oven top-side full-time	150	72	29	35	3.70[b]	22	5.12[b]	12	7.63[b]	25	9.19[b]	16	11.79[b]	8	15.72[b]
Oven top-side part-time	290	245	159	26	1.59[b]	31	1.85[b]	32	2.73[b]	12	2.29[b]	16	3.07[b]	18	4.72[b]
Oven side only	553	257	137	40	1.17	32	1.46	19	1.51	17	1.79[c]	12	1.99[b]	7	2.00
Nonoven	836	578	392	65	1.28	48	1.10	39	1.13						
No one coke plant area	31	42	73	0	d	3	d	6	1.34						

	Deaths and RR's of death from cancer of digestive system among non-oven workers					
	5+		10+		15+	
	Obs.	RR	Obs.	RR	Obs.	RR
All malignant neoplasms of digestive system	28	1.58[c]	23	1.53	19	1.53
Large intestine	11	2.31[c]	10	2.52[b]	8	2.37[c]
Pancreas	8	3.67[b]	7	3.75[b]	6	4.29[b]
Other	9	0.83	6	0.65	5	0.65

[a] Adapted from Redmond (1976).

[b] $P<0.01$.

[c] $P<0.05$.

[d] Less than five deaths.

Table 8. SUMMARY OF EPIDEMIOLOGICAL STUDIES OF LONG-TERM MORTALITY OF COKE PLANT WORKERS

Year	Author	Title	Study population and years of observation	Comparison group
1970	Lloyd, Lundin, Redmond, Geiser	Long-Term Mortality Study of Steelworkers IV. Mortality by Work Area	SMRs[a] of workers by area - coke plant; white, non-white	Total steelworker population, (58,828 men), 1953-1961
1971	Lloyd	Long-Term Mortality Study of Steelworkers V. Respiratory Cancer in Coke Plant Workers	Oven and nonoven workers employed in 1953-1961 and prior years	Total steelworker population, (58,828 men) 1953-1961
1972	Redmond, Ciocco, Lloyd, Rush	Long-Term Mortality Study of Steelworkers VI. Mortality from Malignant Neoplasm Among Coke Oven Workers	Any worker with coke oven experience, 1951-1955 (expanded to also include 10 plants not in Allegheny County - 12 plant study)	1) All steelworkers including nonoven coke plant workers employed from 1951-1955 in 10 plants 2) Steelworkers including nonoven coke plant workers employed in 1953 in two Allegheny County plants
1975	Mazumdar, Redmond, Sollecito, Sussman	An Epidemiological Study of Exposure to Coal Tar Pitch Volatiles Among Coke Oven Workers	Coke oven workers from 12 plants, 1951-1966, 1953-1966 (see above)	Steelworkers including nonoven coke plant workers from 12 plants, 1951-1966 and 1953-1977 (see above)
1976	Redmond, Strobino, Cypess	Cancer Experience Among Coke By-Products Workers	Oven and nonoven workers, 1953-1966	All steelworkers with no coke plant exposure, 1953-1966
1976	Redmond	Epidemiological Studies of Cancer Mortality in Coke Plant Workers	Oven and nonoven workers, 1953-1970	All steelworkers with no coke plant exposure, 1953-1970

[a] Standard Mortality Ratios.

which released the volatile matter (by-products) into the atmosphere, the by-product oven recovers most of the tar, oil, and chemicals from the volatiles. Exposure to effluents from by-product coke ovens is due to the escape of volatiles during charging, quenching, and discharging and to their escape through improperly sealed openings.

In these studies the workers were classified by work area within the plant in terms of function and exposure to effluents, a task made difficult by the variety and vagueness of job titles used in occupational histories by different companies and changes in titles over long periods of time. The by-product coke plant was therefore analyzed in terms of three distinct areas: 1) the coal-handling area, 2) the coke oven area, and 3) the by-products plant for recovery of gas and chemical products (areas 1 and 3 are nonoven workers). Since earlier work (e.g., Doll, 1972; Kennaway and Kennaway, 1936, 1947) had shown no apparent increased cancer risk for men involved in work similar to that performed in areas 1 and 3, some of the initial study groups included only those workers employed in area 2.

In this long-term study, Lloyd (1971) examined the mortality records of the workers in relation to length of employment and work area within the coke plant and compared the cause-specific mortality of coke plant workers as a whole with the mortality of the total steelworker population. Thus he eliminated the difficulty of comparing nonworkers with supposedly healthier workers. The cohort for the study included all men employed in two of the three Allegheny County steel plants operating coke plants during 1953. Coke plant workers were categorized as oven workers and nonoven workers. In this phase of the study, the excess mortality from respiratory cancer among all coke plant workers employed in 1953 could be accounted for by the excess mortality of workers employed on the coke oven itself (20 observed, 7.5 expected).

The excess mortality of coke oven workers was further demonstrated when men employed at the ovens before 1953 were included

in the coke oven worker category. This inclusion added 84 deaths and increased the mortality rate by 84 percent. Deaths among men employed in 1953 accounted for 13 of the 33 deaths observed from respiratory neoplasms, more than twice the expected number. In total, the current plus the former coke oven workers experienced a 2-1/2-fold excess mortality from respiratory cancer.

Although the initial study also showed a difference between white and nonwhite workers, this difference resulted from too few white workers and disappeared later when more white workers were added to the study. Further, a significant excess of cancers of the digestive system was observed in nonoven workers employed in 1953 and prior years (17 vs. 9.7 expected; significant at the 5% level). Cancer of the pancreas and large intestine showed the greatest excess.

The results of this first study showed the importance of analyzing mortality by job classification, indicative of relative exposures, and by length of exposure. Deaths among full-time top-side workers accounted for all of the excess mortality of coke oven workers from all causes and almost all of the mortality from lung cancer. Deaths from lung cancer among full-time top-side workers were 7 times the expected rate (19 vs. 2.6; significant at the 1% level). Lloyd comments that because the population was followed for only 9 years, his estimates of lung cancer mortality may be conservative owing to the long period of latency in occupational lung cancers (15 to 25 years), a comment borne out by the continuing studies.

Elevated rates in mortality of coke oven workers from all causes of death were associated with length of employment. Excess mortality among men employed at the ovens less than 5 years was slight, whereas among those employed more than 5 years the overall mortality was 17 percent higher than expected and the lung cancer death rate was 3-1/2 times that expected. These findings can be interpreted as preliminary evidence for a dose-response relationship between respiratory cancer and exposure to

coke oven emissions. Total mortality of men employed 5 or more years at full-time top-side jobs was twice the expected value (35 vs. 17; significant at the 1% level). Almost all of this increase was due to a 10-fold risk of lung cancer for full-time top-side workers (15 vs. 1.5; significant at the 1% level).

Redmond et al (1972), in a follow-up of earlier reports in the series, examined the mortality records of cohorts of coke oven workers in an expanded study at 12 steel plants. In addition, the data from the earlier study (1971) of two Allegheny County plants were updated from 1961 to 1966 and were compared with data from 10 other plants for the same period. The cohorts at the 10 additional plants included all men who had worked at the oven at any time in the 5-year period 1951 through 1955. (The criterion for inclusion in the prior Allegheny County study was employment in one of the two coke plants during 1953.)

The findings of Redmond et al indicate that both the level and duration of exposure to coke oven emissions are correlated with mortality from various types of cancer. The additivity of time and dose was further substantiated. Analysis of mortality by cause shows significantly elevated mortality of coke oven workers from malignant neoplasms (RR 1.34; $p<0.01$), from malignant neoplasms associated primarily with respiratory cancer (RR 2.85; $p<0.01$), from kidney cancer (RR 7.49; $p<0.01$), and from prostate cancer (RR 1.64; not significant).

Initial analysis showed a discrepancy between the risks of white and nonwhite coke oven workers until data on relative exposure by race were analyzed. The data showed that 41.5 percent of the nonwhites and 29.8 percent of the whites had been employed at the coke ovens for 5 or more years at the time of entry to the study. Only 2.2 percent of the whites had been employed full-time top-side and 11.2 percent were employed part-time top-side; in contrast, 27.3 percent of the nonwhites were employed full-time top-side. Since top-side work entails the heaviest exposure to coke oven emissions, the exposure of

nonwhite workers clearly is disproportionately heavy relative to that of white workers.

The study showed that men employed at full-time top-side jobs for 5 years or more have a relative risk of lung cancer of 6.87 ($p<0.01$) as against risks of 3.22 ($p<0.01$) for men with 5 years of mixed top-side and side-oven experience and 2.10 ($p<0.05$) for men with 5 or more years side-oven experience. These data indicate a definite gradient in response based on both type and duration of exposure. When relative exposures and responses are accounted for, the racial differences are lost.

Overall, the study confirmed the Lloyd findings of a 2-1/2-fold excess of mortality from respiratory cancers. A new finding of Redmond's was a significant excess of kidney cancer among coke oven workers (RR 7.49; $p<0.01$).

Redmond concludes that the 6.87 ($p<0.01$) relative risk for malignant neoplasms of the respiratory system for men employed full-time top-side and the 1.70 relative risk (not significant) for men employed less than 5 years suggest a dose-response relationship, which Mazumdar et al (1975) further substantiates by calculating cumulative exposures of the cohort to CTPV's. (These data are analyzed later.) Redmond's work also confirms the need to allow an adequate induction period in study design, since workers with less than 5 years of experience at time of entry could have accumulated only 20 years of total exposure at most.

Table 7 summarizes additional data (1967 to 1970) analyzed by Redmond (1976). These data from the Allegheny County steel plants demonstrated a consistent increase in the level of risk of malignant neoplasms with increased exposure for each of the coke oven groups. Further, the risk of side-oven workers for lung cancer, which had not been statistically significant in the earlier studies, reached significance (RR 1.79; $p<0.05$). Although no dose-response relationship was apparent, the relative risk for cancer of the pancreas and the relative risks for respiratory diseases other than cancer increased markedly with

length of exposure. Estimates of exposure levels for this set of studies are discussed later.

The latest study by Redmond et al (1976) again confirmed elevated risks for coke oven workers for lung cancer (44 deaths vs. 24.5 expected; $p<0.01$) and genitourinary cancer, relative risk 1.82 ($p<0.05$), due primarily to a 5-fold increase in kidney cancer. Data on nonoven workers continue to demonstrate excess kidney cancer, and the most recent studies in the Lloyd series show that incidences of buccal and pharyngeal malignancies are highly significant.

Redmond's study also presents evidence that the observed elevated incidence of intestinal and pancreatic cancer is not attributable to the country of origin of the workers, an important consideration because studies of migrants have established differences in risk among those populations. The overall conclusion of the paper is that "these observations indicate the need to consider nonoven coke plant workers as well as oven workers when evaluating cancer hazards in the plant." The health implications of these data are discussed in Section 6.

SECTION 5
AMBIENT POLLUTION AND RESPIRATORY DISEASE

The effects of exposure to coke oven emissions among the general population are not well understood. There are no definitive epidemiological studies of low-level exposure of populations near coke plants to coke oven emissions. A recent paper (Graff and Lyon, 1977) reports findings near a large coke oven in a northern Utah county. A statistically significant excess of lung cancer cases (as compared with controls) was found among residents living 4.8, 6.4, and 8 kilometers from the coke oven but not at points nearer (1.6 and 3.2 kilometers) and farther (16 and 24 kilometers) from the oven. Only an abstract of this paper is available, and without more information the results are difficult to interpret.

Most of the pollutants that make up coke oven emissions are present in urban air but in different proportions from those found in the vicinity of coke ovens. Some studies on urban air pollution have found that the lung cancer death rate in urban areas is roughly twice that in rural areas (NAS, 1972), and several studies have shown a correlation between the "urban factor" and BaP concentrations (Carnow and Meier, 1973; Pike et al, 1975). However, because of the confounding effect of cigarette smoking as the dominant cause of lung cancer and because of the limitations of benzo(a)pyrene as an indicator of the carcinogenic potential of air pollution, it has not been possible to demonstrate conclusively that part of the urban excess of lung cancer cases is due to general air pollution.

Nevertheless, researchers in a recent conference, after weighing the available evidence, concluded that:

> "Combustion products of fossil fuels in ambient air, probably acting together with cigarette smoke, have been responsible for cases of lung cancer in large urban areas, the numbers produced being of the order of 5-10 cases per 100,000 males per year. The actual rate will vary from place to place and from time to time, depending on local conditions over the previous few decades." (Environ. Health Perspectives, 1978).

It has been noted that the occurrence of cancer of certain other sites besides the lung is higher in urban than in rural areas. Using mortality data from Erie County (which includes Buffalo) for the years 1959 to 1961, Winkelstein and Kantor (1969a, 1969b) found positive associations between suspended particulate air pollution and stomach cancer and between suspended particulate air pollution and prostrate cancer. Associations obtained in correlation studies of this kind, as the authors point out, must be interpreted cautiously in view of the small numbers of cases involved and the "...many possible ways in which unknown factors might be influencing the distribution." Information concerning occupation, smoking, and residence history was not taken into account in these studies. The authors note, however, that their findings of associations of stomach and prostate cancer with suspended particulate agree with similar findings of Hagstrom et al (1967) based on the Nashville Air Pollution Study. Coke ovens appear to be a major source of air pollution in Erie County.

In contrast to the inconclusiveness of the data linking air pollution and lung cancer, there is substantial evidence that air pollution contributes to the increased incidence of both morbidity and mortality from nonmalignant lung disease [much of this evidence is cited in a recent review of air pollution and health by Goldsmith and Friberg (1977)]. For example, the College of General Practitioners (1961) in Great Britain has published data showing a 2- to 4-fold increase in the incidence of chronic bronchitis in urban over rural areas, a difference not completely accounted for by the 2- to 3-fold increase in incidence of chronic bronchitis attributed to smoking.

Buck and Brown (1964) found high correlations of particulate matter and sulfur dioxide with bronchitis mortality, and Toyama (1964) found significant correlations between bronchitis and dustfall in 21 Tokyo districts where age-standardized mortality rates reflected increased levels of exposure. Nose (1960) reported a strong association of bronchitis and pneumonia with dustfall in Ube, Japan. Carnow et al (1970) correlated sulfur dioxide concentrations with increased chronic bronchitis. Spicer et al (1962) observed that respiratory symptoms in patients with chronic bronchitis were associated with SO_2 levels measured 38 hours previously. This finding was substantiated by McCarroll et al (1967), who reported intervals of 24 hours and 48 hours between the occurrence of sulfur dioxide and particulate pollution and symptoms of respiratory ailment.

Winkelstein et al (1967), using mortality data from Buffalo and Erie counties for the years 1959 to 1961, found a positive association between air pollution, as indexed by suspended particulate, and chronic respiratory disease.

A number of acute air pollution episodes, described by Goldsmith and Friberg (1977), have demonstrated that an extreme deterioration in air quality can have a serious effect on human health. Most of these episodes occurred when stagnant polluted air was trapped over a city for several days during a temperature inversion. The numbers of deaths and hospital admissions due to respiratory complications rose dramatically during these episodes, the greatest number of cases occurring among older persons. During the worst recorded episode (in London in 1952), the total excess of deaths was between 3500 and 4000, with bronchitis, bronchopneumonia, and heart disease as the main causes of death. The only common factor revealed by autopsy was irritation of their respiratory tract (Ministry of Health; London, England, 1954). In the London episode, as in other episodes, the levels of sulfur dioxide and particulate matter were exceedingly high.

Both general air pollution studies and the effects of acute air pollution episodes suggest that bronchitis is related to air

pollution, but the parameters of a possible dose-response relationship are not well defined.

SECTION 6
ANALYSIS OF HEALTH EFFECTS

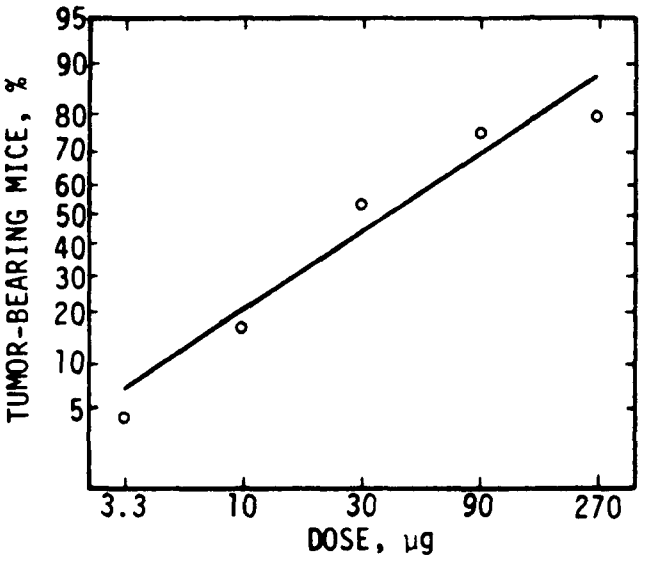
INTRODUCTION

Assessment of the health effects attributable to the array of toxic pollutants in coke oven emissions must be based on quantitative and qualitative judgments. Qualitatively, it is clear that coke oven emissions represent a serious carcinogenic risk to human beings. Extensive epidemiological evidence shows that workers exposed to relatively high levels of coke oven emissions develop cancer, especially cancer of the respiratory tract, at rates significantly higher than those reported for other workers and for the general population.

The epidemiological evidence is confirmed by equally powerful results of experimental bioassays, which show that BaP is carcinogenic in all species tested by all routes of administration (see Table A1 for examples). Further, other components of the emissions also induce cancer in test animals, and combinations of the components are even more effective in experimental induction of cancer (Hoffmann and Wynder, 1976; Laskin et al, 1970). Dose-response relations are observed in these assays. An example of the dose-response data is given in Figure 1.

Investigations of the binding of various PAH metabolites to DNA have yielded additional evidence of potential human health hazards (Gelboin, 1969; Sims et al, 1974; Huberman et al, 1976). These findings have been supplemented by positive Ames tests indicating the mutagenicity of various PAH's as noted in Table A2. This microbiological assay system is in many instances correlated with carcinogenicity.

The data describing human experience, tests with animals, and <u>in vitro</u> experiments constitute one body of evidence.



[Source: Pott et al, 1977]

Figure 1. Dose-response relationship for tumor induction in mice and BaP administered subcutaneously.

Further, it is known that the particulate size distribution associated with coke oven emissions is optimum for penetration and absorption into the human respiratory system, and that the composition of the particulate matter [hematite, (Saffiotti, et al, 1968); carbon, (Boren, 1964; and others)] optimizes such absorption. Considered together, these facts lead to the conclusion that coke oven emissions present a definite health hazard to persons exposed to industrial concentrations.

Despite the strength of the evidence, difficulties arise in attempts to quantify the level of risk and to extrapolate it to the population at large, who are exposed to much lower levels of the pollutants. Part of the difficulties are experimental, part theoretical, and a large part philosophical. The problems are addressed systematically in the following analysis.

BIOASSAY RESULTS

Although extensive experimental evidence shows that many of the components of coke oven emissions are carcinogenic, experimental carcinogenesis does not purport to establish that a given factor contributes to cancer in man. At present, such proof can be based only on epidemiological data. The laboratory studies do allow us to identify the chemical and physical nature of tumorigenic agents, to explore their biological action and to devise means of reducing their concentrations in or eliminating them from our environment.

In the past 25 years considerable progress has been made in developing organ-specific bioassay techniques, in understanding damage to host defenses against toxic agents, and in exploring the metabolic activation of environmental carcinogens (Hoffmann and Wynder, 1976). Laboratory studies support the concept that in only a few cases is a single factor responsible for an increased risk of developing a specific type of cancer and that cancer attributable to environmental factors often is induced by the combined effects of several agents (Van Duuren et al, 1969). Model studies have helped to explain the combined effects of

occupational factors, smoking, and urban pollution in induction of cancer of the lung (Hoffmann and Wynder, 1976).

Experimental data are not adequate, however, to allow determination of a safe dose for any chemical carcinogen, below which there will be no tumorigenic response in humans. Bioassays can be used to evaluate the carcinogenic potential of various environmental agents by means of observed dose-response relationships.

An abundance of in vivo and in vitro experimental evidence confirms the carcinogenicity of various PAH's and elucidates the roles of other PAH's, irritating substances, a variety of solvents, and other factors in promoting and initiating tumors and in cocarcinogenesis. These findings are discussed in Section 3 and are detailed in Table A1. It is important to note that in these studies all animal species tested developed tumors in many sites by all routes of administration.

CHARACTERIZATION DIFFICULTIES AND HEALTH EFFECTS

In addition to the widely recognized problems inherent in extrapolating among species and in applying results of experiments with animals to humans, the multiple and varied constituents of coke oven emissions further complicate the assessment of health effects.

Most investigators of the carcinogenic effects of air pollutants use BaP as an index of the level of carcinogens. Many inaccuracies are inherent in a BaP index. Sawicki (1967) notes that urban pollution from various sources is characterized by different proportions of polycyclic arenes, some carcinogenic and some not. However, some PAH's thought to be noncarcinogenic alone may, in combinations with other factors such as ultraviolet light, induce tumors. Thus, Sawicki suggests that the nature of the mixture determines its carcinogenicity for humans. This suggestion has been verified in laboratory experiments (Van Duuren et al, 1969; Laskin et al, 1970).

The problem of an accurate index need not be considered if we treat "coke oven emissions" as a whole and do not apply an exposure index, such as the concentration of BaP or the sum of the concentrations of several PAH's in extrapolating health effects. Because the extensive epidemiological evidence describes adverse health effects experienced by an industrial work force exposed to "coke oven emissions" (i.e., the total, complex mixture, often characterized as the benzene-soluble fraction of the total particulate matter), we need not delineate, for the human experience, the effects of the constituents acting separately or in various combinations with each other. IT IS, THEREFORE, ESSENTIAL THAT THE ASSESSMENT OF HEALTH EFFECTS PRESENTED HERE BE APPLIED TO "COKE OVEN EMISSIONS" AS AN ENTITY AND NOT TO ANY PARTICULAR COMPONENT, SUCH AS BaP.

Other biological evidence supports the position that coke oven emissions must be considered as a whole in evaluation of health effects. For example, the association between lung cancer and cigarette smoking confirms the interaction of various factors in a complex mixture, since the carcinogenicity of cigarette smoke cannot be explained by the identified carcinogens alone (Hoffmann and Wynder, 1976).

The similarity of the constituents of tobacco smoke and those of coke oven effluents further supports the plausibility of a dose-response relationship for coke oven emissions, since there is such a relationship for cigarette smoke (Table 9). The presence of irritants, toxicity promoters, and cocarcinogens must play an important role in the carcinogenicity of coke oven emissions as it does in cigarette smoke since, as Table 10 shows, similar agents are present in both mixtures.

The temperature of carbonization in cigarette smoking is about 860°C, whereas in coal carbonization the temperatures range from 1200° to 1400°C. As noted earlier, the proportion of toxic compounds produced by carbonization increases with an increase in temperature, and there is a corresponding increase in the incidence of disease, as shown in Table 4. The greater concentration of

Table 9. RELATIVE RISK FOR LUNG CANCER AS A FUNCTION OF DAILY TAR DOSAGE FROM CIGARETTES IN MALE SMOKERS WITH TEN YEARS OR MORE OF SMOKING[a]

Tar dosage,[b] mg	No. of cigarettes/day[c]	No. cases of lung cancer	No. controls	Relative risk[d]
Up to 340	up to 20	54	247	13.9
341 - 480	20 - 29	71	231	19.6
481 - 630	29 - 37	102	216	30.0
631 - 1000	37 - 59	159	270	37.5
1001 and up	59 and up	109	197	35.2
Nonsmokers		8	509	

[a] Source: S. Stellman, in preparation.

[b] Average daily tar intake for the past 10 years.

[c] For example, a cigarette that contains 17 mg tar.

[d] Relative risk is defined as the incidence of disease in the exposed group divided by the incidence of disease in the nonexposed group, as estimated by the odds ratio.

Table 10. PARTIAL LIST OF TUMORIGENIC AGENTS AND OTHER TOXIC COMPOUNDS IN COKE OVEN EMISSIONS AND IN CIGARETTE SMOKE

Toxic agent	Range of concentration in coke oven emissions		Concentration in smoke of one cigarette[a]
Carcinogens			
Dimethylnitroso compounds	present but not quantified		5-180 ng
N-nitroso compounds (6 compounds)	present but not quantified		2-200 ng
Hydrazine	present but not quantified		24-43 ng
Vinyl chloride	present but not quantified		10-40 ng
ß-naphthylamine	2 ng/m^3[b]		22 ng
PAH (tumor initiators)			
Benzo (a) pyrene (+++)[c]	0.21-15 µg/m^3 (coke plant)[d] 17 µg/m^3 (ambient air)[e]		10-50 ng
Benz (a) anthracene (+)	12.9 µg/m^3 (coke plant)[e] 13.1 µg/m^3 (ambient air)[e]	Carcinogenic subset identified by Schulte et al as comprising 2% of BSO fraction	40-70 ng
Benzo (b) fluoranthene (++)	5.04 µg/m^3[e]		30 ng
Benzo (j) fluoranthene (++)	1.78 µg/m^3[e]		60 ng
Benzo (e) pyrene	present but not quantified		5-40 ng
Benzo (h) fluoranthene	present but not quantified		
5-Methylchrysene (+++)	present but not quantified		0.6 ng
Dibenz (a,h) anthracene (++)	present but not quantified		40 ng
Dibenzo (a,h) pyrene (++)	present but not quantified		present but not quantified

(continued)

Table 10 (continued)

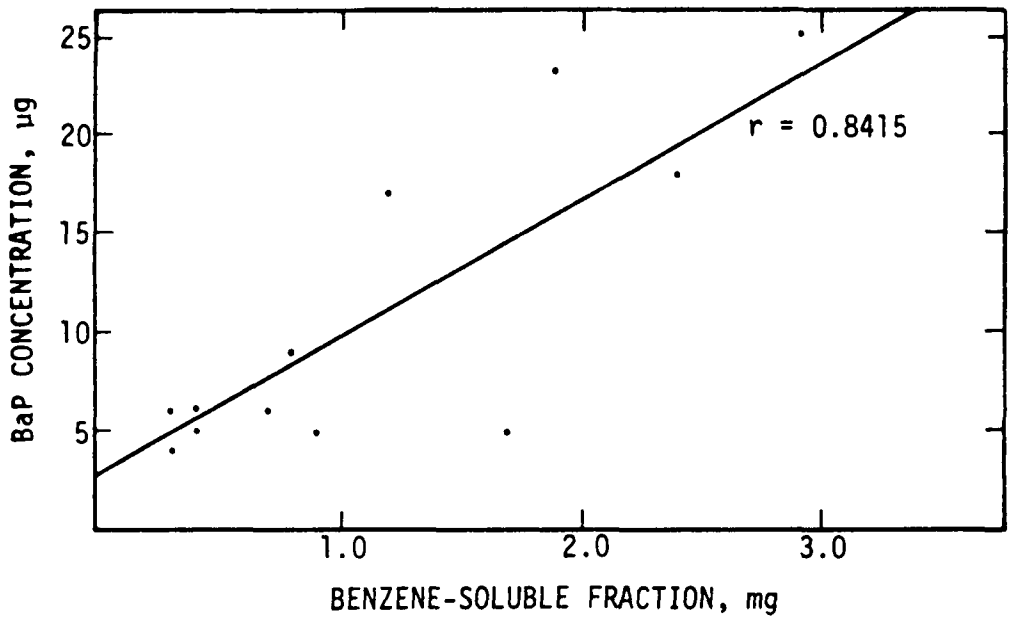
Toxic agent	Range of concentration in coke oven emissions	Concentration in smoke of one cigarette[a]
Dibenz (a,j) acridine (++)	present but not quantified	3-10 ng
Indeno (1,2,3-cd) pyrene (+)	present but not quantified	4 ng
Chrysene (+)	present but not quantified	40-60 ng
Methylchrysenes (+)	present but not quantified	18 ng
Methylfluoranthenes (+)	present but not quantified	50 ng
Tumor promoters		
Formaldehyde	0.311 mg/m^3[e]	20-90 ug
Volatile phenols	0.14 mg/m^3 (coke oven charging)[e]	150-500 ug
Cilia toxic agents		
Hydrogen cyanide	2000-4000 mg/m^3 (in coke oven gas);[e] 0.4 mg/m^3 (top-side)[e]	100-700 ug
Formaldehyde	0.311 mg/m^3[e]	20-90 ug
Acrolein	0.55 mg/m^3[e]	45-140 ug
Acetaldehyde	present but not quantified	18-1440 ug
Cocarcinogens		
Cathechol	present but not quantified	200-500 ug
1-Methylindoles	present but not quantified	1000 ng
9-Methylcarbazoles	present but not quantified	140 ng

[a] Wynder and Hoffmann, Tobacco and Tobacco Smoke, Seminars in Oncology, Vol. 3, No. 1 (March 1976).
[b] Doll (1972).
[c] Indications of carcinogenicity refer to NAS (1972).
[d] Sawicki (1976).
[e] White, L., Doctoral Dissertation (1975).

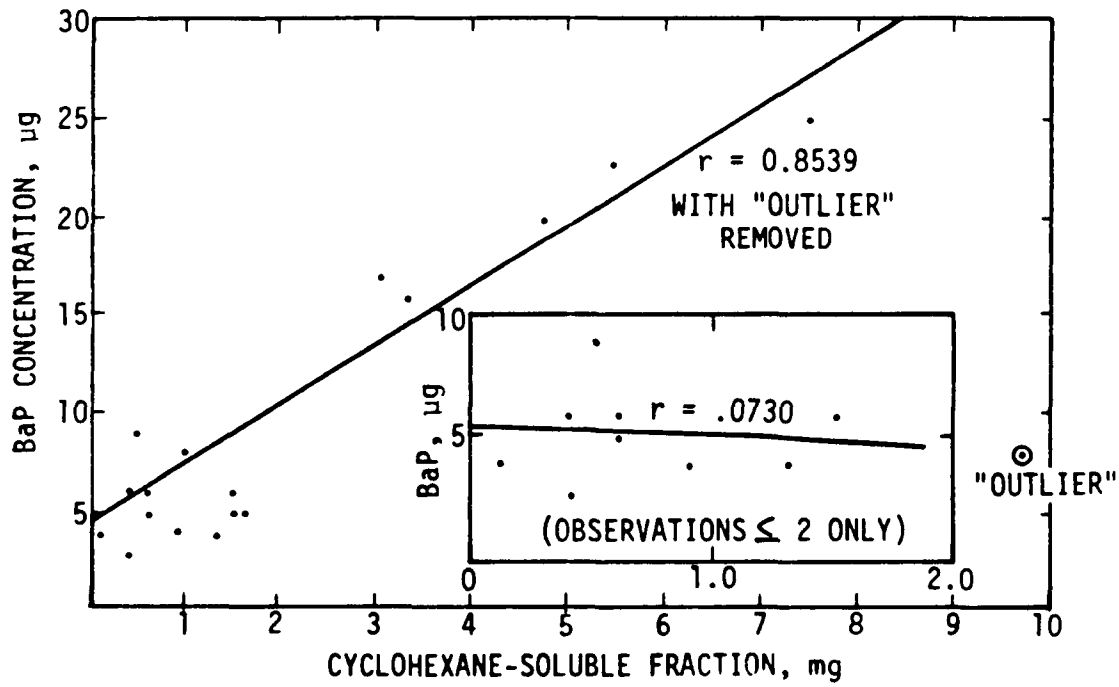
toxic substances may explain why the observed incidence of lung cancer among coke oven workers is equivalent to a risk 3 times that of a person who smokes two packs of cigarettes per day. The cancer rate among coke oven workers appears to be due not just to the carcinogens but also to irritants and particulate matter. This fact is in accord with evidence of synergism between irritants and carcinogens in animal studies (Laskin et al, 1970; Saffiotti et al, 1968; Boren, 1964) and with epidemiological evidence.

Despite the need to consider coke oven emissions as an entity, some of the discussion and the experimental results are, of course, based on exposures to BaP. This is inevitable because most scientific work relating to air pollution relies on BaP as an indicator substance, although, in fact, most environmental assays of coke oven emissions have dealt with the benzene-soluble fraction of total particulate matter (CTPV). To facilitate the interpretation of epidemiological evidence, we sometimes "translate" CTPV values into the corresponding BaP concentration units. The use of BaP units is a method of converting the available data on coke oven emissions, usually given as CTPV, into the same units given in most data on urban exposures, although the ratio of constituents varies with the source.

The conversion of CTPV data to BaP units is not a trivial or obvious procedure. As Sawicki (1967) notes, there is a "tremendous range" in concentrations of airborne particulates, benzene-soluble organics (BSO), and BaP in various urban air samples. Figure 2a shows that a good correlation between BaP and the benzene-soluble fraction of CTPV can be obtained (Smith, 1971). As shown in Figure 2b, the correlation between cyclohexane extracts and BaP is not as good, particularly at low concentrations (Smith, 1971). For purposes of this discussion, the concentration of BaP is taken as 1 percent of the total organic fraction. This approximation probably involves at most a 2-fold error and is commonly applied by others (Schulte et al, 1975).



a. BaP in benzene-soluble fraction of total particulate matter.



b. BaP in cyclohexane-soluble fraction of total particulate matter. Insert shows no correlation for concentrations lower than 2 mg cyclohexane-soluble.

Figure 2. Least-squares fits of BaP in benezene- and cyclohexane-soluble fractions of total particulate matter [Source: Smith, 1971].

The validity of extrapolation and comparison of exposure levels among various studies is limited even further by the sampling method. A 2- to 4-fold margin of error is probable in comparison of values obtained by high-volume air samples with those obtained with a personal monitoring pump, as demonstrated by Schulte et al (1975). Other sources (White, 1975) believe that the error may be even greater. Combinations of these errors, if they are acting in the same direction, may lead to as much as 4- to 8-fold overestimate or underestimate of exposure to BaP. Since, however, we are here dealing with differences of 3 to 5 orders of magnitude in exposures of the general population and occupational exposures to BaP (based on urban exposure levels due to coke oven emissions as determined by Stanford Research Institute, 1977), a 4- to 8-fold range of error can be tolerated, although it is certainly not desirable.

BASES FOR INTERPRETING MORTALITY DATA

Overall and cancer mortality rates of the general population are not readily applicable in evaluating the effects on the general population of exposure to coke oven emissions. First, if an increased rate of lung cancer among the general population results from exposure to coke oven emissions, such an increase may be masked by the very large increase in lung cancer due to cigarette smoking. Although coke oven emissions contain similar and possibly more potent carcinogenic agents, the levels of pollution from coke oven emissions in the general population, away from the plant, are very much lower than those of cigarette smoke. As Wynder and Hoffmann (1972) calculate, "heavily polluted air" contains a maximum of 100,000 particles per cubic centimeter of air as compared with 5 billion particles per cubic centimeter in tobacco smoke, a difference of 4-1/2 orders of magnitude. When the relative amounts of air breathed in are taken into account, a difference of about 2 orders of magnitude remains.

The long period of induction for lung cancer, usually 15 to 30 years, increases the difficulties of correlating urban air pollutants with lung carcinogenesis because of such factors as urban mobility and the inadequacies of both air quality data and mortality data. For these reasons, it is useful to examine the results of human high-level (occupational) exposures in estimating the health effects of exposure to coke oven emissions for the general population.

It is important to note that the overall mortality experience of coke oven workers is better than that of the general population, either urban or rural, in most epidemiological studies. This is typical of an industrial work force and has come to be called the "healthy worker effect." If a person is strong and healthy enough to be an industrial worker, that person is part of a group that on the average must be stronger and healthier than nonworkers and hence experiences a more favorable mortality rate. Therefore, because it is in direct contrast to an otherwise favorable mortality rate, the unfavorable mortality rate for specific causes of death such as all cancer, respiratory cancer, bladder cancer, kidney cancer, and bronchitis among coke oven workers as compared to others is of special interest. In general, caution must be exercised against "underinterpreting" data and incompletely evaluating the magnitude of the risk. As is shown in Table 7, as the period of observation increased, the relative risk or relative mortality also increased. Further, as noted by Mazumdar et al (1975), the current period of observation, on the average 20 years, is not long enough to allow full assessment of magnitude of risk.

With these caveats in mind, we must attempt to establish that the elevated mortality rates of coke oven workers can be attributed to their exposure to coke oven emissions. In his analysis of long-term mortality among steelworkers, Lloyd (1971) develops criteria for interpreting excessive mortality as a consequence of environmental exposures as opposed to excessive mortality that can be associated with selection for health; that

is, the criteria should differentiate between a true causative agent in a work area and the movement of people into and out of a work area because of health considerations. Lloyd states that if the excess mortality is limited to a single organ system or a single cause, then one would tend to suspect a causative factor in the workplace environment. (The converse is not necessarily true. If excess death from many causes is observed, one cannot rule out the environment as a cause.)

A second Lloyd criterion that can be useful in differentiating effects due to occupational exposures from effects associated with selection for health is that within certain work areas excessive mortality is unaffected by race, nativity, and residence.

When the Lloyd criteria are applied to the subgroup of steelworkers who are employed at the coke ovens, it is observed that, contrary to general mortality of steelworkers, the reasoning he applied implicates environmental factors as the cause of disease among coke oven workers. Since diseases of one system, the respiratory system, and one disease in particular, lung cancer, are the most prominent causes of excessive mortality among coke oven workers, the first criterion is fulfilled. The second criterion is also fulfilled, since the mortality from cancer and respiratory disease crosses bounds of race, nativity, and residence among coke oven workers. Lloyd, of course, drew the same conclusions, and he and others have been investigating the experience of workers exposed to coke oven emissions.

ESTIMATING HEALTH EFFECTS FROM OCCUPATIONAL MORTALITY DATA

In assessing the health risk of coke plant workers and its meaning for the general population, one must make several approximations and assumptions. The problem of assembling a comparison group for epidemiological investigations, especially those involving occupational exposures, is always a great one, and the long-term mortality study of steelworkers studies is no exception. As Table 8 shows, the series of reports devoted to the mortality of coke plant workers is based on the use of several different

comparison groups. In several studies the oven and nonoven workers were compared with the entire steelworker population, then steelworkers with no direct oven work experience but with nonoven work experience in the coke plant, and finally, with steelworkers with no coke plant exposure. A further difference in these studies is that some reports include all workers employed in 1953, and others include workers employed in 1951-1955 (Redmond et al, 1972). Because the studies involve different comparison groups as controls and because the basic study population is not constant, it is difficult to compare the relative risks cited in different reports of the series.

In gauging the effects of coke oven emissions on coke plant workers, it is instructive to compare the lung cancer death rate of steelworkers having no coke plant experience with that of the nonsmoking general population. In Redmond's (1976) calculation of the risk for lung cancer among coke oven workers, the population of steelworkers with no coke plant exposure served as the control population. This population has a mortality rate (127 per 100,000) greater than that of a person in the 45-54 year age bracket who smokes two packs of cigarettes per day (95 per 100,000) and comparable to that of moderate and heavy smokers in higher age brackets. In all age brackets the mortality of steelworkers from lung cancer is 15- to 100-fold greater than that of nonsmokers. Table 11 shows the age-specific mortality from lung cancer of steelworkers per 100,000 person-years of exposure and the mortality rates of cigarette smokers and nonsmokers. The data show that the excess mortality of the coke oven workers from lung cancer cannot be attributed solely to cigarette smoking.

The relative risk of lung cancer among coke oven workers can be recomputed using the nonsmoking general population as a control. This is done by drawing on statistics comparing the lung cancer death rate of two-pack-per-day smokers and of the nonsmoking general population. Such an approximation will overestimate the risk in the higher age brackets where the steelworkers mortality is less than that of a two-pack-per-day smoker, and will

Table 11. ESTIMATES OF AVERAGE ANNUAL LUNG CANCER MORTALITY RATES PER 100,000 PERSON-YEARS OF EXPOSURE FOR SELECTED U.S. SMOKING GROUPS (1954-1962) AND STEELWORKER GROUPS (1953-1961)[a]

	Age, years						
U.S. smokers	35-44		45-54		55-64		65-74
Steelworkers		<45		45-54		≥55	
Never smoked or occasional only[b]					10		30
Current cigarette smokers - total[b]	5		42		138		281
Current cigarette smokers, 1-9/day[b]					53		132
Current cigarette smokers, over 39/day[b]			95		316		606
Steelworkers		12		127		162	
Coke oven, never top-side		9		230		313	
Coke oven, top-side		141		819		1356	

[a] From National Institute for Occupational Safety and Health, 1973.

[b] Kahn (1966).

underestimate the risk in the lower age brackets, where the steelworker lung cancer mortality is greater than that of a two-pack-per-day smoker.

The conversion (Table 12) of Redmond's relative risks to relative risks taking the nonsmoking general population as a control is calculated by use of the following algorithm:

$$\text{Derived relative risk}_{\text{nonsmoker}} = \frac{\text{death rate coke oven workers}}{\text{death rate steelworkers}} \times \frac{\text{death rate 2 pack/day smokers}}{\text{death rate nonsmokers}}$$

$$\text{where} \quad \frac{\text{(the death rate 2 pack/day smokers)}}{\text{(death rate steelworkers)}} \approx$$

Since the mortality rate of steelworkers shown in Table 11 is approximately that of the two-pack-per-day smokers, a conversion factor for a comparison of steelworkers and nonsmokers is derived from data compiled by Hammond (1966), calculating age-specific mortality rates of smokers with respect to nonsmokers. This relationship, of course, is not rigorously true, but the error is certainly not inordinately great and the formula may yield an underestimate, since the steelworker mortality is greater that that of smokers, at least in the 45-54 age bracket. The mortality ratio for smokers over 40 years of age is used. This is equivalent to a relative risk for lung cancer of 16.6 for smokers relative to nonsmokers. Multiplying the data presented by Redmond et al, 1976, by this factor gives the data in Table 12.

It is clear that since mortality due to lung cancer is considerably higher in the steelworker population than in the nonsmoking general population, use of the steelworker population as a standard for evaluating coke plant workers, as is done in this study, yields an underestimate of the potential effects of coke oven emissions on the general population. Although some of the elevated risk can be attributed to cigarette smoking, this does not affect the argument because, whatever its cause, the mortality rate still exceeds that of the nonsmoking general

Table 12. RELATIVE RISKS FOR LUNG CANCER AMONG COKE PLANT WORKERS BASED ON COMPARISON WITH STEELWORKERS AND WITH NONSMOKING GENERAL POPULATION[a]

	Relative risks[b]	
	Steelworker comparison	Derived nonsmoker nonsteelworker comparison
Coke plant workers	1.93	32.0
Coke oven workers	3.19	53.0
Nonoven workers	0.95	15.8

[a] Data from Redmond (1976); Redmond, Strobino, Cypess (1976); Hammond (1966).

[b] Relative risks shown in the right-hand column were derived from relative risks given in Redmond, Strobino, and Cypess (1976), and from established data for two-pack-per-day smokers in comparison with the lung cancer death rate for the nonsmoking general population using the following algorithm:

$$\text{Derived relative risk nonsmoker} = \frac{\text{death rate coke plant workers}}{\text{death rate steelworkers}} \times \frac{\text{death rate 2 pack/day smoker}}{\text{death rate nonsmokers}}$$

where $\frac{\text{death rate 2 pack/day smoker}}{\text{death rate nonsmokers}} = 16.6$ (from Hammond, 1966)

and where death rate steelworkers $\cong$ death rate 2 pack/day smoker (NIOSH, 1973).

Thus, the values in the right-hand column were obtained by multiplying the values in the middle column by 16.6.

population. When the elevated mortality rate of steelworkers is taken into account, the relative risks for nonoven workers and all coke plant workers for death from lung cancer grow to 15.8 and 32.0, respectively. Of course, some of the excess cancer observed among the coke oven workers is also attributable to smoking, and thus the mortality risks shown in the table cannot be attributed solely to exposure to coke oven emissions. However, cigarette smoking cannot solely account for observed elevated cancer incidence, expecially since no documented evidence is available that indicates that coke oven workers smoke to any greater extent than the steelworkers in the control population. Thus the true value of the relative risk for lung cancer must lie between the values presented here, which are as high as a 53-fold relative risk, and those in Redmond et al (1976), which are at least a 16-fold relative risk.

ESTIMATING EXPOSURE

Once revised mortality estimates are calculated it is, of course, essential to estimate corresponding exposures to etiological agents, in this case coke oven emissions. One approach was applied to the gas production workers studied by Doll (1952, 1965, 1972) and was carried out by Pike et al (1975).

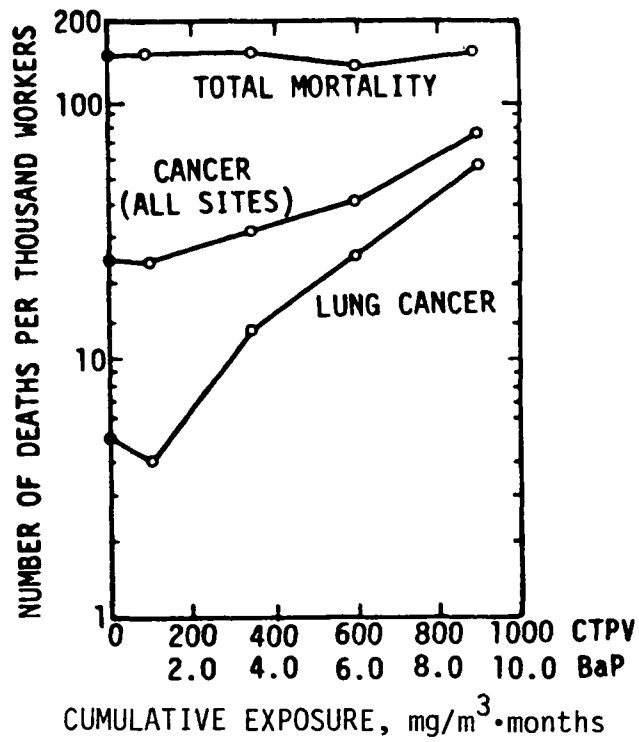
> "The carbonization workers were exposed to an estimated 2000 ng/m^3 BaP for about 22 percent of the year (assuming a 40 hour working week, 2 weeks paid leave, 1 week sick leave); very roughly, the men were exposed to the equivalent of 440 (2000 x 0.22) ng/m^3 BaP general air pollution. This exposure caused an extra $160/10^5$ lung cancer cases, so that we may estimate, assuming a proportional effect, that each ng/m^3 BaP causes $0.4/10^5$ ($160/10^5 \div 440$) extra lung cancer cases per year. A city with 50 ng/m^3 BaP air pollution might therefore have an extra $18/10^5$ lung cancer cases per year. These numbers are not negligible, although they are small when compared, say, to smoking a pack of cigarettes every day.
>
> This estimate of a small, but not negligible, general air pollution effect on lung cancer agrees with most other epidemiologic evidence on the subject."

Another approach can be derived from studies of steelworkers by Lloyd, Redmond, and their colleagues, who observed a dose-response relationship among the cohort of coke oven workers. (Table 7 summarizes some of the findings.) In an evaluation of the cumulative exposure to CTPV's in the cohorts of these studies, Mazumdar et al (1975) derived exposure histories from occupational records and air quality measurements conducted by the Pennsylvania Department of Health and thus quantified the dose. The results obtained for nonwhite coke oven workers are taken from Mazumdar and are presented in Figure 3.

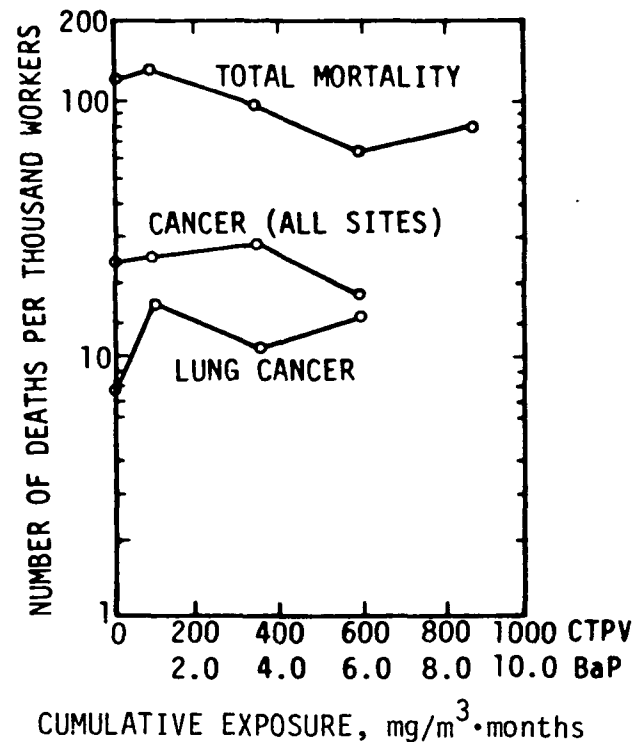
The cumulative exposures were calculated from an algorithm combining length of time spent in various jobs with average levels of CTPV's. The death rate was calculated by the direct method of age adjustment using the nonwhite coke oven workers as a control population. The second value on the x-axis represents an estimate of the equivalent of BaP exposure of the cohort calculated for the purposes of this study and is not part of the original publication. The BaP values are taken as 1 percent of the CTPV's, which gives an estimate well within an order of magnitude of error.

It is interesting to contrast the results in Figure 3a with those in Figure 3b, the plot of cumulative exposure versus death rate for the white coke oven workers, in which a dose response relationship was not originally apparent. According to Mazumdar et al the failure to observe such a relationship "may be due to the small numbers of white workers in the high exposure categories." In neither case, however, can one carry out a simple extrapolation from the death rate in the figure to the death rate of the general population because of the constraints of the age-adjustment method used, in which the nonwhite coke oven worker population served as the control.

It is possible to carry out a very approximate extrapolation of the death rate observed in the coke oven worker population to the death rate expected for the general population. The statistics for nonwhite workers are used here because it is among the



a. Nonwhite workers, age-adjusted, 1951-1966.



b. White workers, age-adjusted, 1951-1966.

Figure 3. Dose-response data for cumulative exposure to CTPV's, nonwhite and white coke oven workers. [CTPV values from Mazumdar et al, 1975. BaP values = 1% CTPV per Schulte et al, 1975.]

nonwhites that the dose-response relationship was observed. The age stratum 45 to 54 years at time of entry into the study is selected because men in the age range of 45 to 70 would be the most likely to be developing cancer and other diseases over the course of this study. An expected death rate is derived from the U.S. Vital Statistics, using 1960 data on age-specific, cause-specific rates for deaths of nonwhite males from all causes, all malignant neoplasms (140-205), and all respiratory cancer (160-164). The rates for ages 45 to 54 and 55 to 64 are each applied to the number of workers at risk in each exposure category, as calculated by Mazumdar et al (1975). The resulting expected numbers of deaths are averaged as follows:

$$\text{No. of expected deaths} = \frac{(\text{rate factor} \times \text{number at risk 45-54 years}) + (\text{rate factor} \times \text{number at risk 55-64 years})}{2}$$

The rate factor is the annual rate multiplied by 14.5, which is an approximation of the number of years of observation, which ranged from 13 to 16 years, depending on when the worker entered the study. The factor is divided by 1000 to allow comparison with the Mazumdar rate, which is given as deaths per thousand. No corrections are made for adjusting the number at risk to take into account those who had already died, which results in only a very small underestimate of the true number. The results of this calculation, given in Table 13, represent the range of observed and expected deaths for each of the exposure categories. Figure 4 also compares observed and expected deaths.

It should again be noted that as in other calculations, overall mortality of the coke oven workers is more favorable than that of the general population, and respiratory cancers again account for a relatively large proportion of the total cancer mortality. Although the ratio of observed/expected overall mortality in this calculation is highly approximate, it can serve as the basis of a crude measure of the estimated increase in

Table 13. ESTIMATED CUMULATIVE EXPOSURE TO BaP AND CTPV AND CORRESPONDING OBSERVED MORTALITY[a]

	Cumulative exposure $\left(\frac{mg/m^3 \cdot months\ CTPV \times 10^{-2}}{ng/m^3 \cdot month\ BaP}\right)$[b]				
	<1.99	2.00-4.99	5.00-6.99	7.00+	Total nonwhite oven workers
Nonwhite coke oven workers					
Number at risk, age 45-64	54	151	108	155	468
Overall mortality					
Number of deaths observed	14	48	30	45	137
Death rate/1000	259.2	317.9	277.8	290.3	292.7
Estimated expected deaths[c]	18.4	51.5	36.9	52.9	159.6
Observed/estimated expected	0.761	0.932	0.813	0.851	0.858
Cancer, all sites					
Number of deaths observed	3	11	10	19	43
Death rate/1000	55.6	72.9	92.6	122.6	91.9
Estimated expected deaths[c]	3.07	8.57	6.13	8.80	26.6
Observed/estimated expected	0.977	1.28	1.63	2.16	1.62
Lung cancer					
Number of deaths observed	1	3	5	8	17
Death rate/1000	18.5	19.9	46.3	51.6	36.3
Estimated expected deaths[c]	0.497	1.39	0.993	1.43	4.30
Observed/estimated expected	2.01	2.16	5.03	5.59	3.95

[a] Age-adjusted, age-specific death rates for overall mortality, cancer of all sites, and lung cancer, based on mortality observed from 1951-1966 for nonwhite coke plant workers, by estimated cumulative exposure to BaP and CTPV, and age of entry into study. Expected rates are derived from average of U.S. age-specific mortality by cause for nonwhite males aged 45-54 and 55-64 with approximated average of exposure time of 14.5 years. Adapted from Mazumdar (1975).

[b] Derived from mg/m^3 of coal tar pitch volatiles.

[c] Estimated from average cause and age-specific U.S. mortality rate, 1960, for age brackets 45-54, 55-64 over estimated average exposure of 14.5 years.

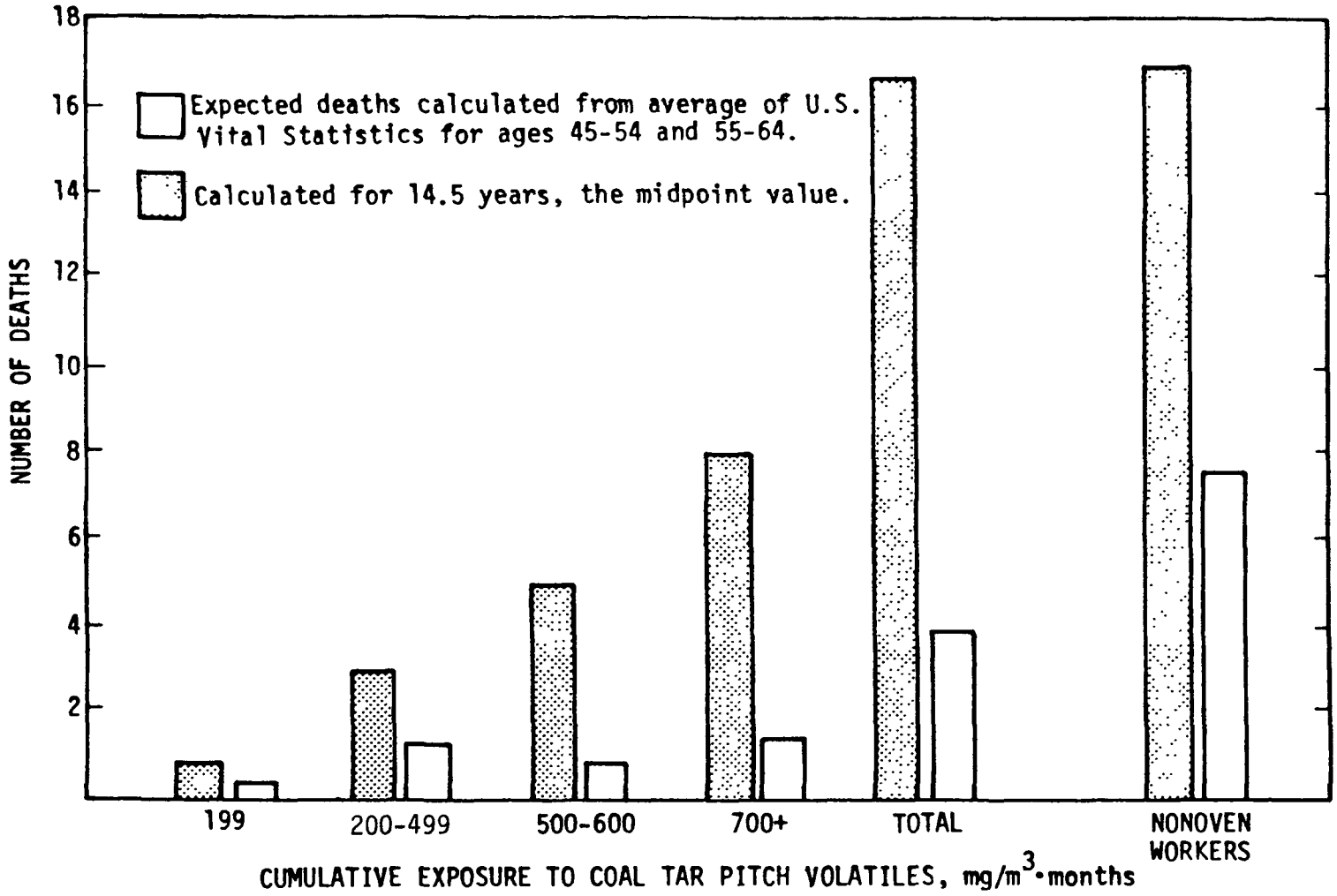


Figure 4. Observed versus expected deaths from lung cancer among coke plant workers as a function of cumulative exposures, 1951-1966.

mortality rate of the general population if they were exposed to lifetime dosages similar to those of coke oven workers.

Each of the columns in Table 13 represents a cumulative exposure in $mg/m^3 \cdot$months for members of the work force, as calculated by Mazumdar. For estimation purposes we can calculate equivalent exposures for the general population. By setting arbitrary durations of exposure, say 60 months, the ambient levels needed to achieve a particular cumulative exposure are obtained simply by dividing the exposure by the duration. In this way one can determine the ambient concentration that, over a period of time (e.g., 5 years, 60 months), would give a total exposure equivalent to that experienced by the various segments of the cohort in the Mazumdar study.

$$\frac{\text{Lifetime cumulative exposure}}{\text{Hypothesized duration}} = \text{Ambient concentration level}$$

For example:

$$\frac{mg/m^3 \cdot \text{months}}{\text{months}} = mg/m^3$$

(The CTPV values are converted to BaP concentrations by multiplying by 1 percent, as previously.)

Performing this calculation for the time periods of 5 years (60 months) to 50 years (600 months) yields the levels given in Table 14. These levels range from a low of 3.32 $\mu g/m^3$ BaP to a high of 116.7 $\mu g/m^3$. Each column represents the concentration necessary for the given time period in the left hand column to yield lifetime dose equivalent to that experienced by coke oven workers. These equivalent exposure values can be compared with the exposures of the general population to BaP and coke oven emissions when assessing the risk to the general population.

Although it is difficult to extrapolate an exact expected rate, the following should be kept in mind. First, the cancer rates observed in the studies discussed here represent the minimum increase in rate because the period of observation has been only 14 to 16 years and Mazumdar's "...data indicate that the

Table 14. ESTIMATION OF EQUIVALENT LIFETIME DOSE FOR THE GENERAL POPULATION[a]

Lifetime exposure, (μg BaP-months) m^3 x 10	μg BaP/m^3 x 10^3·months			
	≤1.99	2.00-4.99 (calc. as 3)	5.00-6.99 (calc. as 6)	7.10
Duration, months	Calculated concentration leading to lifetime dose, μg/m^3			
60	33.2	58.3	100	116.7
120	16.6	29.2	50	58.3
180	11.1	19.4	33.3	38.9
240	8.29	14.6	25.0	29.2
300	6.63	11.7	20.0	23.3
360	5.53	9.72	16.7	19.4
420	4.74	8.33	14.3	16.6
480	4.15	7.29	12.5	14.6
540	3.69	6.48	11.1	13.0
600	3.32	5.83	10	11.7

[a] Values calculated represent the ambient air levels required to achieve the lifetime dose listed for the hypothetical time periods shown in the first column.

time between first exposure to coal tar pitch volatiles and death from lung cancer varies from 10 to 40 years, with an average of 25 years." Second, the exposure values are inaccurate because of the sampling and analysis problems discussed earlier. If the combination of insufficient observation time and sampling error together act toward underestimation, the actual increased risk of the exposed population may be much greater than the calculations show.

Comparison of the ambient data calculated by the Stanford Research Institute (SRI) with the calculated ambient data in Table 14 shows that a value of 2 ng/m^3 BaP, a median concentration given by SRI, which is within about 3 orders of magnitude of the lowest level in Table 14, results in at least a doubling of the lung cancer rate. For reasons stated earlier, this rate is assuredly an underestimate.

NONMALIGNANT RESPIRATORY DISEASE

Several mortality studies have shown that workers at coke plants are at an increased risk of dying from chronic bronchitis. Unlike the risks from respiratory malignancy, the risk appears to be about the same for coke oven workers and for nonoven workers employed at the coke plant. The data, summarized in Table 15C, show that the risk of coke plant workers is significant and is greater than 2-fold relative to the rate of mortality from chronic bronchitis in the steelworker population.

Doll (1965, 1972) has observed a similar excess mortality from chronic bronchitis among gas retort workers. In these studies the risk again extended to men with heavy and light exposures to the effluent from the retorts. These data, tabulated in Table 15B, indicate the same magnitude of risk as that observed in the studies of Lloyd, Redmond, and their colleagues.

Mortality rates for nonmalignant respiratory disease constitute an incomplete assessment of any potential correlation between occupational exposure to coke oven emissions and chronic bronchitis and emphysema. This is so because, unlike lung cancer,

Table 15. OBSERVED BRONCHITIS MORTALITY

A. Standardized annual death rate per 1000 men for bronchitis; all gas boards grouped together and England and Wales, 1953-61.[a]

Occupational class					All classes	England and Wales
A	B	C_1	C_2	C		
2.89	1.34	1.94	1.19	1.28	1.62	1.36

Class A = heavy exposure in carbonizing plants; Class B = intermittent exposure to conditions in other gas-producing plants; Class C_1 = exposure only to by-products, i.e., process and maintenance workers in chemical and by-products plant. Class C_2 = minimal or no exposure, i.e., all other employees; Class C = $C_1 + C_2$.

B. Numbers of deaths from bronchitis in each occupational class and numbers expected from the experience of all gasworkers, allowing for age and employing board.[a]

Occupational class						Probability of trend arising due to chance
A		B		C		
Observed	Expected	Observed	Expected	Observed	Expected	
49	28.54	40	47.33	52	65.13	<0.001

C. Observed deaths and relative risks of death from nonmalignant respiratory diseases, 1953-1970, for coke plant workers by work area and length of employment through 1953.[b]

Work area	Years employed through 1953					
	5+		10+		15+	
	Obs.	RR	Obs.	RR	Obs.	RR
Total coke plant	34	1.47[c]	31	1.82[d]	25	2.01[d]
Coke oven	20	1.47	17	1.92[c]	12	2.20[c]
Nonoven	14	1.45	14	1.75	13	2.07[c]
No one coke plant area	0	e	0	e	0	e

[a] Adapted from Doll (1965).

[b] From Redmond (1976).

[c] $p < .05$.

[d] $p < .01$.

[e] Less than 5 deaths.

from which mortality is extremely high, other chronic lung disease is not necessarily fatal. A better measure of the effects of coke oven emissions in producing nonmalignant respiratory disease is a combination of increased incidence of both morbidity and mortality. An increase in incidence of both morbidity and mortality has been observed in several investigations of the chronic bronchitis rate of coke plant workers.

Adequate morbidity data for nonmalignant respiratory disease are difficult to obtain. Whereas lung cancer has been readily diagnosed for at least the last 30 years, some cases of chronic bronchitis very probably remain undiagnosed (Ferris, 1973). Also, chronic bronchitis is not a reportable disease. For this reason, observations of bronchitis and other nonmalignant respiratory disease therefore usually entail monitoring and medical surveys of working populations, from which retirees are most often excluded.

In light of the combination of the relatively low rate of fatality from nonmalignant respiratory disease, the competitive risk from other diseases associated with coke oven exposure, and the difficulties of estimating incidence, the true incidence of such nonmalignant respiratory disease must be greater than the sum of the morbidity and mortality data presented here. Coke plant workers are both healthier than the general population and younger than the population at greatest risk for chronic bronchitis, among whom are the elderly. The very young are also highly susceptible to bronchitis. The increased mortality among coke plant workers from this disease therefore indicates that coke oven emissions pose a powerful hazard to the respiratory systems of exposed workers.

MORBIDITY STATISTICS

A consideration in assessment of risk for bronchitis among coke plant workers is that these workers have been "selected" for tolerance to sulfur dioxide mixed with particulates, both constituents of coke oven emissions. It has been estimated that 10

to 20 percent of healthy young adults show susceptibility to industrial levels of SO_2 (Burton et al, 1969) and are unable to work at jobs involving exposure. This means that the workers who are included in epidemiological studies are those who can tolerate industrial levels of SO_2 and can be considered to be less sensitive to, or able to adapt to, these levels, as noted by Amdur (1969). If this relatively "SO_2 resistant" portion of the work force is showing an increased rate of bronchitis, it is prudent to assume that lower levels will produce similar effects on the general population, which includes those who are at elevated risk for bronchitis by virtue of age, preexisting conditions, or other factors.

Mittman et al (1974) in a survey of the incidence of chronic bronchitis among 246 coke plant workers, found that 33 percent of the workers complained of symptoms and 17 percent were classified as having varying degrees of chronic bronchitis, defined by standard criteria for sputum production and dyspnea. The authors conclude that consumption of cigarettes by the entire group was related to the severity of symptoms, and they emphasize the need for more data on the influence of smoking and on genetic susceptibility as factors in occupational disease. Despite the authors' emphasis on genetics and smoking, careful examination of their data reveals that exposure to coke oven emissions (that is, the index of job exposure) is the most significant correlate for the occurrence of pulmonary disease.

The analysis of Mittman et al is summarized in Table 16. Three groups of workers were tested for symptoms of chronic bronchitis and smoking, work exposure history, and genetic susceptibility (as determined by serum trypsin inhibitory characteristics [STIC] and Pi phenotypes). Simple correlation coefficients were calculated. The worker groups were (1) all 246 coke oven workers in the study; (2) 81 men with symptoms and 20 men chosen at random; and (3) 42 men with diagnosed chronic bronchitis. Even though the authors' conclusion that the incidence of chronic

Table 16. CORRELATIONS FOR CHRONIC BRONCHITIS AMONG COKE OVEN WORKERS[a]

	Group I overall group (246 coke oven workers)			Group II 81 men with symptoms 20 men chosen at random			Group III 42 men with diagnosed chronic bronchitis		
	r	r^2[b]	p	r	r^2[b]	p	r	r^2[b]	p
Smoking history									
Total cigarettes (Pack years)	0.28	7.8	0.01	0.2	4.0	BS	0.07	0.5	NS
Family history									
(o=none, 1=yes)	0.28	7.8	0.01	0.3	9.0	0.01	0.18	3.2	NS
Work experience									
Duration (yr on oven)	0.09	0.08	NS	0.19	3.6	0.05	0.52	27	0.01
Type of job (index)	-0.05	-0.3	NS	-0.02	-4	NS	0.02	4	NS
Duration X index of oven jobs				0.19	3.6	BS	0.52	27	0.01
Duration X index of all jobs				0.21	4.4	0.05	0.49	24	0.01
Antitrypsin studies									
STIC[c] (units)	0.1	0.1	NS	0.05	2.5	NS	0.20	4.0	NS
Pi phenotypes	0.02	0.04	NS	0.04	0.4	NS	-0.15	2.3	NS

[a] Taken and adapted from Mittman, C., Pedersen, E., Barbels, T., and Lewis, H. Prediction and Potential Prevention of Industrial Bronchitis: An Epidemiologic Study of a Group of Coke Oven Workers. Amer. J. of Med. 57:192-199, (1974).

[b] Percentage of cases explained.

[c] Serum trypsin inhibitory characteristics.

NS = Not significant. BS = Barely significant (probability of change significance just exceeds 5%).

bronchitis of the entire group tested is not significantly correlated to job exposure is valid, it is important that the calculated index of total job exposure was the only statistically significant measure among the third group tested, those with chronic bronchitis. Furthermore, the index for total job exposure is the correlate that explains the largest percentage of variability shown in the study; about 25 percent of the bronchitis was explained by total job exposure. It should also be noted that in this group cigarette smoking was not a statistically significant variable, accounting for only about 0.5 percent of the disease.

Among the second group of workers cigarette smoking and work experience were of comparable statistical significance and explained the same small percentage of variability in the data.

The apparent inconsistency of the results may stem from the inclusion in the overall group of many workers with only a few years of heavy exposure to substances that cause chronic bronchitis. This would dilute the incidence of disease and decrease the possiblity of observing an effect of working conditions on pulmonary disease. This effect of duration of exposure is consistent with the results of other studies. The reports of Lloyd and others (Table 15) indicated that chronic bronchitis mortality increased by 33 percent after 10 years of additional follow-up and also reached statistical significance. Unfortunately, because Mittman et al (1974) do not present data on the distribution of workers according to exposure or to years of work, this hypothesis cannot be independently confirmed or denied.

Walker et al (1971), in a study of bronchitis among British coke plant workers, observed that of 112 men who had worked for 1 year or more in the vicinity of the oven, 18.8 percent (26) had bronchitis, defined by productive phlegm, as compared with 11.3 percent (27 out of 212) of the other coke plant workers. The authors found a strong correlation between prevalence of bronchitis and cigarette smoking, and they suggest that smoking, a combination of smoking and exposure to coke oven emissions, and

previous employment in dusty industry (e.g., coal mining) all have an important effect on the incidence of bronchitis. "Oven-men" in this study were defined as workers who had spent 1 year or more in the environment of the coke ovens. The effect of long-term exposure to coke oven emissions on the incidence of bronchitis is difficult to determine because the study gives no data on the length of exposures of the oven men and nonoven men.

The work of Lloyd, Redmond, Doll, and others indicates that both oven workers and nonoven workers are at risk for nonmalignant respiratory disease. It may be that those suffering the greatest risk are cigarette smokers. However, when the data presented by Walker are examined for the incidence of chronic bronchitis among nonsmokers, ex-smokers, pipe smokers, and light smokers (1 to 10 cigarettes per day), analysis shows that this mixed group having less exposure to cigarette smoke also experiences a significant incidence of chronic bronchitis, about 13.7 percent, as shown in Table 17. The table also shows the observed relationship between age and bronchitis incidence. The incidence of bronchitis among relatively young men should be noted.

Walker et al (1971) conclude that some adverse effects apparently are due to a combination of smoking and history of earlier exposure to a dusty environment, and that inclusion of workers with only 1 year of exposure in the study population may produce an underestimate. Thus, the report can be taken as further evidence of a risk of bronchitis among workers exposed to coke oven emissions and as evidence of the complexity of interactions of such various etiologic agents as smoking, job exposure, and previous history.

Since the elevated risk in all the studies discussed here appears to be coke-plant-wide, it is not unreasonable to extrapolate the health effects for the general population from the effects observed for those in the study group with the lowest exposure to the emissions, the nonoven workers at the coke plants. This means that workers exposed to the constellation of factors that make up coke oven emissions (e.g., particulate matter,

Table 17. CHRONIC BRONCHITIS IN THE COKE INDUSTRY[a]

A. Incidence and smoking habits

	No. of men	Bronchitis	
		No.	%
Nonsmokers, ex-smokers (all workers)	242	16	6.6
Nonsmokers, ex-smokers (all workers over 25 yr old)	224	16	7.1
Light smokers (1-10 cigarettes/day)	150	40	26.7
Pipe smokers	52	5	9.6
Total	444	61	13.7

B. Incidence and age

Age, yr	15-24		25-34		35-44		45-54		55-64		All ages	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
No bronchitis	51	96.2	119	87.5	184	86.0	206	78.3	152	70.7	712	80.8
Bronchitis	2	3.8	17	12.5	30	14.0	57	21.7	63	29.3	169	19.2
Total	53	100.0	214	100.9	214	100.0	263	100.0	214	100.0	881	100.0

[a] Adapted from: Walker et al (1971).

sulfur dioxide, PAH) at levels well below those that are normally associated with "exposure" suffer a significantly increased risk of developing nonmalignant respiratory disease, an irreversible, debilitating condition. Levels of BaP measured at the periphery of coke plants have been as low as 150 ng/m^3 (Jackson et al, 1974), a value that is within one to two orders of magnitude of general population exposure levels presented by SRI.

APPENDIX A

SELECTED BIOASSAY RESULTS

Table A1. IN VIVO BIOASSAYS FOR CARCINOGENICITY OF PAH'S AND OTHER POLLUTANTS

Animal	Agent	Dose	% Tumor bearing animals	Reference
Complete carcinogenicity				
Cutaneous application				
Mice	BaP	0.001-0.5%	Dose response study	Wynder et al, 1957
	Urban pollutants 2 U.S. cities	Total org. sample 12.5%	30 - 87	Hoffmann and Wynder, 1977
		Neutral portion		
		N-1 5.25-12.0%	0	
		N-2(PAH) 0.48-0.9%	70 - 95	
		N-3 20.8-22.5%	0	
		Acidic portion 1.6-3.7%	0	
Subcutaneous injection				
Mice	BaP, MCA, DBA	0.001-1 mg	Dose response study	Bryan and Shimkin, 1943
	Urban pollutants 7 U.S. cities	Total org. sample 4 mg/month	0 - 15	Hueper et al, 1938
		Neutral portion		
		N-1 0.5 mg/month	0 - 2	
		N-2(PAH) as in 4 mg sample once a month	0 - 10	
		N-3 0.1 mg/month	0 - 18	

N-1, N-2, N-3 refer to different fractions.

(continued)

Table A1 (continued)

Animal	Agent	Dose	% Tumor bearing animals	Reference
Subcutaneous injection (continued)				
Mice	**Urban pollutants**	**Total org. sample**		Rigdon and Neal, 1971
	Texas city near petroleum plant	1965 - 68 1.0-10 mg	0 - 7	
		1969 2.5-10 mg	12 - 61	
Infant mice	MCA, DBA, DMBA	4.5 - 10 µg/g	Induction of lymphomas, lung adenomas, hepatomas	Della Porta and Terracini, 1969
	Pollutants	Total org. sample		
	New York City	10-40 mg M	28.2	Asahina et al, 1972
		F	12.5	
		Neutral fraction		
		10-40 mg M	19.1	
		F	20.8	
		N-1		
		10-40 mg M	11.9	
		F	31.8	
		N-2 (PAH)		
		10-40 mg M	22.4	
		F	40.7	
		N-3		
		10-40 mg M	22.0 - 32.7	
		F	24.4 - 35.4	
		Basic fraction		
		10-40 mg M	46.4	
		F	43.5	
		Acidic fraction		
		10-40 mg M	6.5	
		F	0	
		Insoluble portion		
		10-40 mg M	15.5	
		F	17.2	
		Solvent alone		
		M	16.1	
		F	8.6	

(continued)

Table A1 (continued)

Animal	Agent	Dose	% Tumor bearing animals	Reference
Intratracheal instillation				
Syrian	BaP (on Fe_2O_3)	Dose response study M F	0 - 60 trachea 0 - 80 bronchi tumors	Saffiotti et al, 1972
	BaP (on Fe_2O_3)	15 x 0.3 mg	7.6 lung tumors	McGandy et al, 1974
	210 P_o (on Fe_2O_3)	60 rads 12 rads	12.2 lung tumors 10.8 lung tumors	
	BaP + $210P_o$ + (on Fe_2O_3)	15 x 0.3 mg 60 rads	34.2 lung tumors	
	BaP + $210P_o$ + (on Fe_2O_3)	15 x 0.3 mg 12 rads	10.8 lung tumors	
Inhalation studies				
Rats		10 ppm SO_2 (6 hr/day) + 10 mg/m^3 BaP + 3.5 ppm SO_2 (1 hr/day)	5 rats out of 21, bronchogenic carcinoma	Laskin et al, 1970
		10 mg/m^3 BaP + 3.5 ppm (1 hr/day)	2 rats out of 21, bronchogenic carcinomas	
		10 ppm SO_2 (6 hr/day)	no tumors	

(continued)

Table A1 (continued)

Animal	Agent	Dose	% Tumor bearing animals	Reference
Incomplete carcinogenicity				
Tumor initiation				
Mice (skin) (Promoter 2.5% Croton oil)	BaP	50; 100; 200 µg	0.6; 1.2; 2.3 Tumors per mouse	Hoffmann and Wynder, 1977
	PAH fractions from urban pollutants from 80,000 m^3 air (2 U.S. cities)	11 samples containing 34 - 130 µg BaP	0.2 - 3.6 Tumors per mouse	
Tumor promotion				
Mice (skin) (Initiator 300 µg DMBA)	Urban pollutants 2 U.S. cities	Neutral portion N-1 5.25-12.0% N-3 2.8-5.2% Acidic portion 1.6-3.7% DMBA (control)	 30 - 50 30 - 80 10 - 60 7	

Table A2. IN VITRO BIOASSAYS OF EXTRACTS OF AIRBORNE PARTICULATE

Bacterial strain	Liver enzyme	Test material[a]	Relative activity[b]	Reference
Salmonella typhimurium				
TA 100	none	Air particulate extract Buffalo	1	Talcott and Wei, 1977
TA 100	S-9 (Aroclor 1254)	Air particulate extract Buffalo	9	
TA 100	none	Berkeley airduct particulate extract	8	
TA 100	S-9 (Aroclor 1254)	Berkeley airduct particulate extract	4	
TA 98	none	Buffalo air particulate extract	1	
TA 98	S-9 (Aroclor 1254)	Buffalo air particulate extract	5	
TA 98	none	Berkeley airduct particulate extract	9	
TA 98	S-9 (Aroclor 1254)	Berkeley airduct particulate extract	5	

[a] Air particulate extracts (400 µg) prepared from filters with acetone and rendered for assay as 10 mg residue/ml dimethyl sulfoxide.

[b] Relative activity based on net revertants/plate with 400 µg extract. Buffalo sample without activation rated 1 in each strain.

(continued)

Table A2 (continued)

Bacterial strain	Liver enzyme	Test material[a]	Relative activity[b]	Reference
TA 1537	none	Buffalo air particulate extract	1	
TA 1537	S-9 (Aroclor 1254)	Buffalo air particulate extract	5	
TA 1537	none	Berkeley airduct particulate extracts	6	
TA 1537	S-9 (Aroclor 1254)	Berkeley airduct particulate extracts	5	

[a] Air particulate extracts (400 µg) prepared from filters with acetone and rendered for assay as 10 mg residue/ml dimethyl sulfoxide.

[b] Relative activity based on net revertants/plate with 400 µg extract. Buffalo sample without activation rated 1 in each strain.

APPENDIX B

SOURCE AND CONCENTRATION DATA

Table B1. PAH CONCENTRATIONS IN COKE OVEN EMISSIONS

Compound	Sample No. 1[a]		Sample No. 2[b]		Sample No. 3[c]		Sample No. 4[d]	
	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample
Octahydrophenanthrene	1	31.85						
Octahydroanthracene	1a	29.89	1	8.77	1	29.98	2	70.31
Dihydrofluorene	2	30.31	2	13.62	1a	15.68	2a	18.26
Dihydrofluorene	2a	18.76					2b	23.20
Benzidene	3	106.73	2a	6.72	2	58.15	2c	20.81
Fluorene	4,4a	271.52	3	20.86	3	19.29	2d	15.37
Dihydrophenanthrene	4b,5	586.98	4	79.55	4	316.49	3	325.83
Dihydroanthracene	6	168.88	5	21.92	5	101.68	4	232.54
2-Methylfluorene	7	98.71	6	9.06	5a	8.87	5	40.28
1-Methylfluorene	8	73.46	7	24.35	6	44.01		
9-Methylfluorene	9	44.32	8	11.81	7	6.71	6	102.83
Methylfluorene	10	87.84	9	10.77			6a	10.38
Benzoquinoline	11	77.74	10	8.34	8	31.41	7	79.77
Acridine	12,12a	85.98	11	32.44	9	74.98	8	172.79
Phenanthrene	13	2,828.54	12	163.53	11	458.80	9	636.98
Anthracene	14	942.85	13	46.44	11a	305.89	9a	500.36
Fluorene carbonitrile	15	180.29	14	16.76	11b	32.55	9b	11.47
Methylphenanthrene	16	1,023.41	15	44.67	12	130.22	10	283.92
Methylanthracene	17	1,692.26	16	85.30	13	258.93	11	573.25
Ethylphenanthrene	18	1,578.60	17	58.04	14	202.97	12	197.39
Ethylanthracene	19	1,096.71	18	49.19	15	249.86	13	1,473.68
Octahydrofluoranthene and octahydro-pyrene	20	280.42	19	11.06	16	64.36	13a	44.53
Dihydrofluoranthene	21	115.07	20	73.57	17	64.87	13b	31.86
Dihydropyrene	22	575.06	21	36.65	18	52.29	14	404.25
Fluoranthene	23	5,979.74	22	269.74	19	451.95	15	1,097.82
Dihydrobenzo(a)fluorene	24	791.41	23	24.03				
Dihydrobenzo(b)fluorene and dihydrobenzo(c)fluorene	25	213.53	24	28.77	20	99.07	16	46.38
Pyrene	26	4,627.33	25	206.35	21	472.09	17	1,446.64
Benzo(a)fluorene	27	971.18	26	87.42	22	62.97	17a	37.21
Benzo(b)fluorene	28	109.45	27	16.70			17b	22.63
Benzo(c)fluorene	29	627.02	28	38.96	23	290.03	17c	98.47

(continued)

Table B1 (continued)

Compound	Sample No. 1[a]		Sample No. 2[b]		Sample No. 3[c]		Sample No. 4[d]	
	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample
Methylfluoranthene	30	1,817.37	29	124.73	24	126.03	18	101.56
Methylfluoranthene	31	390.94	30	21.87	25	179.04	18a	34.83
Methylpyrene	32	1,016.76	31	31.12	26	97.80	19	120.66
Methylpyrene	33	856.91	32	106.34	27	233.37	20	175.42
Benzo(c)phenanthrene	34	220.45	33	82.70	28	1,510.34	21	2,156.14
Benzo(ghi)fluoranthene	35	677.35	34	164.25	29	201.74	21a	151.88
Dihydrobenz(a)anthracene, dihydrochrysene and dihydrotriphenylene	36	383.03	34a	54.75	29a	101.78	22	271.38
Benz(a)anthracene	37	2,740.45	35	105.15	30	5,509.43	23	2,673.65
Chrysene and triphenylene	38	4,202.02	36	119.04				
Dihydromethylbenz(a)anthracene, dihydromethylchrysene and dihydromethyltriphenylene	39	841.67	37	93.30	30a	247.80	23a	86.35
Methylbenz(a)anthracene	40	159.33	38	22.36	31	1,015.70	24	1,669.72
Methyltriphenylene	41	463.99	39	40.81	32	371.97	25	369.10
Methylchrysene	42	1,151.61	40	107.59	33	193.68	26	448.19
Dihydromethylbenzo(k and b) fluoranthenes and dihydromethylbenzo (a and e)pyrenes	43	434.38	40a	8.63	34, 35	185.08	26a	137.26
Dimethylbenz(a)anthracene					36	174.71		
dimethyltriphenylene and					37	62.25	27	160.89
dimethylchrysene	44,44a	246.35	41	46.73	38	30.16	28	451.70
Benzo(j)fluoranthene	45	176.92	42	18.66	39	80.04	29	285.34
Benzo(k)fluoranthene and benzo(b)fluoranthene	46	3,930.34	43	155.03	40	2,170.92	30	2,556.98
Methylbenzo(k)fluoranthene and methylbenzo(b) fluoranthene	47	735.95	44	33.05	41	430.05	31	492.13
Benzo(e)pyrene	48	103.86						
Benzo(a)pyrene	48a	2,630.92	45	122.15	42	2,007.75	32	2,291.93
Perylene	49	702.12	46	22.07	43	616.85	33	698.44
Methylbenzo(a)pyrene	50	330.85	47	5.88	44	344.12	34	247.96
Dimethylbenzo(k)fluoranthene and dimethylbenzo(b) fluoranthene	51	116.74			45	73.13		
Dimethylbenzo(a)pyrene	52	82.68			46	70.18		

(continued)

Table B1 (continued)

Compound	Sample No. 1[a]		Sample No. 2[b]		Sample No. 3[c]		Sample No. 4[d]	
	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample	Peak No.	Concentration, µg/g of sample
Dibenzanthracene	53	123.66			47	84.52		
o-Phenylenepyrene	54	101.54						
Benzo(thi)perylene and anthanthrene	55	72.35						
Methyldibenzanthracene	56	89.04						
Methylbenzo(thi)perylene	57	36.79						
Coronene	58	864.55			51	833.30	35	766.58
Dibenzopyrene	59	693.21			52	587.05	36	493.27

[a] Glass fiber filter No. 1: total weight of material collected, 12.59 mg; total volume of solvent extract, 1 ml; injected sample size, 10 µl.

[b] Glass fiber filter No. 2: total weight of material collected, 39.67 mg; total volume of solvent extract, 1.0 ml; injected sample size 10 µl.

[c] Silver membrane filter No. 1: total weight of material collected, 5.75 mg; total volume of solvent extract, 0.6 ml; injected sample size, 6 µl.

[d] Silver membrane filter No. 2: total weight of material collected, 1.96 mg; total volume of solvent extract, 1.0 ml; injected sample size, 10 µl.

Source: Lao et al (1975).

Table B2. MINOR CONSTITUENTS OF COKE OVEN GAS

Substance	Concentration, mg/m^3	Country
HCN	2,000-4,000	Czechoslovakia
	1,300-3,000	USSR
	120	West Germany
NO	0.8-4.9	USSR
	22	USSR
	16-24	USSR
	3.5-4.5	USSR
Dust	1,800-36,000	West Germany
Benzo(a)pyrene	334 ave	USSR
	158-515	USSR
	190-630	USSR
Benzene	35,800	USSR
	23,900	USSR
	21,400	West Germany
Toluene	3,000	USSR
	1,520	West Germany
Xylene	500	USSR

Source: White et al.

Table B3. ESTIMATED ATMOSPHERIC EMISSIONS FROM COKE PLANTS IN POLAND AND CZECHOSLOVAKIA

Type of emission	Emissions in Poland (1966), tons	Emissions in Czechoslovakia (1968), tons
Dust	16,039	9,900
Tar	8,565	
SO_2	40,385	13,000
CO	5,457	3,030
NH_3	1,702	950
H_2S	1,794	990
HCN	166	99
NO	351	
Phenols		990
Benzene		1,660
Coke production	13 million	4 million

Source: White et al.

Table B4. COMPARISON OF SELECTED POLLUTANTS AT TOP-SIDE WORKPLACES IN THE SOVIET UNION (concentrations, mg/m^3)

Pollutant	Conventional charging	Smokeless charging
NH_3	6.3-8	3.5-4.4
CO	40-74	6-18
Cyanides	0.9-3.6	0.3-0.4
Pyridine Bases	0.17	0.02
Phenols	0.14	0.07
Benzo(a)pyrene	0.0718	0.0177

Table B5. CONTENT OF NOXIOUS POLLUTANTS IN THE WORKPLACE ENVIRONMENT OF CZECHOSLOVAKIAN COKING PLANTS (concentrations, mg/m^3)

Compound	Top-side	Side
Benzene	0.1-13.0	0.0-0.2
CO	1.0-36	0.0-0.5
HCN	0.0-0.4	0.0-0.1
SO_2	0.1-4.7	0.0-0.2

Source: White et al.

Table B6. CONCENTRATION OF PYRIDINE AND ITS HOMOLOGUES AT WORKSITES IN CZECHOSLOVAKIA ($\mu g/m^3$)

Compound	Coal coke battery	Pitch coke battery
Pyridine	155-1854	222-827
2-Methylpyridine	348-8256	2100-4157
3-Methylpyridine	73-402	110-411
4-Methylpyridine	47-289	112-337
2,5-Dimethylpyridine	47-107	114-455
2,6-Dimethylpyridine	48-903	210-572

Table B7. SELECTED VAPOR CONCENTRATIONS IN THE COKE-OVEN BATTERY ENVIRONMENT AT FIVE PLANTS IN THE UNITED STATES (mg/m^3)

Compound[50]	Mean	Maximum	OSHA TLV
Benzene	9.5	162.7	34.3
Toluene	0.6	1.38	800
Xylene	0.3	1.03	435
Naphthalene	0.7	1.31	50

Source: White et al.

Table B8. COMPARISON OF SELECTED PARTICULATE CONCENTRATIONS

Country		Concentration, mg/m^3
	Charging levels	
Czechoslovakia		1.13-113
USSR	(conventional)	173.3
	(smokeless)	15.4-38.9
USSR	(conventional)	143-851
	(smokeless)	1-57
England		374.3
USA	(catwalk)	39.1-84.2
	Top-side levels	
Czechoslovakia		8.3-17.35(13.3 ave)
Czechoslovakia		1.9-40.8
Czechoslovakia	(total particulate)	1.1-78.8 (15.2 ave)
	(respirable)	0.28-9.22 (3.34 ave)
USA		2.6-6.9
USA		0.35-84.2 (8.05 ave)
USA		26.7-64
England	(total particulate)	4.1-15.7
	(respirable)	0.6-1.7
England	(total particulate)	5.1-8.5
	(respirable)	1.7-3.7
	Battery side levels	
Czechoslovakia	(pusher)	0.4-395
	(coke car)	1-136

(continued)

Table B8 (continued)

Country		Concentration, mg/m^3
	500 meters from battery	
USSR		1.2-2.7
	Cigarette smoke	
USA		95,000
	Urban levels	
USA	1965	up to 1.254 (0.105 ave)

Source: White et al.

Table B9. COMPARISON OF BENZO(a)PYRENE CONCENTRATIONS MEASURED AT COKE OVEN BATTERIES AND AT OTHER SELECTED SITES

Country	Year	Concentration, $\mu g/m^3$	
		Top-side	Side
Soviet Union	1962	1.27-27.4	
Soviet Union	1968	0.05-7.38 (3.84)[a]	0.08-0.27 (0.17)
Japan	1968		1.5-3.14
Norway	1959	2-7.3	
Czechoslovakia	1966	1.1-94.8	
Czechoslovakia	1967	3.6-32.2	
Czechoslovakia	1968	10.7-12.7	0.6-3.4
Czechoslovakia	1974	0.1-13.1	
England	1965	3-216	
USA	1974	1.2-15.9 (6.5)	0.3-1.98 (1.0)
USA	1960	8.3-51	
USA	1974	0-225.9 (9.55)	
USA	1974	0.18-36.3 (5.78)	
			Contrast
USA	1968	95	Cigarette smoke
USA	1961	6.1	Auto exhaust
USA	1961	14-78	Roof tarring
Switzerland	1961	640	Roof tarring
USSR	1966	13.7-22	Aluminum Plant
England	1965	(0.02)	Urban - London
England	1965	2330	Maximum found in fumes emitted from coke ovens
USA	1959	(0.022)	Birmingham
USA	1966	(0.0185)	Birmingham

[a] Mean.

Source: White et al.

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