

Rubber work and cancer — Past, present and perspectives

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NUTT A. Rubber work and cancer — Past, present and perspectives. *Scand j work environ health* 9 (1983): suppl 2, 49–57. In the early years, the study of health in the rubber industry was hampered by lack of information in three fields. Epidemiology was just beginning, industrial hygiene had hardly begun, and little or no work had been done on the ways in which rubber chemicals affect the human body. The difficulties this created can clearly be seen in the problems of bladder cancer discovered in the industry in 1949. Since that time epidemiologic studies have become very detailed, more results are available on concentrations of material in factory atmospheres, and the effects of different chemicals on the body are being better understood. This review considers the historical problems of β -naphthylamine exposure, summarizes the epidemiologic results on the industry to date, and considers the potential problems posed by polycyclic aromatic hydrocarbons and nitrosamines.

Key terms: β -naphthylamine, bladder cancer, health, lung cancer, nitrosamines, polycyclic aromatic hydrocarbons, rubber industry, stomach cancer.

The investigation of health hazards in the rubber industry does not have a very long history. It really only dates back about 30 years to Prof Case's work on bladder cancer in the United Kingdom. Over this 30 years the various studies which are necessary for the investigation of health problems in the industry have expanded considerably; there is now extensive epidemiology; industrial hygiene, which was almost nonexistent at the beginning of the period, has become a detailed science; and people are beginning to understand more clearly the way in which the chemicals that are used in the industry interact with the body.

However, there is still a tendency for each of these studies to remain isolated from the others. Before the health hazards present in the industry can be removed, the available information must be applied to have a maximum effect. In other words the information from each area must be combined to obtain as complete a picture as possible of the true position. The pro-

ceedings in which the present paper is appearing presents communications from each of these disciplines and provides an opportunity for all readers to assess how work from one area may relate to that in the others.

If one looks first at the historical situation, it is easy to see how the lack of information in specific areas has caused problems. Since the study of health in the industry originated with the work on bladder cancer, this is a good place to begin.

Bladder cancer

The bladder cancer problem was discovered in the United Kingdom by Case in 1949 and has been well documented since (24, 25). Table 1 shows Case's results and the later study of the British Rubber Manufacturers' Association. The major chemical causing this problem was the antioxidant Nonox S, which was used in the industry between the late 1920s and 1949, when it was withdrawn. The initial study of the British Rubber Manufacturers' Association clearly showed that men entering the industry between 1945 and 1949 suffered an excess rate of bladder cancer

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Table 1. Bladder cancer incidence in the rubber industry of the United Kingdom.

	Observed	Expected	Standardized mortality ratio
Case's study 1936–1951 (10)			
Rubber industry nationally	26	15.9	163
Birmingham area rubber industry	22	4.0	550
Initial British Rubber Manufacturers' Association/Birmingham University study 1945–1960 (with 10-year latency) (4)			
Rubber industry nationally	18	13.0	138.7
Cohort 1 (1945–1949)	15	9.9	152.0
Cohort 2 (1950–1954)	3	3.1	96.7
Cohort 3 (1955–1959)	—	—	—

Table 2. Results of the British Rubber Manufacturers' Association/Birmingham University study – Bladder cancer by job (cohort 1) (4).

	Observed	Expected	Standardized mortality ratio
Extruder operators	5	1.0	503.2
Component builders	6	3.1	195.8
Molders	4	1.0	390.3

Table 3. Bladder cancer in the American rubber industry.

Author	Conclusion
Monson et al (22)	Deficit in one plant, small excess in two plants; the excess was greatest among those first employed before 1935 and those who had worked for more than 35 years
Checkoway et al (8)	A case-referent study of 220 bladder cancer deaths in five tire and rubber companies against 440 rubber industry referents; found that the bladder cancer cases were more likely to have worked in milling (1.9), calender operation (2.2) and final inspection (1.5)
Cole et al (11)	Case-referent study in the Boston area; 470 patients with bladder cancer against 500 referents from the general population; found 51 bladder cancer cases had worked in the rubber industry compared with 34.6 expected from the referents
Howe et al (14)	Study similar to the above; found five cases had worked in the rubber industry against one expected from the referents

Table 4. Bladder cancer in the European rubber industry.

Author	Conclusion
Bovet & Lob, Switzerland (3)	Found four cases in a rubber industry population where 1.1 was expected
Tola et al, Finland (28)	180 patients with bladder cancer compared with 180 age- and sex-matched referents; two of the patients had worked in the rubber industry against none of the referents

Table 5. β -naphthylamine content of antioxidants (Data from various chemical manufacturers).

	Total amines (ppm)	β -naphthylamine (ppm)
Nonox S	25,000	2,500
Aldol α -naphthylamine		
1937–1966	—	< 300
1966–1968	—	< 30
1968 – end of production	—	< 3–5
Phenyl β -naphthylamine		
1930–1976	—	30–50
1976 – present (some varieties)	—	< 1
Di- β -naphthyl p phenylenediamine		
1935–1975	—	100–200
1975 – present	—	20–50

Table 6. Atmospheric concentrations of β -naphthylamine (historical) (27).

	Total amines (mg/m ³)	β -naphthylamine (μ g/m ³)
By open door of Banbury mixer (150°C) containing		
1 kg smoked sheet and 1 kg of Nonox S	290	15,000
1 kg smoked sheet and 1 kg of aldol α -naphthylamine (Agerite resin)	610	Not detectable

Table 7. Atmospheric concentrations of β -naphthylamine during Nonox S production (29).

Location	Total amines (mg/m ³)
At the door of vacuum drying ovens used for production of Nonox S	10–15
Detraying and grinding of Nonox S	50

Table 8. Atmospheric concentrations of β -naphthylamine recently determined by Imperial Chemical Industries, Ltd (16).

	β -naphthylamine
Processing rubber containing 1 % phenyl β -naphthylamine (which contained approximately 30 ppm w/w of free β -naphthylamine)	
Over front roll of the sheeting mill beneath the internal mixer	Not detectable (less than 0.7 μ g/m ³)
Near the feed nip of a calender	Not detectable (less than 0.7 μ g/m ³)
Over belting as it left curing press (140°C)	Not detectable (less than 0.7 μ g/m ³)
Processing rubber containing 1 % di- β -naphthyl p phenylenediamine (which contained 50–100 ppm w/w of free β -naphthylamine)	
Over front roll of the sheeting mill beneath the internal mixer	Not detectable (less than 0.7 μ g/m ³)
Near the feed nip of a calender	Not detectable (less than 0.7 μ g/m ³)
Over belting as it left curing press (140°C)	Not detectable (less than 0.7 μ g/m ³)

(standardized mortality ratio 152.0), whereas the rate among those men entering the industry after 1950 was no greater than expected. Particular jobs were shown to be associated with an excess risk of bladder cancer, as shown in table 2.

Although most of the problems of bladder cancer occurred in the United Kingdom, some evidence of bladder cancer excess has been found in the United States, Canada, Switzerland, and Finland. Tables 3 and 4 summarize the work in these countries.

Nonox S caused bladder cancer because it contained residues of the potent bladder carcinogen β -naphthylamine. The amount of β -naphthylamine in this and other antioxidants is shown in table 5.

What is lacking from these early days is some evidence of the amounts of β -naphthylamine to which people were exposed. The only measurements recorded in rubber work in the period before 1950 were obtained at the open door of a small-scale Banbury mixer processing a masterbatch of Nonox S. These results are shown in table 6.

Some evidence of atmospheric amine concentrations is also available for the production process for Nonox S (table 7). More recently, tests have been made during rubber processing operations involving modern antioxidants containing traces of β -naphthylamine (table 8). It is instructive to speculate on the amounts of β -naphthylamine which would have been inhaled at the various concentrations present in these measurements. Although the actual concentrations of β -naphthylamine present during the use of Nonox S can now only be guessed at, some idea of the quantities which might be involved are given in table 9.

β -naphthylamine is also produced in the body by metabolic dephenylation of the antioxidant phenyl β -naphthylamine, which is still in production. The quantities which may be produced by metabolic dephenylation are shown in table 10. It should be pointed out that there is strong epidemiologic evidence that the use of phenyl β -naphthylamine in industry has not caused bladder cancer. It is likely therefore either that the quantities of phenyl β -naphthylamine taken in during practical work with this antioxidant are too small to produce significant quan-

Table 9. Quantities of β -naphthylamine inhaled.

	Micrograms/day
8-h shift, β -naphthylamine concentration 1,000 $\mu\text{g}/\text{m}^3$	10,000
8-h shift, β -naphthylamine concentration 10 $\mu\text{g}/\text{m}^3$	100
8-h shift, β -naphthylamine concentration < 0.7 $\mu\text{g}/\text{m}^3$	< 7
From cigarette smoking (heavy smoker, 40 +/day with 3-4 fold likelihood of suffering from bladder cancer) (9)	1

Table 10. Quantity of β -naphthylamine metabolized from phenyl β -naphthylamine (PBN) (17).

	Quantity of β -naphthylamine produced in urine
Single oral intake of 10 mg of PBN	10 μg
Quantity inhaled during an 8-h shift at 10 mg/m^3 PBN in air = 100 mg	100 μg ?

Table 11. Results of the latest British Rubber Manufacturers' Association study, which allowed for a 10-year latency period (26).

Site of cancer	Observed	Expected	Standardized mortality ratio
Lung	638	517.4	123
Stomach	183	141.8	129
Prostate	30	45.4	66
Thyroid	4	2.2	182
Colon	67	73.7	90
Rectum	50	54.1	92
Esophagus	40	31.8	126
Brain	35	41.1	85
Leukemia	31	28.1	110
Bladder	36	43.0	83
Others	245	242.4	101
All cancers	1,339	1,221.0	111

ties of β -naphthylamine by metabolic dephenylation or that the β -naphthylamine is produced at too late a stage for subsequent conversion to the hydroxy derivatives which are the proximate carcinogens.

Current epidemiology

Moving to more recent times, the considerable body of work in epidemiology has enabled a detailed analysis to be made of health in the industry. The two cancers which seem to be in excess in most countries which have carried out surveys are lung cancer and stomach cancer. The latest study of the British Rubber Manufacturers' Association (26) shows excesses for both these cancers (table 11), as does the

Table 12. Results of the study of the United Kingdom's Health and Safety Executive (2).

Cause of death	Observed	Expected	Standardized mortality ratio
Respiratory disease (nonmalignant)	659	711.4	93
Ischemic heart disease	1,983	2,014.6	98
Diabetes mellitus	31	37.4	83
All cancers	1,776	1,617.2	110
Cancer of the lung, trachea, or bronchus	822	716.5	115
Cancer of the stomach	216	176.4	122
Cancer of the pancreas	66	70.8	93
Cancer of the prostate	55	55.8	99
Cancer of the bladder	73	57.6	127
Cancer of the brain	21	34.8	60
Cancer of the colon	107	93.2	115
Cancer of the rectum	75	70.6	106
Cancer of the esophagus	35	44.0	80
Cancer of the lymphatic and hematopoietic tissue	77	89.9	86
Leukemia	33	33.8	98
All causes	5,773	5,912.5	98

Table 13. Observed and expected mortality found in the University of North Carolina study (20).

Cause of death	Observed	Expected	Standardized mortality ratio
Chronic respiratory disease	61	68.5	89
Ischemic heart disease	870	916	95
Arteriosclerosis	89	60.1	148
Diabetes mellitus	54	37.2	145
Cancer of the lung, trachea or bronchus	106	115	92
Cancer of the stomach	40	23.4	171
Cancer of the pancreas	18	21.9	82
Cancer of the prostate	53	37.8	140
Cancer of the bladder	10	13.3	75
Cancer of the brain or central nervous system	4	6.15	65
Cancer of the colon	42	34.4	122
Cancer of the lymphatic and hematopoietic systems	43	31.6	136
Lymphosarcoma and Hodgkin's disease	15	9.15	164
Leukemia	17	13.5	126
All causes	1,983	2,033	98

Table 14. Observed and expected cancer rates found in the University of North Carolina study (1).

Cancer site	Observed	Expected
Stomach	34	27.7
Large intestine	53	45.7
Pancreas	34	27.9
Prostate	59	45.9
Bladder	21	18.1
Lymphatic and hematopoietic	52	41.9

United Kingdom's Health and Safety Executive study (2) (table 12). No excesses for cancers of the prostate or brain or leukemia were found in either of these studies.

In the United States the University of North Carolina has carried out two studies

Table 15. Observed and expected cancer rates determined in the Harvard School of Public Health's study of the rubber industry (23).

	Observed	Expected	Standardized mortality ratio
Stomach cancer	98	93.9	104.4
Bladder cancer	48	39.5	121.5
Leukemia	55	43	127.9
All cancers	984	1,046.4	94

Table 16. Observed and expected rates of lung cancer found in a study done by the British Rubber Manufacturers' Association and the Birmingham University (26).

	Observed	Expected	Standardized mortality ratio
Cohort 1			
Tire	348	279.8	124
General rubber goods	84	46.4	181
Cohort 2			
Tire	120	114.6	105
General rubber goods	30	23.2	119
Cohort 3			
Tire	47	43.3	109
General rubber goods	9	8.2	110

(1, 20). The main results are shown in tables 13 and 14. The Harvard School of Public Health has also studied the rubber industry, and the excesses identified are shown in table 15 (23). These studies found excess incidences of stomach, prostate (University of North Carolina) and leukemia, but no excess of lung cancer. However, a more-detailed study of the University of North Carolina population did reveal some lung cancer excesses (19).

Lung cancer

Some information is available on where the lung cancer cases occur.

Table 16 shows that the position seemed to be worse in cohort 1, which entered the industry in 1925–1950, than in later years. It was also worse in the nontire side of the industry than in tire production.

Table 17 shows that the largest excesses seemed to be present in curing, inspection and finishing – all areas in which fumes may be present from hot rubber.

Table 18 shows the results of a case-referent study carried out on the lung cancer cases of the British Rubber Manufacturers'

Table 17. Observed and expected rates of lung cancer according to occupation in a study done by the British Rubber Manufacturers' Association and the Birmingham University (26).

Occupation	Tire			General rubber goods		
	Observed	Expected	Standardized mortality ratio	Observed	Expected	Standardized mortality ratio
Stores	8	6.7	119	2	1.8	111
Mixing	42	38.7	109	19	10.5	181
Latex	15	19.8	76	3	2.1	143
Extruding, calendering	45	38.7	113	17	12.5	136
Building	199	166.8	123	31	21.0	148
Curing	68	56.1	121	20	13.2	152
Inspection	23	15.3	163	11	4.1	268
Finishing	46	32.1	143	8	4.1	193
Laboring, site workers	45	33.8	133	6	5.1	118
Maintenance	92	89.0	103	21	14.3	147

Table 18. Results of the case-referent study of the British Rubber Manufacturer's Association and the Birmingham University (Unpublished case-referent study of the British Rubber Manufacturers' Association).

Contaminant	Number of referents reported as exposed to this environment ($\times 0.25$)	Number of lung cancer cases reported as exposed to this environment	Lung cancer : referents (%)
Vulcanized fume	96.8	114	118
Unvulcanized fume	139.3	133	96
Solvent	115.3	103	89
Talc	87.5	81	104
Other powder	63.3	76	120
Mineral oil	7.5	6	80
Rubber dust	10.8	4	37
No significant exposure	206.8	201	97
Other and unknown exposure	70.8	76	107

Table 19. Specific cancer occurrence according to job in the study done by the Harvard School of Public Health (22).

Cancer	Job	Observed	Expected
Lung cancer	Tire curing	31	14.1
	Tire molds	10	5.0
	Fuel cells/deicers	46	28.8
Bladder cancer	Tire building	16	10.7
Skin cancer	Tire building	12	1.9
Brain cancer	Tire building	8	2.0
Lymphatic cancer	Tire building	8	3.2
Leukemia	Calendering	8	2.2
	Tire curing	8	2.6
	Tire building	12	7.5

Association. Again the vulcanized fume area produced an excess population, as judged by the reference group.

In the United States evidence of lung

cancer excess is not so strong, but certain jobs were identified as producing excesses in the Harvard study (table 19). Again, tire curing made an appearance (23).

Stomach cancer

The figures of the British Rubber Manufacturers' Association showed that the

Table 20. Observed and expected rates of stomach cancer determined in a study done by the British Rubber Manufacturers' Association and the Birmingham University (26).

	Observed	Expected	Standardized mortality ratio
Cohort 1			
Tire	96	78	123
General rubber goods	22	13.3	165
Cohort 2			
Tire	33	30.5	108
General rubber goods	8	6.7	119
Cohort 3			
Tire	22	11.2	196
General rubber goods	2	2.1	95

stomach cancer problem continues to more recent years than lung cancer (table 20). Analysis by job location showed a rather general spread of excess, the largest figures occurring in the stores and mixing areas, where atmospheric contamination due to dust is a problem (table 21).

These results are in agreement with the study of the University of North Carolina, in which compounding and mixing was identified with the stomach cancer excess (table 22), and with the Harvard results, in which the "front processing" area correlated with the stomach cancer excess (table 23) (12).

These epidemiologic studies therefore show small but positive excesses of lung and stomach cancer as the major findings. They also point to the lung cancer being

Table 21. Observed and expected rates of stomach cancer according to occupation in a study done by the British Rubber Manufacturers' Association and the Birmingham University (26).

Occupation	Tire			General rubber goods		
	Observed	Expected	Standardized mortality ratio	Observed	Expected	Standardized mortality ratio
Stores	4	1.8	222	1	0.5	200
Mixing	17	10.3	165	4	2.8	143
Latex	4	5.4	74	0	0.6	—
Extruding, calendering	15	10.4	144	5	3.4	147
Building	52	43.6	119	9	5.7	158
Curing	18	14.7	122	2	5.7	158
Inspection	7	3.9	179	2	1.2	167
Finishing	4	9.0	44	2	1.2	167
Laboring, site workers	24	10.6	226	2	1.7	118
Maintenance	20	24.2	83	6	3.9	154

Table 22. Specific cancer occurrence according to job in the case-referent study done by the University of North Carolina (21).

Disease	Job	Number of cases	Risk ratio
Stomach cancer	Compounding and mixing	5	2.0
	Extruding, tread cementing	5	2.3
Colorectal cancer	Extruding, tread cementing	7	2.2
	Maintenance	5	1.8
Respiratory cancer	Receiving and shipping	11	1.9
	Compounding and mixing	12	1.4
	Mill mixing	5	2.1
	Extruding, tread cementing	8	1.4
	Reclaim	10	2.3
Prostate cancer	Compounding and mixing	6	1.6
	Calendering	9	2.4
	Janitorial and trucking	16	3.5
Lymphatic and hemotopoietic cancers	Compounding and mixing	5	1.4
	Inspection and finishing	6	2.0
	Synthetic plant	6	6.2

associated with hot rubber fumes, and the stomach cancer with compounding and mixing.

There are no clear associations between these cancers and specific chemicals, but certain chemical species have come under suspicion as potential causes of the cancers. The final part of this paper examines two of these areas.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons are present in the aromatic oils and carbon black which the rubber industry uses. There is a significant concentration of carcinogenic polycyclic aromatic hydrocarbons in the aromatic oils, as shown by the results in table 24.

When these oils were repeatedly painted onto mouse skin in one series of tests, 96 % of the mice developed a skin cancer, under conditions under which less than 4 % would have done so with a solvent-refined mineral oil (personal communication from the Institute of Petroleum to the British Rubber Manufacturers' Association).

Atmosphere tests in areas of hot rubber fumes have, however, failed to find significant concentrations of the carcinogenic polycyclic aromatic hydrocarbons (table 25).

Some idea of the amounts of benzo(a)-

Table 23. Occurrence of specific types of cancer according to type of processing in the study of the Harvard School of Public Health (12).

Site	Observed	Expected
<i>Front processing</i>		
All digestive cancer	51	54.0
Stomach	15	7.1
Large intestine	19	11.2
<i>Back processing</i>		
Biliary and liver cancer	9	5.0
Leukemia	14	5.8

Table 24. Polycyclic aromatic hydrocarbons (PAH) in aromatic mineral oil as determined by the British Rubber Manufacturers' Association and the Institute of Petroleum (5).

	Aromatic oil A	Aromatic oil B	Aromatic oil C
Total PAH (% of weight by the dimethyl sulfoxide extraction method)	25.9 (ppm)	32.7 (ppm)	18.2 (ppm)
Fluoranthene	11.0	0.6	1.4
Pyrene	25.6	6.4	6.9
Benzo(a)fluorene	0.9	Not detectable	0.7
Benzo(a)anthracene	34.2	9.4	5.8
Chrysene	395.3	195	63.4
Benzo(b)fluoranthene	72.9	43.2	11.7
Benzo(e)pyrene	113.2	97.9	27.7
Benzo(a)pyrene	13.4	11.5	4.0
Dibenz(a,j)anthracene	4.6	5.6	2.8
Dibenz(a,h)anthracene	5.7	3.5	1.4
Indeno(123-cd)pyrene	6.2	1.7	1.4
Benzo(ghi)perylene	17.9	21.1	15.3
Anthanthrene	6.6	9.8	12.3
Total	707.5 0.707%	403.7 0.404%	154.8 0.155%

Table 25. Polycyclic aromatic hydrocarbons (PAH) in rubber factory atmospheres as determined by the British Rubber Manufacturers' Association and the Institute of Petroleum (5).

PAH	Carcinogenicity ^a	Concentration of PAH (ng/m ³)					
		Outside air		Tire curing (November 79– March 80)	Tube curing (March 80– April 80)	Tread extrusion (July 80)	Calendering (September 80)
		January 80	March 81				
Fluoranthene	–	5	6	9–67	12–139	5–37	2–30
Pyrene	–	3	3	10–119	36–248	12–79	5–66
Benzo(a)fluorene	–	2	1	6–16	2–6	2–9	< 1–7
Benzo(a)anthracene	+	3	11	2–9	1–10	1–20	< 1–13
Chrysene	±	5	11	8–25	3–36	5–17	1–27
Benzo(b)fluoranthene	+	4	13	6–8	3–10	1–6	1–4
Benzo(e)pyrene	++	2	6	4–5	2–5	1–4	< 1–3
Benzo(a)pyrene	+++	2	7	3–5	2–5	< 1–4	< 1–2
Dibenz(a,j)anthracene	+	< 1	2	< 1–1	< 1–2	< 1–1	< 1
Dibenz(a,h)anthracene	++	< 1	1	< 1	< 1	< 1	< 1
Indeno(123-cd)pyrene	+	1	2	2–3	< 1–3	< 1–2	< 1–1
Benzo(ghi)perylene	–	2	5	3–7	2–5	1–4	< 1–2
Anthanthrene	–	< 1	2	< 1–2	< 1–1	< 1–1	< 1–1
Perylene	–	< 1	1	< 1–2	< 1–2	< 1–2	< 1–1

^a – = negative, ± = negative/weakly positive, + = weakly positive, ++ = fairly positive, +++ = strongly positive.

pyrene which might be considered significant can be obtained from table 26.

Nitrosamines

The subject of the generation of nitrosamines in the rubber industry will be dealt with in

Table 26. Amount of benz(a)pyrene in the atmosphere and the amount inhaled in specific situations.

Situation	Atmospheric concentration (ng/m ³)	Amount inhaled per 8-h shift (ng)
Rural air	5	50
Urban air in winter	20	200
Rubber industry	20	200
Gas works/coking		
Industry in 1960s (18)	1,000–5,000	10,000–50,000
Smoking 50 cigarettes (15)	—	100–6,000

detail in a later paper. The spread of results which have been found in rubber factories from this type of work is shown in table 27 (unpublished results).

Some idea of the quantities of nitrosamine which are taken in from different sources has been tabulated in table 28. Obviously it is necessary to consider routes of absorption, state of materials in the atmosphere (vapor, aerosols, etc) when this type of data is considered, but nevertheless it must be clear that the concentrations of nitrosamines in rubber factory atmospheres when N-nitrosodiphenylamine was in use were adding significantly to the normal intake of these materials.

Table 27. Concentrations of nitrosamines in rubber processing operations (Nutt, unpublished results). (NDMA = nitrosodimethylamine, NDEA = nitrosodiethylamine, NMor = nitrosomorpholine).

Process	Sample	Nitrosamine concentrations (μg/m ³)		
		NDMA	NDEA	NMor
Injection molding, compound containing N-nitrosodiphenylamine, tetramethylthiuram disulfide and Sulfasan R (temperature 175°C)	Personal sample, press operator	90	—	380
	Personal sample, press operator	36	—	120
	Static sample, in direct fumes	1,060	18	4,700
	Static sample, in direct fumes	520	10	2,000
Injection molding after replacement of N-nitrosodiphenylamine by alternative retarder	Personal sample, press operator	0.7	—	1.1
	Static sample in direct fumes	1.9	—	8.7
	Static sample in direct fumes	0.5	—	0.2
Ethylene/propylene/diene monomer compound containing nitrosodiphenylamine but no secondary amines				
Brake hose manufacture, compound containing N-nitrosodiphenylamine but no secondary amines	Extruder head	0.6	0.2	1.0
	Mill site	0.2	0.1	0.4
	Curing pan	0.1	—	0.1
Conveyor belt manufacture, compound containing N-nitrosodiphenylamine, tetramethylthiuram disulfide and 2,2'-dibenzothiazyl disulfide	Exit from calender	29	1	8.5
	Exit from curing pans	230	6	37
Nitrite/nitrate salt-bath curing of rubber strip containing tetramethylthiuram disulfide	In direct fumes from rubber at exit from salt bath	150	210	720
	Personal sample, extruder operator	1.1	1.1	0.6
Zinc diethyldithiocarbamate but no N-nitrosodiphenylamine	Personal sample, operator coiling strip	1.6	1.7	0.6

Table 28. Nitrosamine intakes. (NDMA = nitrosodimethylamine, NMor = nitrosomorpholine).

Situation	Atmospheric concentration (μg/m ³)	Amount (μg) of nitrosamine inhaled (ingested) per 8-h shift (day)
Working with N-nitrosodiphenylamine in the rubber industry	30 (NDMA)	300 (NDMA)
	100 (NMor)	1,000 (NMor)
Non-N-nitrosodiphenylamine operations in the rubber industry	1 (NDMA)	10 (NDMA)
	1 (NMor)	10 (NMor)
Smoke-filled rooms (bars, discotheques) (7)	0.24 (NDMA)	2.4 (NDMA)
50 cigarettes (6)		
Mainstream smoke	—	0.25–3.2 (NDMA)
Sidestream smoke	—	34–88 (NDMA)
From foodstuffs (United Kingdom) (13)	—	0.14 (dialkyl nitrosamines)
		0.43 (heterocyclic nitrosamines)

Conclusions

The amount of information which exists from epidemiology in the rubber industry is now substantial. A considerable amount of work on industrial hygiene has also been completed, although it is still expanding in quantity and detail. Work on the mechanisms of the interaction of rubber chemicals on the human body is still relatively young but is also expanding rapidly. An appreciation of all three areas is necessary in order that decisions can be made concerning the elimination of adverse health effects in the industry, and the symposium at which this paper was presented has provided a good opportunity for the three fields to be brought together.

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