Exposure to Welding Fumes, Hexavalent Chromium, or Nickel and Lung Cancer Risk

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Tables and Figures of Contents:

Web Table 1. Welding Exposure Matrix with Estimates of Average Shift Concentrations of Welding Fumes, Hexavalent Chromium and Nickel for Major Welding Processes and Materials, Germany

Welding process	Material	Welding fumes [µg/m^3]	Cr(VI) [µg/m^3]	Ni [µg/m^3]
Manual metal arc welding	Mild steel	2,700	1	4
	Stainless steel	1,600	8	19
	Ni alloys	1,600	12	37
Fluxed-cored arc welding	Mild steel	4,700	0	3
	Stainless steel	3,200	5	12
Metal active gas welding	Mild steel	3,900	1	5
	Stainless steel	2,300	2	24
	Ni alloys	2,300	2	48
	Aluminum	4,100	0	0
Metal inert gas welding	Mild steel	3,500	1	5
	Stainless steel	2,100	2	24
	Ni alloys	2,100	2	48
	Aluminum	3,000	0	0
Tungsten inert gas welding	Mild steel	900	0	3
	Stainless steel	500	0	5
	Ni alloys	500	0	11
	Aluminum	900	0	0
Autogenous welding	Mild steel	900	1	6
Arc spraying	Mild steel	1,000	0	10
	Stainless steel	1,000	2	33
Torch cutting	Mild steel	2,800	1	14
Spot welding	Stainless steel	500	1	1
Plasma cutting	Stainless steel	1,300	1	1

Abbreviations: Cr(VI), hexavalent chromium; Ni, nickel.

Web Table 2. Lung Cancer Risks of Welding Processes in Men, AUT and HdA Study, Germany, 1988-1996

Duration of Exposure	No. of Cases	No. of Controls	OR1[a] (Model 1)	95% CI (Model 1)	OR2[b] (Model 2)	95% CI (Model 2)	OR3[c] (Model 3)	95% CI (Model 3)
Reference group[d]	2,618	2,843	1.00	Referent	1.00	Referent	1.00	Referent
Ever								
Autogenous welding	635	536	1.28	1.13, 1.45	1.23	1.06, 1.42	1.24	1.08, 1.44
Spot welding	177	149	1.30	1.04, 1.63	1.22	0.94, 1.58	1.24	0.96, 1.60
Manual metal arc welding	593	495	1.30	1.14, 1.48	1.22	1.05, 1.42	1.23	1.06, 1.43
Torch cutting	503	401	1.36	1.18, 1.57	1.27	1.08, 1.49	1.28	1.08, 1.50
Arc spraying	31	24	1.41	0.83, 2.42	1.72	0.93, 3.18	1.73	0.94, 3.19
Gas metal arc welding	94	68	1.54	1.12, 2.12	1.35	0.94, 1.95	1.36	0.95, 1.96
Tungsten inert gas welding	41	37	1.23	0.79, 1.93	1.07	0.65, 1.77	1.06	0.64, 1.76
≥10 years								
Autogenous welding	379	289	1.43	1.22, 1.69	1.42	1.18, 1.72	1.44	1.20, 1.74
Spot welding	91	75	1.34	0.98, 1.83	1.19	0.83, 1.69	1.20	0.84, 1.72
Manual metal arc welding	380	286	1.46	1.24, 1.71	1.36	1.13, 1.64	1.37	1.14, 1.65
Torch cutting	305	226	1.48	1.24, 1.77	1.39	1.13, 1.71	1.41	1.14, 1.73
Arc spraying	15	12	1.38	0.65, 2.96	1.51	0.65, 3.51	1.95	0.95, 3.99
Gas metal arc welding	49	45	1.22	0.81, 1.83	1.19	0.74, 1.91	1.20	0.75, 1.93
Tungsten inert gas welding	29	20	1.62	0.91, 2.87	1.52	0.78, 2.96	1.51	0.77, 2.94

Abbreviations: AUT, *Arbeit und Technik* Study; CI, confidence interval; HdA, *Humanisierung des Arbeitslebens* Study; OR, odds ratio.

[a] Odds ratios for model 1 are adjusted for log(age) and conditional on study.

[b] Odds ratios for model 2 are additionally adjusted for log(pack-years + 1), time-since-quitting smoking cigarettes (current smokers, ever other types of tobacco only, stopped smoking 2–7,8–15, 16–25, or ≥ 26 years before interview or diagnosis, never smokers).

[c] Odds ratios for model 3 are additionally adjusted for ever working in a List A job except in those with exposure to hot metal fumes.

[d] Subjects who were never exposed to metal fumes from welding or smelting.

Web Table 3. Lung Cancer Risks for Cumulative Exposure to Welding Fumes, Hexavalent Chromium, or Nickel in Men with Welding Activities Estimated with Unconditional Models, AUT and HdA Study, Germany, 1988-1996

Cumulative Exposure	No. of Cases	No. of Controls	OR1[a] (Model 1)	95% CI (Model 1)	OR2[b] (Model 2)	95% CI (Model 2)	OR4[c] (Model 4)	95% CI (Model 4)
Reference group[d]	2,618	2,843	1.00	Referent	1.00	Referent	1.00	Referent
Welding fumes[e]								
>0-629	208	210	1.09	0.89, 1.32	1.04	0.83, 1.30	1.09	0.80, 1.48
630-4,721	293	215	1.49	1.24, 1.79	1.46	1.18, 1.81	1.55	1.15, 2.09
≥4,722	299	220	1.48	1.24, 1.78	1.31	1.06, 1.61	1.40	1.03, 1.89
>0-1,837	352	322	1.19	1.02, 1.40	1.11	0.92, 1.33	1.18	0.89, 1.55
≥1,838	448	323	1.51	1.30, 1.76	1.44	1.21, 1.71	1.55	1.17, 2.05
P Value[f]				<0.0001		<0.0001		0.003
P Value[g]				0.01		0.04		0.04
Cr(VI)[e]								
>0-0.49	200	213	1.05	0.86, 1.28	1.00	0.80, 1.25	1.12	0.84, 1.49
0.5-3.69	336	212	1.59	1.32, 1.91	1.52	1.23, 1.88	1.87	1.37, 2.54
≥3.7	264	220	1.43	1.19, 1.71	1.30	1.06, 1.61	1.75	1.22, 2.51
>0-1.39	347	323	1.17	1.00, 1.38	1.12	0.93, 1.34	1.29	0.99, 1.68
≥1.4	453	322	1.53	1.32, 1.79	1.42	1.19, 1.70	1.85	1.35, 2.54
P Value[f]				<0.0001		0.009		0.095
P Value[g]				0.01		0.59		0.45
Ni[e]								
>0-2.99	217	212	1.12	0.92, 1.36	1.05	0.84, 1.32	1.07	0.82, 1.40
3-20.99	279	213	1.43	1.19, 1.72	1.42	1.15, 1.76	1.54	1.17, 2.03
≥21	304	220	1.51	1.26, 1.81	1.34	1.09, 1.65	1.59	1.16, 2.18
>0-8.99	358	322	1.21	1.04, 1.43	1.16	0.96, 1.39	1.19	0.94, 1.51
≥9	442	323	1.49	1.28, 1.74	1.39	1.16, 1.65	1.60	1.21, 2.11
P Value[f]				<0.0001		0.004		0.039

P Value[g]	0.004	0.42	0.25

Abbreviations: AUT, *Arbeit und Technik* Study; CI, confidence interval; Cr(VI), hexavalent chromium; HdA, *Humanisierung des Arbeitslebens* Study; Ni, nickel; OR, odds ratio.

[a] Odds ratios for model 1 are adjusted for log(age) and study.

[b] Odds ratios for model 2 are additionally adjusted for log(pack-years + 1) and time-since-quitting smoking cigarettes (current smokers, ever other types of tobacco only, stopped smoking 2–7,8–15, 16–25, or ≥ 26 years before interview or diagnosis, never smokers).

[c] Odds ratios for model 4 are additionally adjusted for ever working in a List A job except in those with exposure to hot metal fumes and for average intensity of exposure to the other agents under study.

[d] Subjects who were never exposed to metal fumes from welding or smelting.

[e] Cumulative exposure of single agents presented in $\mu g/m^3$ x years.

[f] *P* values of trend for log-transformed exposure variables.

[g] *P* values of trend for log-transformed exposure variables, tests restricted to exposed men.

Web Table 4. Lung Cancer Risks of Cumulative Exposure to Welding Fumes (Estimated with 3% Annual Reduction of Concentrations since 1960) in Men with Welding Activities, AUT and HdA Study, Germany, 1988-1996

Cumulative Exposure	No. of Cases	No. of Controls	OR1[a] (Model 1)	95% CI (Model 1)	OR2[b] (Model 2)	95% CI (Model 2)	OR4[c] (Model 4)	95% CI (Model 4)
Reference group[d]	2,618	2,843	1.00	Referent	1.00	Referent	1.00	Referent
Welding fumes[e]								
>0-1,442	217	214	1.12	0.91, 1.35	1.04	0.83, 1.30	1.09	0.81, 1.48
1,443-13,329	284	211	1.47	1.22, 1.77	1.47	1.19, 1.82	1.56	1.15, 2.11
≥13,330	299	220	1.48	1.23, 1.78	1.31	1.06, 1.62	1.40	1.04, 1.90
>0-4,757	353	322	1.20	1.02, 1.41	1.15	0.96, 1.39	1.21	0.92, 1.60
≥4,758	447	323	1.51	1.29, 1.76	1.38	1.16, 1.65	1.47	1.11, 1.95
P Value[f]				0.047		0.371		0.876
P Value[g]				0.68		0.44		0.48

Abbreviations: AUT, *Arbeit und Technik* Study; CI, confidence interval; HdA, *Humanisierung des Arbeitslebens* Study; OR, odds ratio.

[a] Odds ratios for model 1 are adjusted for log(age) and conditional on study.

[b] Odds ratios for model 2 are additionally adjusted for log(pack-years + 1) and time-since-quitting smoking cigarettes (current smokers, ever other types of tobacco only, stopped smoking 2–7,8–15, 16–25, or ≥ 26 years before interview or diagnosis, never smokers).

[c] Odds ratios for model 4 are additionally adjusted for ever working in a List A job except in those with exposure to hot metal fumes and for average intensity of Cr(VI) and Ni under study.

[d] Subjects who were never exposed to metal fumes from welding or smelting.

[e] Cumulative exposure of welding fumes presented in $\mu g/m^3$ x years assuming decreasing annual average concentration (3% per year since 1960).

[f] *P* values of trend for log-transformed welding fumes.

[g] *P* values of trend for log-transformed welding fumes, tests restricted to exposed men.

Web Table 5. Joint Effects of the Lung Cancer Risks of Cumulative Exposure to Welding fumes, Hexavalent Chromium, or Nickel in Men, AUT and HdA Study, Germany, 1988-1996

Combinations of Exposure	Cases				Controls				OR1[b]	95% CI	OR3[c]	95% CI
	No	Median Fume[a]	Median Cr(VI)[a]	Median Ni[a]	No	Median Fume[a]	Median Cr(VI)[a]	Median Ni[a]	(Model 1)	(Model 1)	(Model 3)	(Model 3)
Reference group[d]	2,618	0	0	0	2,843	0	0	0	1.00	Referent	1.00	Referent
Low fumes, Cr(VI) and Ni	286	338	0.28	1.61	275	280	0.23	1.28	1.14	0.95, 1.35	1.08	0.88, 1.31
Low fumes, high Cr(VI) or Ni	27	861	2.45	5.40	14	888	1.89	5.98	2.11	1.10, 4.03	1.59	0.78, 3.27
High fumes, low Cr(VI) and Ni	37	2,997	0.81	5.80	24	2,806	0.96	7.02	1.68	1.00, 2.82	1.77	0.97, 3.24
High fumes, high Cr(VI) or Ni	450	7,212	5.12	31.98	332	7,128	5.96	32.00	1.48	1.27, 1.72	1.39	1.16, 1.65

Abbreviations: AUT, *Arbeit und Technik* Study; CI, confidence interval; Cr(VI), hexavalent chromium; HdA, *Humanisierung des Arbeitslebens* Study; Ni, nickel; OR, odds ratio.

[a] Median cumulative exposure of single agents presented in $\mu g/m^3$ x years.

[b] Odds ratios for model 1 are adjusted for log(age) and conditional on study.

[c] Odds ratios for model 3 are additionally adjusted for log(pack-years + 1), time-since-quitting smoking cigarettes (current smokers, ever other types of tobacco only, stopped smoking 2–7,8–15, 16–25, or ≥ 26 years before interview/diagnosis, never smokers), and for ever working in at-risk jobs except in those with exposure to hot metal fumes.

[d] Subjects who were never exposed to metal fumes from welding or smelting.

Web Table 6. Sensitivity Analyses of Lung Cancer Risks in Relation to Cumulative Exposure to Welding fumes, Hexavalent Chromium and Nickel , AUT and HdA Study, Germany, 1988-1996

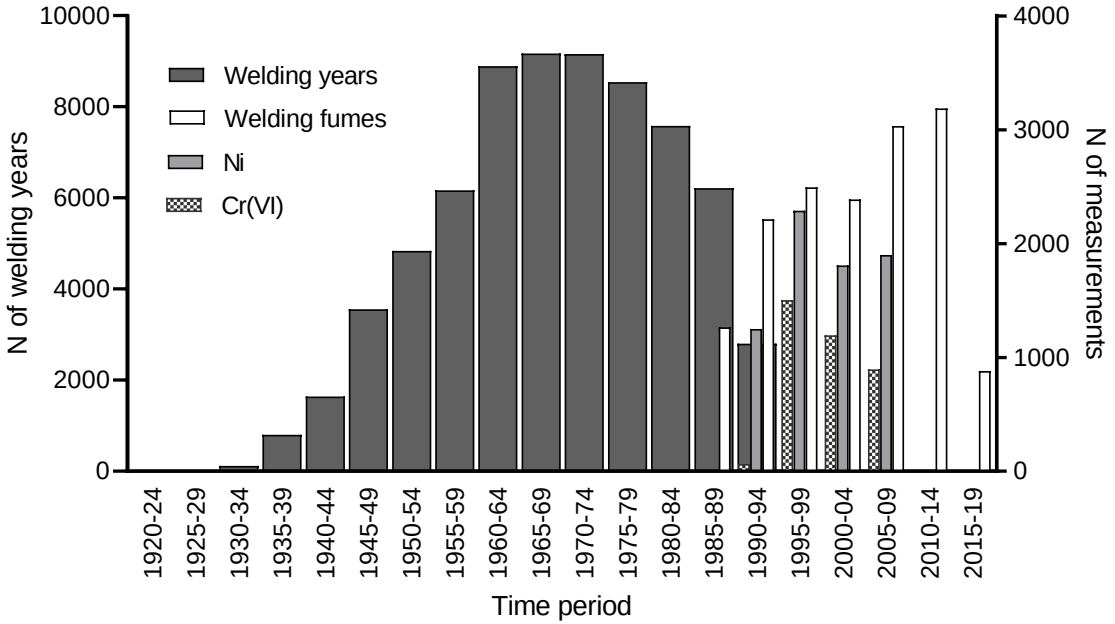
Cumulative Exposure	HdA Study				AUT Study				Regular Welding				Regular Welder (Job Code)			
	N of Cases	N of Controls	OR[a]	95% CI	N of Cases	N of Controls	OR[a]	95% CI	N of Cases	N of Controls	OR4[b]	95% CI	N of Cases	N of Controls	OR4[b]	95% CI
Reference group[c]	590	636	1.00	Referent	2,028	2,207	1.00	Referent	2,618	2,843	1.00	Referent	2,618	2,843	1.00	Referent
Welding fumes[d]																
>0-1,837	106	96	1.45	0.89, 2.38	246	226	1.06	0.76, 1.48	50	35	1.45	0.82, 2.58	13	7	1.31	0.49, 3.48
≥1,838	131	96	1.64	0.99, 2.72	317	227	1.51	1.07, 2.13	346	242	1.55	1.06, 2.26	125	57	1.87	1.30, 2.68
Cr(VI)[d]																
>0-1.39	110	98	1.56	0.97, 2.51	237	225	1.17	0.84, 1.61	58	33	2.36	1.32, 4.23	19	8	1.87	0.75, 4.67
≥1.4	127	94	1.85	1.02, 3.38	326	228	1.83	1.26, 2.68	338	244	1.95	1.27, 3.00	119	56	1.78	1.24, 2.57
Ni[d]																
>0-8.99	116	95	1.32	0.87, 2.01	242	227	1.12	0.84, 1.50	55	34	2.06	1.18, 3.61	17	10	1.38	0.59, 3.21
≥9	121	97	1.17	0.70, 1.96	321	226	1.84	1.31, 2.57	341	243	1.78	1.22, 2.59	121	54	1.88	1.30, 2.72

	Welding without Smelting				Blue-collar Workers				Lag 10 Years			
	N of Cases	N of Controls	OR4[b]	95% CI	N of Cases	N of Controls	OR4[b]	95% CI	N of Cases	N of Controls	OR4[b]	95% CI
Reference group[c]	2,618	2,843	1.00	Referent	2,199	1,964	1.00	Referent	2,618	2,843	1.00	Referent
Welding fumes[d]												
>0-1,837	330	309	1.25	0.93, 1.67	352	322	1.00	0.76, 1.32	367	342	1.18	0.90, 1.56
≥1,838	319	263	1.56	1.13, 2.14	448	323	1.32	0.99, 1.75	431	300	1.52	1.15, 2.02
Cr(VI)[d]												
>0-1.39	319	309	1.33	1.00, 1.78	347	323	1.10	0.84, 1.43	352	334	1.22	0.93, 1.59
≥1.4	330	263	1.89	1.33, 2.70	453	322	1.57	1.14, 2.16	446	308	1.55	1.16, 2.09
Ni[d]												
>0-8.99	331	306	1.21	0.95, 1.55	358	322	1.01	0.80, 1.28	366	332	1.19	0.94, 1.51
≥9	318	266	1.55	1.15, 2.11	442	323	1.36	1.02, 1.80	432	310	1.61	1.21, 2.15

Abbreviations: AUT, *Arbeit und Technik* Study; CI, confidence interval; Cr(VI), hexavalent chromium; HdA, *Humanisierung des Arbeitslebens* Study; Ni, nickel; OR, odds ratio.

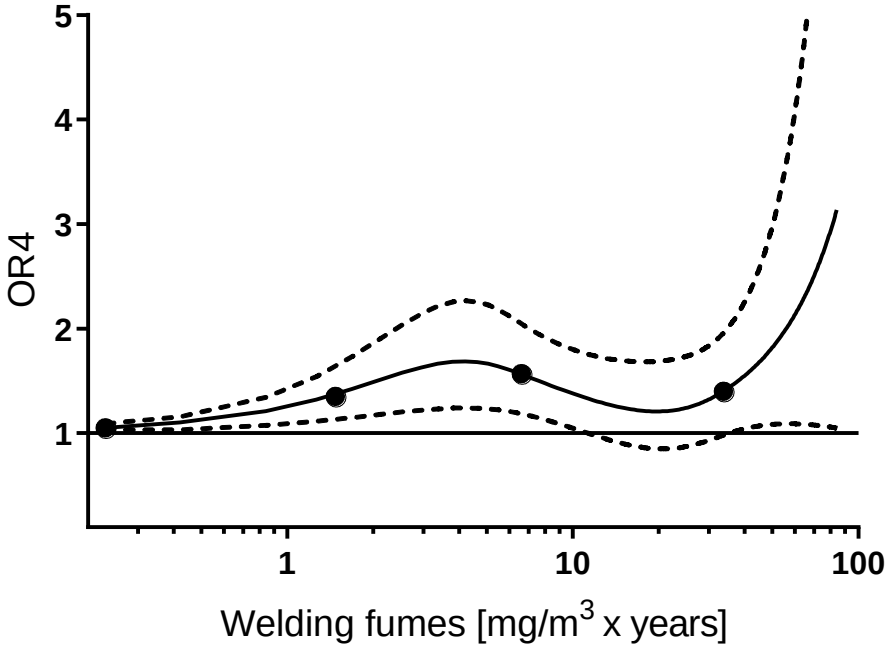
[a] Odds ratios (OR4) are adjusted for log(age), time-since-quitting smoking cigarettes (current smokers, ever other types of tobacco only, stopped smoking 2–7,8–15, 16–25, or ≥ 26 years before interview/diagnosis, never smokers), for ever working in at-risk jobs except in those with exposure to hot metal fume, and for average intensity of exposure to the other agents under study.
[b] Odds ratios are additional conditional on study.
[c] Subjects who were never exposed to metal fumes from welding or smelting.
[d] Cumulative exposure of single agents presented in $\mu g/m^3$ x years.

Web Figure 1. Distribution of Measurements (Welding Fumes, Hexavalent Chromium and Nickel over Time Compared to the Welding Activities of Men in the AUT and HdA Study, Germany, 1988-1996

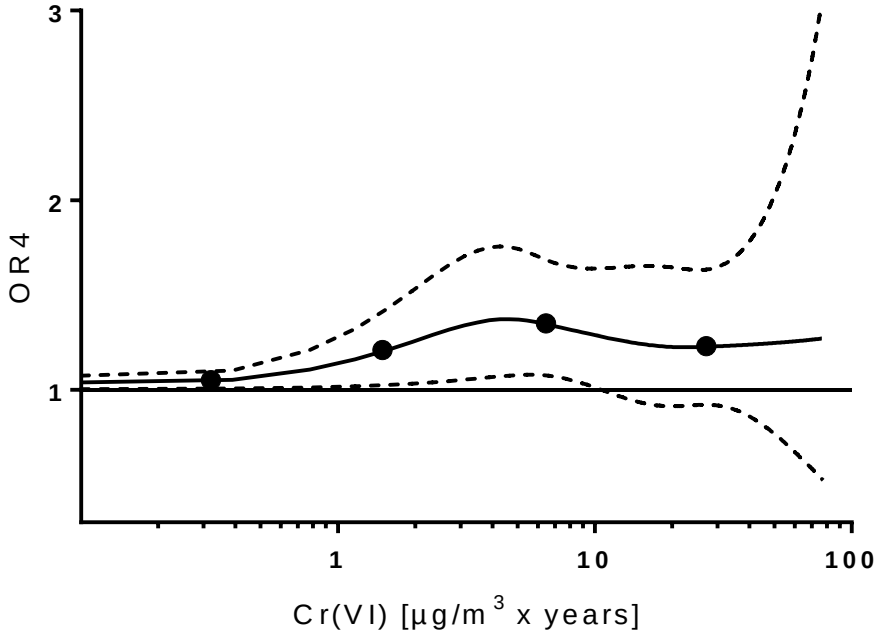


Web Figure 2. Exposure–Response Relation for Cumulative Exposure to Welding Fumes, Hexavalent Chromium and Nickel with 95% Confidence Intervals in Men, AUT and HdA Study, Germany, 1988-1996

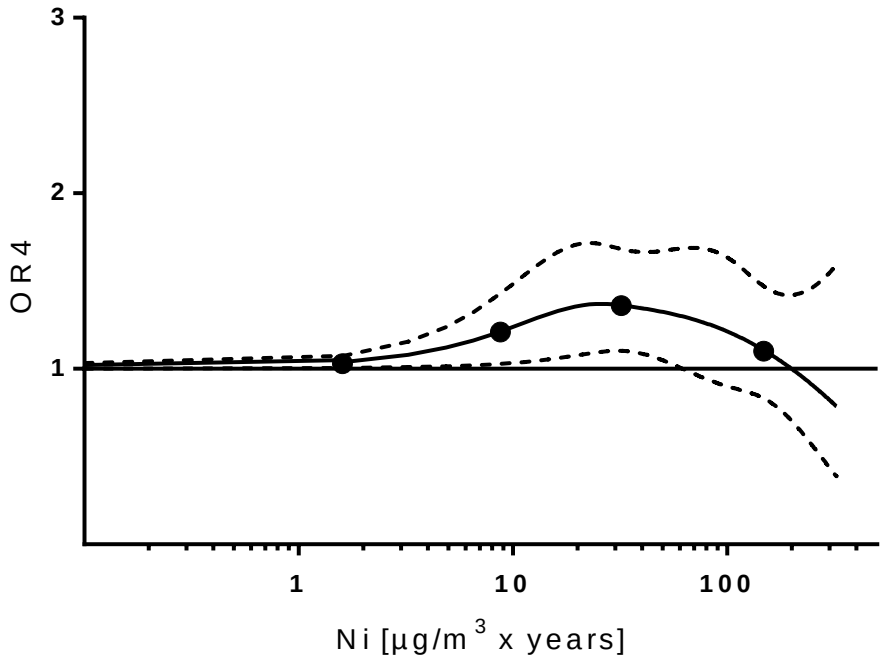
a) Welding fumes[a]



b) Hexavalent chromium[a]



c) Nickel[a]



[a] Lung cancer risks (OR4) were adjusted for log(age), log(pack-years + 1), time-since-quitting smoking, ever-employment in a “list A” job, and for average intensity of exposure to the other agents under study, conditional on study. Cubic spline functions with 4 knots defined at the 25th, 50th, 75th and 95th percentile among exposed controls.