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Cancer Incidence Among Welders: Possible Effects of Exposure to Extremely Low Frequency Electromagnetic Radiation (ELF) and to Welding Fumes

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Epidemiological studies of cancer incidence among welders disclose a pooled total of 146 cases of leukemia observed versus 159.46 expected, a risk ratio of 0.92, and 40 cases of acute leukemia observed versus 43.39 expected, a risk ratio of 0.92. For respiratory tract cancer, the pooled total is 1789 cases observed versus 1290.7 expected, a risk ratio of 1.39. Most electric welders are exposed to extremely low frequency electromagnetic radiation (ELF) (magnetic flux densities of up to 100,000 μT), a suspected leukemogen, and to concentrated metallic aerosols (up to 200 mg/m^3), which can contain the putative respiratory tract carcinogens Cr(VI) and Ni. The two exposures are usually coincident, since welding with an electric current produces welding fumes. The observation of an excess risk for respiratory tract cancer strongly suggests significant exposure both to fumes and to ELF. The absence of increased risk for all leukemia or for acute leukemia among ELF-exposed welders does not support the hypothesis that the observed excess risk for leukemia or acute leukemia among workers in the electrical trades is due to their ELF exposure, which on the average is lower than that of welders.

Introduction

Recent reports (*1–10*) suggest excess proportional incidence or mortality for leukemia in workers exposed to extremely low frequency (ELF) electromagnetic radiation. The pooled data from five studies (*1–4,9*) with many occupational classifications in common (see Appendix 1 for details) give: for all leukemia, observed (O) = 449; expected (E) = 392.97 cases; and risk ratio (RR) = 1.14. For all acute leukemia, O = 213; E = 150.8 cases; and RR = 1.41. Acute myeloid leukemia (where indicated) has O = 88; E = 64.3 cases; and RR = 1.37. The pooled data suggest that men in electrical occupations have excess acute leukemia, although the risk of nonacute leukemia is apparently not raised; however, the absence of data on cumulative dose and dose rate for ELF exposures in these occupations makes it difficult to draw conclusions with respect to causality (*11*).

Recent studies suggest that leukemia incidence or mortality is higher in households near to high current electrical distribution networks (*12,13*). Levels of such ELF exposure are difficult to verify absolutely, although they are suspected to be higher than those in households far from high current sections of the power grids. Typically, household and office exposures to ELF are at levels that do not exceed 50 μT (*14*). A small risk due to the distribution of electrical power would pose a serious public health problem. A review of the literature on effects of exposure to ELF, however, does not provide a reasonable hypothesis for human effects of ELF exposure, although some *in vitro* and *in vivo* effects of ELF have been observed (*15–23*).

Exposure of Welders to ELF

Electric arc welding is a technology that has developed rapidly since the early 1940s and involves the use of electric current to locally melt metal workpieces, resulting in a strong joint. Typical processes, such as manual metal arc welding with covered electrodes, metal inert gas welding with solid or flux cored wires, flash welding, spot welding, seam welding, and submerged arc welding, involve direct, alternating, or pulsed electric currents ranging from 100 to 100,000 amperes. Welding transformers and current-carrying cables produce magnetic flux densities ranging from 100 to 10,000 μT [1 tesla = 10^4 orsteds (gauss)] at distances of 0.2 to 1.0 m (*14*), which are among the highest occupational ELF levels recorded. As a typical electrode welder has an arc struck for 30 to 50% of the working day and frequently works in the close vicinity of several other

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welders and their equipment, it can be assumed that, on the average, welders also have an extremely high cumulative exposure to ELF magnetic flux.

At very low frequencies, e.g., 50 to 60 Hz and below (typical of household and engineering currents), the electrical and magnetic fields that are normally related by Maxwells' equations can be considered to be decoupled, so that the exposures are considered separately. Magnetic flux densities in the home and at most working places are generally below 50 μT, associated with lighting and electrical appliances. On the other hand, electric fields and field gradients, especially those due to static electricity, are ubiquitous, so that identifying exposed and unexposed cohorts is impossible, and hence will not be discussed further.

Because welders are exposed to ELF magnetic flux densities that are from 2 to 200 times those of exposed households and most exposed electrical occupations, they might suffer an excess incidence of leukemia or other cancer associated with ELF, provided there were no confounding exposures and there was a dose- or dose-rate-response relationship related to magnetic flux density *per se*.

Welders' Confounding Occupational Exposures

Electric arc welding produces high workplace concentrations of fumes, mostly oxides of the metals found in the consumable materials (e.g., iron oxide from all ferrous processes, aluminium oxides from aluminium welding and nickel, and chromium oxides from stainless and high alloy steels); the exact composition and concentration depends on the specific welding process and application (*24*). The rising column of air above the arc can contain concentrations as high as 200 mg/m^3 of particulate matter, almost all of which is in the respirable size range. Breathing zone concentrations average 2 to 10 mg/m^3, with much higher time-weighted averages for some workers. As many of the metallic fume components have been shown to be mutagenic (*24,25*), and some of the fume components are suspected human carcinogens [e.g., Cr(VI) and Ni], effects of inhalation exposures must be considered; the target organ will presumably be the respiratory tract (*25–33*) (see Appendix 2 for a detailed discussion).

In many countries, the welding workforce, which is 0.2 to 2% of the entire workforce (*24*), is quite stable, and cross-sectional studies show current welding cohorts have been exposed for 15 to 20 years. A study of leukemia incidence among welders might therefore provide evidence for or against the effects of exposure to ELF with a confounding exposure to welding fume. The observation of an excess risk of respiratory tract cancer might provide evidence for the effects of exposure to welding fume (*29,31,32,34*). Excess risk could be indirect evidence for exposure to ELF, as there is no suggestion that ELF might effect cancer development at this site. Only 10 to 15% of welders use nonelectric processes, e.g., gas welding (*24*), so that most members of cohorts exposed to fume are also exposed to ELF.

Leukemia and Lung Cancer in Electric Arc Welders: Pooling of the Data

In the process of updating a survey of cancer incidence among welders (*31,32*), some 50 epidemiological studies have been found in the world literature, 15 of which contain information on leukemia incidence (Table 1) among welding cohorts: (a) included in surveys of electrical trades (*1,4,5,10,35,36*); (b) examined primarily for lung cancer (*37–41*); and (c) identified in regional cancer studies (*42–45*). Studies with several different designs are included in the table, preventing direct quantitative comparisons, but pooling the data, however, should at least indicate any trend of incidence. If the pooled data for these studies represent a true average, then the risk for leukemia should reflect any effects of ELF exposure. Lung cancer data is included in Table 1 where available.

There has been considerable discussion in the recent literature concerning questions of pooling data that result from repeated measurement of the same effect (*46,47*). A traditional argument suggests the avoidance of pooling and reliance on studies of sufficiently high quality as to provide statistically significant results. Unfortunately, no single study of leukemia (or for that matter, lung cancer) among welders meets criteria concerning exposure levels, lack of confounders, and sufficient stratification of age, latency, and cumulative exposure to provide a statistically significant measure of dose-response relationship. Preliminary evaluation of the data therefore requires some form of meta analysis. The most simple, but least satisfactory, way is to simply add commensurate studies to arrive at an average risk ratio. A recently suggested alternative approach is to take a (variance) weighted average of the log (risk ratios) (*47*). These two latter approaches are used below and gave similar results. (Additional discussion of meta analysis is found in Appendix 2.)

Results, Discussion, and Conclusions

The results of linear pooling of expected and observed cases are presented in Table 1 in the text and Tables A1–A4 in the appendices, with 95% confidence limits derived from the t table. For a first approximation to meta analysis, the pooled risk ratio RR* is derived from the sum of the values of $\ln RR(i)$ (for each of the substrata "i"), each weighted by the variance $W(i)$, where $W(i) = (O(i) + E(i))/4)$, assuming all values of $RR(i)$ are derived from large independent studies of expected incidence in nonexposed local populations and that the absolute incidence rate (for lung cancer or leukemia) is small: $\chi^2 = \ln RR^*/\mathrm{Var} \ln RR^*$. This form of meta analy-

Table 1. Studies of leukemia incidence in welding populations.

	All leukemia			Acute leukemia			Lung cancer			
	O[a]	RR	E[b]	O[c]	RR	E	O	RR	E	Reference
	6	0.96	6.24	4(m)	1.71	2.33				(*10*)
	—	—	—	0(l)	—	0.66				(*10*)
	20	0.83	25.3	13(a)	1.04	12.5				(*1*)
	7	2.25	3.1							(*36*)
				—[d](m)	(3.8)	—[d]				(*35*)
	19	0.89	21.3	6(a)	0.67	9.0				(*4,5*)
Subtotal	52	0.93	55.34	23	0.94	24.41				
	0	—	1.2				6	0.95	6.3	(*38*)
	0	—	1.56				17	1.5	11.3	(*39*)
	4	4.2	0.94				10	2.2	4.5	(*41*)[e]
	4	0.35	11.0				50	1.32	37.9	(*37*)
	1	2.5	0.4				7	1.38	5.1	(*40*)
				6(a)	1.81	3.3	27	0.99	27.3	(*43*)
	43	0.99	43.62				193	1.42	136.0	(*45*)
All	15	1.14	13.2				12	1.60	7.5	(*44*)
High exposure	(4)	0.6	(6.7)							(*44*)
Low exposure	(11)	1.7	(6.5)							(*44*)
	27	0.85	31.6	7(m)	0.76	9.2	381	1.46	260.1[f]	(*42*)
				4(l)	0.63	6.4	305	1.27	240.6[g]	(*42*)
Subtotal	94	0.90	104.12	17	0.90	18.90				
Pooled data RR[h]	146	0.92[i]	159.46	40	0.92[i]	43.39	1008	1.34	736.6	
Pooled subtotal for studies with both all and acute leukemia data:	72	0.86	84.4	34	0.85	40.09				

[a] Observed
[b] Expected.
[c] (m), Acute myeloid; (l), acute lymphoid; (a), all acute leukemia. All leukemia minus all acute leukemia = nonacute leukemia (where listed): O = 38; E = 44.37; RR = 0.86. For studies without acute leukemia data, O = 74; E = 75.06; RR = 0.99.
[d] Number of welders not given.
[e] Gas welders.
[f] Standardized mortality ratio < 65 years.
[g] Proportional mortality ratio 65–75 years.
[h] For meta analysis, RR* showed no trend for all leukemia and acute leukemia; for lung cancer, RR* = 1.37; $\chi^2 = 41.4$; $p^* < 10^{-10}$.
[i] Nonsignificant.

sis is only used for subgroups of data where (almost) all of the values of RR(i) > 1.0.

For (additively) pooled data for welders, the standardized risk ratios (and 95% confidence limits, two-tailed) are 0.86 (0.67–1.06) and 0.85 (0.55–1.15) for all leukemia and acute leukemia, respectively, and are below unity due to social-class gradient for this disease. Welder's proportional mortality ratio/proportional incidence ratio (PMR/PIR) should also be reduced by about 4 to 5% due to the excess of lung cancer incidence, which is responsible for approximately 1/8 of all male deaths (*48*). Because the values of RR(i) for all leukemia and acute leukemia are distributed both above and below unity, no attempt at meta analysis is made.

The (PIR/PMR) data for electrical trades (Appendix 1) suggest that exposure to ELF increases the ratio of acute to all leukemia by approximately 1.24:1.

Studies of welders with separate data for acute leukemia give a linear pooled risk ratio for all leukemia (RR = 0.86), which is different from that for studies without acute leukemia data (RR = 0.99); the values are not statistically significant different from unity or from each other. The lung cancer risk ratio (RR = 1.34) for the linear pooled data from surveys with leukemia data is similar to the value for the entire set (RR = 1.39, $p < 10^{-10}$) (from meta analysis, RR* = 1.37, $\chi^2 = 41.4$, $p^* < 10^{-10}$). Risk ratios for leukemia and acute leukemia for studies with and without lung cancer data are similar, suggesting that there is no internal bias with respect to fume or ELF exposure. The preponderance of positive studies for lung cancer reinforces the negative conclusion concerning the effects of ELF exposure.

Following the discussion in Appendix 2, and in spite of possible confounding exposures and lifestyle effects, the 39% increase in the average incidence of respiratory tract cancer among welders appears to be statistically significant. When viewed in terms of the pooled data, this excess is suggestively associated with exposure to welding fumes and gases. At present it is impossible to distinguish between the two most prominent hypotheses and determine if there is a significant contribution from exposure to Ni and Cr from the welding of stainless

steel among a small fraction (i.e., 10%) of the population at high risk (i.e., RR = 5.0), or if the excess is primarily due to exposure to fumes in general, perhaps expressed only after a latency period of more than 30 years from first employment.

Since electric arc welders have both absolute and cumulative exposures to ELF magnetic flux densities several orders of magnitude above those of the general public or workers in electric occupations, their risk levels should represent maximal effects of exposure to ELF on leukemia incidence.

The conclusion is that high exposure of welders to ELF magnetic flux densities does not increase leukemia incidence. It cannot raise the risk of acute leukemia by the factor of 1.41, which was the excess risk found by pooling studies on electrical occupations with lower ELF exposures. If there is a risk associated with exposure to ELF magnetic flux densities, it is not proportional to dose or dose rate. The possibility cannot be excluded that some other characteristic of ELF electromagnetic radiation besides the magnetic flux density is leukemogenic.

The use of pooled data requires justification. Pooling is resorted to in the absence of cohorts that are sufficiently large to generate statistically significant results at the observed risk level. Fortunately, the lung cancer literature contains several large studies, each of which is capable of generating, with high statistical significance, risk ratios similar to that of the pooled data from smaller studies. Unfortunately, however, these large, regional studies based on death certificates suffer from uncertainty of exposure data and possible underreporting because of the frequent use of last registered job on the death certificate, which makes drop-out, especially for health reasons, extremely important. In spite of these difficulties, the similarity of the results from all of these studies suggests that small effects can be measured by pooling if the data base is sufficiently large and is unbiased by selection or exclusion of negative studies.

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APPENDIX 1. Leukemia Incidence in the Electrical Trades

Five recent surveys have examined the proportional mortality ratio (PMR) (*1–5*) and the proportional incidence ratio (PIR) (*2,10*) for chronic and acute, myeloid, lymphoid, and other leukemias in workers with suspected high exposure to ELF. Although the selection was based on a job title and exposures were not measured, a large amount of data is reported for a number of different trades. The data may be grouped as follows:

1. Electronic technicians (*1,4,10*), radio/radar mechanics (*2,3*)
2. Telegraph operators (*4*), radio/telegraph operators (*1–3,10*)
3. Electricians (*1–4,10*)
4. Power/telephone linemen (*1,4,10*), linemen/cable joiners (*2,3*), telephone installers/repairmen (*2,3*)
5. TV/Radio repairmen (*1,4,10*), electrical/electronic fitters/assemblers (*2,3*)
6. Power station operators (*1,4,10*)
7. Aluminium workers (*4*)
8. Welders, flamecutters (*1,4,10*)
9. Motion picture projectionists (*1,4,10*)
10. Electrical engineers (*1–4,10*)
11. Streetcar/subway motormen (*1,4,10*)
12. Electrical engineers (professional) (*2,3*)
13. Electronic engineers (professional) (*2,3*)

Mortality and absolute incidence ratios for leukemia are not identical, but no significant differences were found in prognosis among trades or between the regions studied [Washington State (*4*), Wisconsin (*1*), Los Angeles County (*10*), South-East England (*2*), England and Wales (*3*)]. The PIR/PMR data from the five studies were pooled assuming that the proportional ratios were unaffected by treatment.

The pooled results for each of the 13 categories are summarized in Table A1, together with the sum of observed and expected for (a) all leukemia; (b) all acute leukemia; (c) all minus all acute; and (d) acute myeloid (where indicated). The appropriate values of the risk ratio and statistical significance for the pooled data are shown for both linear pooling and variance-weighted logarithmic pooling (where appropriate). The RR for nonacute leukemia (the difference between all leukemia and all acute leukemia) is not statistically significantly different from unity, and the effect of employment in an electric occupation appears limited to raising the risk for acute leukemia only (RR = 1.41, $p < 0.0001$, RR* = 1.40, $p^* < 0.0008$) and, perhaps, especially acute myeloid leukemia (although only at $p^* < 0.1$ from the meta analysis). Note that the elevated risk (SMR = 1.39) for welders' lung cancer (which accounts for approximately 12% of all male deaths) should reduce the PMR for other sites (i.e., leukemia) by about 4 to 5%.

Questions may be raised as to the extent to which individuals so identified are exposed to ELF. In particular, power lineman usually work without power in the sections being installed or repaired, and electrical and electronic engineers may have no practical contact with machinery or equipment. Aluminium workers and electronics technicians are exposed to organic fumes and gases that have significant biological activity, whereas the jobs with observed high risk (radio and telegraph operators, power station operators, electrical engineers, aluminium workers) do not suggest exclusive or unique exposures.

APPENDIX 2. Lung Cancer Incidence Among Welders

The large number of studies of cancer incidence among welders can be grouped by cancer site, study

Table A1. Summary of pooled leukemia data for 13 electrical trades.[a]

	All leukemia		Acute leukemia		All acute		Acute myeloid	
Job category	O	E	O	E	O	E	O	E
1	16	19.3	9	6.79	7	12.5	5	3.48
2	23	11.94	9	3.82	14	8.12	3	1.52
3	159	142.87	68	58.54	91	94.33	25	26.19
4	71	61.1	34	23.92	37	37.2	17	12.52
5	32	22.9	15	7.43	17	15.5	7	3.41
6	9	3.46	4	1.03	5	2.16	1	0.14
7	20	10.6	11	4.3	9	6.3	—	—
8[b]	39	49.8	21	22.6	18	27.2	4	2.34
9	6	3.43	2	1.1	4	2.33	1	1.8
10	45	38.22	30	16.89	15	21.31	17	9.18
11	4	3	0	0	4	3	—	—
12	17	20.2	4	2.78	13	17.42	4	2.42
13	8	6.15	2	1.6	6	4.6	4	1.3
Total	449	392.97	213	150.8	236	252.0	88	64.3
RR	1.14, $p < 0.002$		1.41, $p < 10^{-4}$		0.94, $p < 0.15$		1.37, $p < 0.0003$	
RR	(no trend)		1.40, $p^* < 0.0008$		(no trend)		1.23, $p^* < 0.1$	

[a] From (*1–4,10*). Relative increase of risk for all acute leukemia = RR (all acute): RR (all) = 1.41:1.14 = 1.24. Note that four additional studies (*6–9*) yield further data for several job classifications, as follows: (*8*) PIR: 1,4,5,6,12/13; (*6*) PMR: 2; (*7*) SMR: 12; (*9*) SMR: 4,6. These studies contribute an additional 70 cases observed, 50.8 cases expected for all leukemia, and 14 cases observed, 7.7 cases expected for acute leukemia. The individual risk ratios follow the general trend among the occupational subclasses, and the additional data do not appreciably affect the overall pooled results.

[b] PIR, PMR low by about 5% due to high SMR for respiratory tract cancer.

design, and population origin. Studies of lung cancer among nonshipyard welders are summarized in Table A2. Regional studies of lung cancer based on death certificates (which include some shipyard welders) are summarized in Table A3. Studies of cancer in shipyard welders are summarized in Table A4. Studies of cancer at sites other than the lung, with the exception of leukemias, are summarized in Table A5. The pooled results are presented in Table A6.

One problem that limits the ability to demonstrate excess cancer incidence for welding cohorts is dilution by inclusion of other trades, specifically under the general occupational heading "gas and electric welders, burners and caulkers." However, unless these other activities are accompanied by extremely high risks, the dilution reduces incidence, and only minimally.

Because shipyard welders are subject to bystander exposures, particularly asbestos, these studies are listed separately. The sentinel for asbestos exposure is mesothelioma. As most nonshipyard cohort studies specifically indicated the absence of mesothelioma cases in their reports, the effect of asbestos is not large outside of shipyards. The lung cancer incidence in shipyard populations, which frequently exhibit mesothelioma (*6,49*), will have a small contribution from asbestos exposure; see references (*50,51*) for a recent discussion. Welders have been shown to have an overconsumption of tobacco (*48,52,53*), which might explain some, but not all, of the observed overincidence of respiratory tract cancer. For the case of leukemia, the putative factor is exposure of welders to ELF. ELF exposure is restricted to electric arc and resistance welders, who compose 90% of the

Table A2. Cohort and case control studies of respiratory tract cancer incidence in nonshipyard welding populations.

Study	No. of cases	O	RR	E[a]	Reference	Comments
Cohort						
Dunn and Weir (1968)		49	1.05	46.7	(*65*)	
Fletcher and Ades (1984)		8	1.46	5.5	(*66*)	
Becker et al. (1985)		6	0.95	6.3	(*38*)	Stainless steel
Ott et al. (1976)		2	1.0	2.0	(*67*)	
Polednak (1981)		17	1.5	11.3	(*39*)	Stainless steel
Redmond et al. (1979)		14	1.51	9.3	(*68*)	
Sjögren (1987)		5	2.49	2.0	(*57*)	Stainless steel
Case control						
Breslow et al. (1954)	14		7	2[a]	(*69*)	
Decoufle et al. (1978)	9		0.9	10	(*70*)	
Gerin et al. (1984)	12		2.4	5	(*55*)	Stainless steel
Kjuus et al. (1986)	28		1.9	15.7	(*56*)	All welders
	16		3.3	4.8	(*56*)	Stainless steel

[a] Expected = no. of cases/RR.

Table A3. Regional respiratory tract cancer incidence studies based on death certificates.[a]

Study	O (cases)	RR[b]	E	Reference
Dunn et al. (1986)	19	1.12 (SIR)	17.0	(*71*)
Gallager and Threefal (1983)	74	1.45 (PMR)	51.0	(*72*)
Gottlieb (1980)	8	4.01 (CC)	2 (cases/RR)	(*73*)
Menck and Henderson (1976)	48	1.37 (SMR)	35.0	(*74*)
Milham (1976b, 1981, 1983, 1985)	191	1.35 (PMR)	141.5	(*5,60–63*)
Morgan and Treyve (1982)	31	1.78 (SMR)	17.4	(*75*)
OPCS (1978)	246	1.51 (SMR)	163.0	(*48*)
Peterson and Milham (1980)	27	0.99 (PMR)	27.3	(*43*)
Silverstein et al. (1985)	10	2.20 (SPMR)	4.5	(*41*)
Sjögren et al. (1982)	(96)	(1.44) (SIR)	(66.7)	(*64*)
Sjögren and Carstensen (1986)	193	1.42 (SIR)	136.0	(*45*)
OPCS (1986)	381	1.46 (SMR)[c]	260.1	(*42*)
	305	1.27 (PMR)[d]	240.6	

[a] Includes some shipyard welders.
[b] SIR, standardized incidence ratio; PMR, proportional mortality ratio; CC, case control; SMR, standardized mortality ratio; SPMR, standardized proportional mortality ratio.
[c] SMR < 65 years.
[d] PMR 65–75 years.

Table A4. Studies of respiratory tract cancer among welders working in shipyards (cohort and case control studies).

Study	O	RR	E	Reference	Comments
Beaumont and Weiss (1980, 1981)	50	1.32	37.9	(*37,54*)	Shipyard and construction
McMillian and Pethybridge (1983)	5	0.96	5.2	(*76*)	
Newhouse et al. (1985)	26	1.13	23.0	(*59*)	Mesothelioma, SMR = 1.84
Putoni et al. (1979)	7	1.38	5.1	(*40*)	
Putoni et al. (1984)	12	1.60	7.5	(*44*)	
Sheers and Cole (1980)	—	—	—	(*49*)	Mesothelioma, SMR = 5.0
Blot et al. (1978)	11 (cases)	10.5	10.5	(*77*)	RR = 0.7 vs. shipyard population
Blot et al. (1980)	11 (cases)	1.25	8.8	(*78*)	

Table A5. Studies of cancer incidence among welders at sites other than bronchia and lungs, excluding mesothelioma and leukemias.

Study	Method[a]	Site	Cases	RR	Reference
Polednak (1981)	SMR	Brain, CNS	5	—	(*39*)
Gallager and Threlfall (1983)	PMR	Hodgkins	—	2.42	(*72*)
Milham (1976, 1981)	PMR	Bladder	12	1.62	(*61,63*)
Milham (1983)	PMR	Kidney	20	1.8	(*60*)
Peterson and Milham (1980)	PMR	Hodgkins	6	1.96	(*43*)
Sjögren and Carstensen (1986)	SIR	Kidney	70	1.3	(*45*)
Putoni et al. (1979)	SMR	Kidney	5	4.2	(*40*)
		Bladder			
Englund et al. (1982)	SMR	Brain	50	1.35–1.44	(*79*)
Hernberg et al. (1983)	CC	Nasal	21	2.8	(*80*)
Howe et al. (1980)	CC	Bladder	—	2.8	(*81*)
McLaughlin (1982)	CC	Kidney	13	1.1–1.5	(*82*)
Olesen et al. (1984)	CC	Larynx	20	1.8	(*83*)
Malker and Weiner (1984)	SIR	CNS	50	1.4	(*84*)
OPCS (1986)	SMR	Pancreas	46	1.48	(*42*)
Silverman et al. (1983)	CC	Bladder	18	0.6	(*85*)
Milham (1985)	PMR	Brain	19	1.0	(*5*)
		Pancreas	27	0.93	
		Lymph and blood	57	1.07	

[a] See footnotes of Table A3 for abbreviations.

population. Approximately 10% of the general welding population exclusively uses autogene (gas) welding (*24*), which does not entail exposure to ELF; this subpopulation can be considerably higher in shipyards, but gas welders are frequently listed as a separate trade (*40,44*), and they are important in one study only (*41*).

Possible origins of lung cancer among welding cohorts have been discussed in detail in the literature (*29,31,32*). Although welding fumes contain trace amounts of Pb and As (*32*), the only putative human carcinogens to which welders have significant direct exposures are Ni and Cr(VI) (*24,26,30,33*). It has been suggested that exposure to high concentrations of Cr(VI) and to Ni, which uniquely appear in the fumes from the welding of stainless and alloy steel, might result in a significantly increased incidence of respiratory tract cancer among

Table A6. Summary of pooled data for respiratory tract cancer for welding cohorts.

Subgroup of studies	O	E	Average RR	RR*[a]
Table A2: Nonshipyard	134	98.8	1.36, $p < 10^{-4}$	1.18, $p^* < 0.15$
Table A3: Death Certificate	1533	1095.3	1.40, $p < 10^{-7}$	1.39, $p^* < 10^{-7}$
Table A4: Shipyard	122	97.6	1.25, $p < 10^{-2}$	1.28, $p^* < 0.02$
All welders' lung cancer	1789	1290.7	1.39, $p < 10^{-10}$	1.37, $p^* < 10^{-10}$

[a] Excluding case control studies.

the 10 to 15% of the welding population using these materials (*31*). Because of the large dilution factor, this excess would only be expressed as a small overincidence in studies of general welding populations. It has also been suggested that exposure to welding fumes in general leads to a slight excess in respiratory tract cancer on the average (*29*), which might, however, become high among cohorts with high cumulative exposures or long latency periods.

One study based on union records of a general welding population (*37,54*), which is sufficiently stratified with respect to age, latency, and exposure, supports the association of long latency with high risk (based on 50 cases), although there are less robust effects of age and length of exposure. However, a second study (*42*) based on a national survey of death certificates (686 cases) exhibits a constant age-specific excess risk [SMR = 1.42–1.53 in the range 35–64 years, PMR = 1.27 (corresponding to an SMR of about 1.46) from 65–74 years]. In this latter case, because most welders enter the trade at the same age after an apprenticeship, age, latency from first exposure, and cumulative exposure are equal. Thus, the relative contribution of age, exposure, and latency is still equivocal, and the effect of smoking may become extremely important. Three ongoing studies of stainless steel welding populations with sufficient latency (*55–57*) support the Cr-Ni etiology, although the results of follow-up of these and other studies (*38*) must be awaited before the risk is established.

Chemical exposures may play an important role for tumor incidence at sites other than the respiratory tract among welders (See Table A5), although the number of cases is small and the study designs do not permit assessment of causality; that some of these cancers might have their origin in the ELF exposure of welders cannot be excluded [e.g., tumors of the brain (*58*) and urinary tract (*9*)].

The pooling of epidemiological data requires justification because of the bias introduced by the nonreporting of negative results. For the literature cited, most cohorts of welders are accidentally included in larger studies, and the results are published without bias against negative outcomes. The six epidemiological studies designed exclusively for welders (*37–39,54,57,59*) contribute only 24 cases to the 588 excess respiratory tract cancers observed, so that their contribution to any bias is minimal. For this case of respiratory tract cancer among welders, the existence of four large ($n > 191$) studies [(*5,60–63*), (*42*), (*45*), and (*48*)] with similar (RR = 1.35, 1.42, 1.46, 1.51, RR* = 1.40, $p^* < 10^{-6}$), highly statistically significant risk ratios makes pooling an unnecessary manipulation, as the excess risk is apparent. On the other hand, pooling the small studies ($n < 74$) alone (O = 473, E = 349.5, RR = 1.35, $p < 10^{-9}$, RR* = 1.30, $p^* < 0.00012$) gives a similar and statistically significant result for the average risk, suggesting that pooling of the data from many small studies is occasionally justifiable in the absence of large studies.

The combination of variance-weighted log (risk ratios) (*47*) is recommended if the group of studies belong to a single distribution; this is supported by the observation that the standard deviations of the respiratory tract cancer studies cited are approximately (log) normally distributed (*32*) (with the exception of those from the large regional surveys).

If one can justify pooling the large amount of data for respiratory tract cancers, then one might, by extension, pool the leukemia data as well, although there are fewer large studies on which to independently justify such an approach (see Appendix 1), although meta analysis is not justified on the welders cohort because of the absence of a trend, apparent in the data for electrical trades.

The results of pooling of the respiratory tract data for cohort and cross-sectional studies of welders from Tables A2–A4 are shown in Table A6. Note that pooling these data results in average values of RR that are mostly highly statistically significantly different from unity: RR = 1.36, $p < 0.0001$ (note: RR* = 1.18, $p^* < 0.15$ ns) for pooled data from Table 2, RR = 1.40, $p < 10^{-7}$ (RR* = 1.39, $p^* < 10^{-7}$), for Table A3, RR = 1.25, $p < 0.02$ (RR* = 1.28, $p^* < 0.02$) for Table A4, and RR = 1.39, $p < 10^{-10}$ (RR* = 1.37, $p^* < 10^{-10}$) for all respiratory tract cancer, Tables A2–A4.

The traditional argument against pooling is the alternate suggestion to critically select epidemiological studies based on strict criteria for quality. Unfortunately, none of the studies of welders cancer incidence that might meet such standards are sufficiently large to provide a statistically significant overthrow of the null hypothesis, leaving meta analysis as a necessary exercise to determine if there is an excess of cancer incidence among welders. It should be pointed out, however, that at present, a concerted effort is being made on the part of The World Health Organization, Regional Office for Europe, to initiate a number of carefully controlled prospective mortality studies of cancer among welders both with and without exposure to stainless steel (*34*). The study, coordinated by The International

Agency For Research On Cancer, Lyon, involves a joint exposed population of 14,000 welders, with 60 cases expected among nonstainless steel-exposed welding population, and 40 cases expected among stainless steel-exposed welders, with a target date for completion of mid-1989.

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