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Reproductive Outcomes Among Male and Female Workers at an Aluminum Smelter

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Abstract

Objectives—Several adverse pregnancy outcomes were reported among female laboratory workers in a North American aluminum smelter. To determine whether these outcomes were associated with any occupational exposure at the plant, a cross sectional survey was undertaken.

Methods—Rates of miscarriage, premature singleton birth, and major congenital anomaly occurring during employment were compared to a reference group comprised of all pregnancies that occurred prior to employment.

Results—Among female workers, the excess of congenital anomalies among female laboratory workers that defined the initial cluster was observed, but no specific pattern was found.

Conclusions—Based on these analyses, the increase in congenital anomalies could not be attributed to occupational exposures at the smelter, nor could potential exposure likely explain the diverse anomalies described.

MeSH keywords

Aluminum Smelters; Aluminum Manufacturing; Epidemiology; Occupational Health; Reproductive Health; Pregnancy; Women's Health

Introduction

The proportion of females in the workforce has gradually increased over recent years. In 2006, women comprised 46% of the total U.S. labor force, and occupied jobs in diverse sectors of industry,[1] raising the concern of potential occupational effects on reproduction. Several hazards have been established as risk factors for adverse reproductive outcomes in women

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(such as anaesthetic gases, antineoplastic drugs, lead, etc.) however, the available data on many potential human reproductive and developmental hazards are deficient. [2,3]

Several adverse pregnancy outcomes were reported among female laboratory workers in a North American aluminum smelter between 1992 and 2004. From 1992, to August of 2000 ten pregnancies were reported in female laboratory workers. Four of these had normal outcomes, and there was one spontaneous abortion, two premature births, and three congenital anomalies (one trisomy 9, one musculoskeletal anomaly, and one renal anomaly). In response to the concerns expressed by the Health Service Physician at the plant regarding the occurrence of these unfavorable pregnancy outcomes among the laboratory workers, the local Public Health Director conducted an investigation. The conclusions were that the number of congenital anomalies was greater than one would expect, however the three cases were of very different nature, which did not suggest a single cause. The recommendations were to reassign pregnant workers from the beginning of their pregnancy to administrative jobs, to monitor the outcome of future pregnancies, and to alert the Public Health Director if further unfavorable pregnancy results should appear. After 2000, there were 15 pregnancies reported among female laboratory workers of which, eight were normal, six resulted in spontaneous miscarriages, and one resulted in a congenital anomaly (trisomy 18).

To investigate this cluster of adverse pregnancy outcomes, the authors undertook a cross-sectional survey among both male and female production, technical, and administrative workers at the smelter. The objective of this survey was to determine whether the incidence of adverse pregnancy outcomes in this population increased in workers after they started working at the plant (compared to before), and if particular departments, or exposures within the smelter were more strongly associated with increased risk than others.

Materials and Methods

Target population

The target population was the entire active work force (male and female) at the smelter, which included 730 people (552 full time employees and 178 contractors). In this smelter, contractors occupy the same jobs as full time employees and were therefore included in this analysis. A decision was made to evaluate the reproductive history of males as well, because in several reported cases, both parents worked at the plant.

Survey

An anonymous questionnaire was developed to gather information on the workers' occupational and reproductive history as well as their demographic background. The questionnaires were distributed at the plant and workers had the option to take them home, in case they wanted assistance from their partners to complete them. During that period of time, the primary investigator (CJS) was present on site for one week and was available to answer questions and to assist the workers in completing the questionnaire. Participation in the study was voluntary and all responses were kept anonymous. Workers were also provided with a toll free number to directly contact the investigators in case they had any questions regarding the study. Random numbers were assigned to each questionnaire which allowed the investigators to do a random sampling of 80 questionnaires for reliability estimation. The workers whose numbers were chosen for the reliability testing were requested to fill out the questionnaire a second time. In an effort to maximize participation, several communication sessions with the workers were held at the plant. During these sessions, the survey was described in detail and participation was strongly encouraged.

Questionnaire

The questionnaire was an adapted version of the reproduction questionnaire used by Schenker and colleagues in their semi-conductor health study.[4,5] Different questionnaires were created for male and female respondents, although both surveys included the same information. For females, the questions were focused on each of their pregnancies, whereas for males, questions pertained to all the pregnancies that they had fathered. Each questionnaire was comprised of two parts: the first part contained general information questions (age, level of education, and occupational history). The second part referred to all the pregnancies the person had or fathered. Each worker who had or fathered one or more pregnancies was asked to fill out the second part. This second part included multiple identical sections (one for each pregnancy).

The respondents were asked about the outcome of each pregnancy, their lifestyle habits, and the occupation of their partner during that pregnancy. For each pregnancy, the survey asked for the date (month/year) that the pregnancy ended and the outcome of that pregnancy (single live birth; multiple live birth; ectopic; abortion for abnormality or no; spontaneous abortion; stillbirth; molar). For each outcome, further questions were asked (number of weeks the pregnancy lasted, description of the congenital anomaly, etc.).

The respondents were also asked about medical conditions encountered by the mother during the pregnancy (hypertension, diabetes, pre-eclampsia or eclampsia, thyroid disorder, systemic lupus, or other). They were also asked about the age, smoking and drinking habits of the mother during the pregnancy.

Data collection and management

A data analyst abstracted the data from the completed questionnaires and entered them in an electronic format for analysis. Four pregnancy outcomes were defined as endpoints for the analysis, namely, normal live birth, miscarriage, live birth with congenital anomaly, and premature birth. A nosologist was given the data on the congenital anomalies and classified them as major and minor. A major anomaly was defined as an anomaly of surgical or cosmetic consequence (such as Fallot tetralogy) while a minor anomaly was defined as having little impact on individual well-being (such as low set ear). The nosologist was blinded to the employment status at the time of each pregnancy. We only analyzed major anomalies since minor anomalies are much more likely to be selectively reported. The different jobs at the aluminum smelter were grouped into three categories, corresponding to different exposure potential: production, administration, and laboratory. This classification was done by a member of the human resource department based on job titles.

Evaluation of the work environment

Aluminum smelting is a heavy manufacturing industrial process, historically dominated by male workers. This facility uses the prebake electrolytic reduction process during which aluminum oxide is dissolved in a molten cryolite bath (sodium aluminum fluoride) contained in a large carbon or graphite-lined steel container known as a pot. An electric current flows between a carbon anode and a cathode formed by the lining of the pot. Molten aluminum is deposited at the bottom of the pot during this process and is siphoned off for use in casting ingots. During reduction, the pot emits a variety of gases, including hydrogen fluoride and sulfur dioxide, and dusts of alumina and fluoride as well as coal tar pitch volatiles (CTPV's) containing polycyclic aromatic hydrocarbons (PAH's). Controls of these exposures rely on major ventilation systems for collection at the source, such as air purifiers or dust extractors. However (a fraction of) some fugitive emissions are released in the work area during specific operations like the opening of the hoods on the pots. Other exposures of concern include direct current electromagnetic fields (EMF), physical stress and heat stress.[6]

The smelter laboratory is principally a finished product quality and process control environment. Finished product (i.e., aluminum from ingots) is analyzed and certified before delivery to clients. Process materials (such as aluminum from alloy preparation, smelter pot electrolyte bath, alumina the raw material, and carbon electrodes) are also analyzed for production purposes. Finally environmental samples are analyzed, for plant operation purposes, but also to be reported to the local environment authorities. Though most analytical work requires no reagents, some do. Those needed are principally pelleting powder, acids for solutions, and organic solvents. Reference materials for all the tests performed are also found in the laboratory. The laboratory technicians do not perform any sampling. Production and process samples are brought to the laboratory by operators from the different departments.

Random personal industrial hygiene samples of each hazard of concern have been routinely obtained since the plant opened. This established exposure levels for each group of similarly exposed workers (SEG), defined as a group of workers who have similar job functions with similar exposure profiles and is described by the department, job, task, and exposure material at each location. The software database for each sample includes location name, department name, job title, task name, worker name and identification number, sample sampling date, sampling strategy exposure type, personal protective equipment used, agent identification, agent name, duration of sampling and shift length. All air samples are acquired through personal monitoring in the breathing zone of workers outside of any personal protective equipment, thereby evaluating exposures without consideration of protective measures.

As part of this study, the investigators and location industrial hygienists did a walk-through of the plant including the production areas and laboratory. No new samples were obtained, and measurements contained in the industrial hygiene database from the production areas (total dusts, particulate fluorides, hydrogen fluorides, PAHs, SO_2, noise etc.) and the various chemicals from the laboratory were summarized and reviewed.

Statistical analysis

To evaluate whether any of the outcomes occurred more among a particular job category, the authors identified reference groups which comprised all pregnancies that occurred pre-employment. For each different outcome, the proportion occurring during employment, to the reference group described, was compared. Chi Square test was used to test the difference in proportions across employment groups. In order to incorporate potentially important covariates such as year of birth, logistic regression was utilized to calculate adjusted odds ratios. The main predictor variable was the job category at the time of pregnancy (production, laboratory, and administration).

All data were stratified by gender. All pregnancies were reported for female workers. As for the male workers, the pregnancies they fathered (the information reported is relevant to their spouses, i.e. mother/s of their children) were analyzed. For the analysis of miscarriage, the data was stratified into: pre-1999 and post-1999 since it was around that date that workers at the smelter became more aware of the adverse pregnancy outcomes that had occurred, and thus may have become more likely to note and report miscarriages. In addition, pregnancy tests were made available at the on-site medical department.

Reliability, based on the random sample of 80 questionnaires, was assessed by calculating the percentage of agreement between answers at the two times.

A model parameter was reported as significant if the p-value for the term was less than 0.05. SAS version 9.01 was utilized.

The study protocol was approved by the Yale University Human Investigation Committee.

Results

The participation rate for the survey was 85% (621 workers participated, out of a total of 730 eligible). The rate was higher among females (106/113 or 94%) compared to males (515/617 or 83%).

The authors included in the analyses all men and women who reported one or more pregnancies (343 males and 76 females). Table 1 describes the characteristics of this population.

The majority of men had a high school education, or less (53.9%), while the majority of women had a college education (61.8%). Mean age at time of the survey was 43.7 years (s.d.=6.3) for men and 42.6 years (s.d.=7.3) for women. On average men started working at the plant earlier than women (1992 vs 1994). The majority of men held production jobs (80.5%), while half of the women held administrative jobs (50.0%).

Characteristics of reported pregnancies are described in Table 2 (N=919).

Not surprisingly, for both men and women, the mean age of conception was higher in the period during employment. Cigarette smoking and alcohol drinking were both more prevalent in the before-employment period in both groups. The three main outcomes: miscarriage, premature single birth, and congenital anomaly were analyzed separately.

The proportion of miscarriages reported by females and males was significantly lower pre-1999 when compared to post-1999 (pre-1999: 76/759=10.01%; post-1999: 37/160=23.13%, p <0.0001). When compared to the female spouses of male workers, female workers had higher proportions of miscarriages (spouses of male workers: 79/735=10.75%; female workers: 34/184=18.48%, p=0.004).

The results of the multivariate analysis of adverse pregnancy outcomes reported by female workers are described in Table 3. For female workers, year of conception was associated with miscarriage although the relationship did not reach statistical significance (OR 2.76, 95% CI 0.89, 8.57 for year of conception after 1999, compared to before 1999). Working in the laboratory was significantly associated with the occurrence of congenital anomaly. The relationship between most of the covariates with premature birth was unable to be evaluated because of insufficient number of events (Table 3).

Table 4 shows the multivariate analysis of adverse pregnancy outcomes reported by male workers. For spouses of male workers, year of conception was significantly associated with miscarriage (OR 2.00, 95% CI 1.05,3.80 for year of conception after 1999, compared to before 1999). Employment in the lab for the father was associated with increased miscarriage although this result did not reach statistical significance (OR 2.48, 95% CI 0.74, 8.31). Employment in production area for the father was significantly associated with premature birth. For the premature birth outcome, a medical condition during pregnancy (defined as any of: hypertension, diabetes, eclampsia, thyroid disorder or systemic lupus) was significantly associated with the outcome. For the spouses of male workers, alcohol consumption during pregnancy was significantly associated with miscarriage. None of the covariates evaluated was associated with congenital anomaly for male workers (Table 4).

The list of congenital anomalies reported by females is described in Table 5.

The agreement on the rates of miscarriages, premature births and congenital anomalies between the first survey and the second was calculated. For miscarriage, the agreement was 100% (14 reported in both the first and the second survey), for premature birth 80% (five reported in the first survey, and four in the second), and for congenital anomaly 100% (eight reported in both the first and the second survey).

Results of environmental evaluation

Exposures of note in the production areas included direct current electromagnetic fields and coal tar pitch volatiles. Review of laboratory workers' exposures revealed they would have spent less than 10% of their time in areas with these exposures. The processes and materials unique to the laboratory work areas were evaluated, and standard safety procedures were employed. Chemicals were mixed under hoods that were ventilated outside, and all chemicals were used in very small quantities. Organic solvents and acids were present in very low quantities. Table 6 shows the arithmetic mean time weighted average levels of the different agents measured in the smelter and laboratory. The measured levels were low, compared to the American Conference of Governmental Industrial Hygienists' threshold limit value (TLV) for the specific agent. The TLV is defined as the airborne concentrations of chemical substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effects, although levels safe for reproduction have not been established for some.

Discussion

The authors observed no increase in congenital anomalies between the employment periods (before and during) at the plant among the offspring of all male workers. Male production workers had higher rates of premature birth when compared to the before-employment rates. Male lab workers had higher rates of miscarriage when compared to the before-employment rates, although this result did not reach statistical significance. For female workers, there was not an increase in miscarriages or preterm births, across any of the job categories (administration, production, and laboratory).

For the spouses of male workers, alcohol during pregnancy was significantly associated with miscarriage. This finding was not surprising since alcohol has been identified as a known risk factor for miscarriage.[7,8] The presence of a medical condition during pregnancy (such as hypertension, diabetes, eclampsia, thyroid disorder, or systemic lupus) was associated with premature birth among spouses of male workers. Many of these conditions result in medically-indicated termination of pregnancy, which would explain the preterm birth described.[9,10]

The increased rate of premature birth reported by production males and of miscarriage reported by lab males could not be attributed to occupational exposures. Theoretically, production workers could track home coal tar pitch volatiles, however these compounds are not known to be associated with premature birth. As for laboratory workers, a clear mechanism could not be found that would explain how their occupational exposures (which are already minimal as described above) could cause an increased rate of miscarriage among their spouses.

As expected, an excess of congenital anomalies was observed among female laboratory workers when comparing during-employment to before-employment time periods. This excess was the initial cluster that initiated the study, i.e., the congenital anomalies described among laboratory female workers. However, given the diverse anomaly types, absence of other adverse outcomes and low exposure levels, there is little evidence to suggest that the excess of congenital anomalies documented is due to workplace factors. These anomalies were of different nature as they comprised chromosomal aberrations, as well as isolated organ malformations (one musculoskeletal, and one renal). It would seem unlikely that a single agent might cause this array of outcomes. Environmental or occupational toxicants usually exert specific effects, such as methyl mercury and psychomotor retardation.[2,11] Still, the work environment was evaluated in detail. Although electromagnetic fields and coal tar pitch volatiles in production were potential contributors, laboratory workers have far less exposure to these than production workers, whose reproductive histories were unremarkable. Organic solvents constitute a potential exposure unique to the laboratory. The literature on exposure to solvents and congenital anomalies is controversial. While some described an increased risk of fetal malformations for women with occupational exposure to organic solvents,12,13 others were unable to replicate these findings.[14] The female laboratory workers in this study population had minimal exposure to organic solvents.

The authors are not aware of any prior study that has assessed the reproductive history of workers in aluminum smelters, although a few studies have evaluated the occupational or environmental risks of copper smelters on reproduction. Wulff and colleagues found no effect on spontaneous abortion, birth weight, perinatal death, and congenital anomalies, associated with working in or living close to a smelter.[15–17]

Workers in aluminum smelters have multiple potential occupational exposures (Polyaromatic hydrocarbons, fluorides, electromagnetic fields, etc.). Few studies have evaluated the effects of polyaromatic hydrocarbons or electromagnetic fields on reproduction, although environmental exposure to polyaromatic hydrocarbons has been reported in association with lower birth weight, lower birth length, and smaller head circumference.[18,19] Exposure to electromagnetic fields from power lines was not associated with congenital anomalies.20–22 Evans et al. reported no major reproductive hazard associated with electromagnetic fields exposure among magnetic resonance imaging workers.[23] A study by Li suggested that prenatal maximum magnetic field exposure above a certain level may be associated with miscarriage risk.[24] Exposure to physical stress, and especially shift work has been linked with elevated risk of spontaneous abortion,[25,26] but not with congenital anomalies. For our study populations, these exposures would not explain the excess of congenital anomalies found among laboratory workers since their exposure is significantly less than the exposure of the production workers, based on expert industrial hygiene observation.

The higher proportions of reported miscarriages among female workers and female spouses of male workers after 1999, compared to before 1999 could be attributed to ascertainment and recall biases. In 1999 workers at the plant became more aware of the reports of adverse pregnancy outcomes, which may have contributed to increased reporting. Pregnant women were reassigned to administrative jobs and pregnancy tests were, for the first time, available at the site medical department. These events could have resulted in subsequently higher ascertainment of early pregnancies, and miscarriages that may have been otherwise undiagnosed. Recall bias in the report of miscarriage is not uncommon in non-prospective epidemiologic studies since people tend to remember recent events more accuratly.[27,28]

In order to have the best reference group, especially for females, we compared workers to themselves at a different time period by comparing outcomes that occurred during employment to the period before employment. This type of comparison has been used by others in the analysis of spontaneous abortions among female industrial workers.29 It is acknowledged that age could also confound our results since it is associated with the outcome (older women have higher risk of adverse pregnancy outcomes), and the exposure (women are generally older during employment, compared to before employment). The authors opted for that strategy because working women have different characteristics when compared to the rest of the female population,[30] as demonstrated by this analysis in which the proportions of adverse pregnancy outcomes of female workers were higher than those of the female spouses of male workers. Savitz and colleagues reported that employed women generally had less favorable reproductive histories (more stillbirths, miscarriages, and induced abortions) when compared to unemployed women30 The authors concluded that substantial differences in pregnancy-related risk factors existed in relation to employment, and encouraged restricting the comparison groups to other employed women in studies of work and reproductive health, while taking into consideration heterogeneity among working women as well.30

The major strength of this study was the high participation rate (85%) which should have minimized selection bias. Reproductive surveys reported in the literature maintain significantly lower participation rates (69% Wulff ; 58% Mageroy)[15,30] This elevated participation rate was attributed to the combination of the extensive communication at the plant, the raffle, and a highly motivated workforce.

The questionnaire that we used was adapted from a questionnaire that has already been validated in the Semiconductor Health Study.[4] Reliability testing showed very good agreement rate (80–100%).

On the other hand, the study outcomes were based on self-reported data. By definition these studies are prone to recall bias. In addition, we did not validate the results reported with hospital or state registries because of the anonymous nature of the survey. The authors acknowledge that some outcomes are more likely to be underreported (such as miscarriage) however we do not expect outcomes such as congenital anomalies to be underreported, since these events are less likely to be forgotten.

We restricted our exposure categories to: production, laboratory, and administration. Although we are aware that the production category includes workers from potrooms and anode factory that could potentially have different exposures, however these areas of production are adjacent to each and the exposures are pretty similar in both rooms. In addition, given the outcomes of interest, our numbers were too small to allow further stratification by more specific exposure groups.

In conclusion, the authors observed no increase congenital anomaly among the offspring of male workers when we compared these outcomes between the before and during employment periods at the plant. In our multivariate analysis, among males, production work was associated with higher rates of premature birth and laboratory work was associated with higher rates of miscarriage (although this final result did not reach statistical significance). As we detailed previously, these findings could not be attributed to the males' occupational exposures. For female workers, we observed an excess of congenital anomalies among laboratory women workers when comparing during-employment to before-employment periods. Based on these analyses and on the aforementioned reasons, this increase cannot be attributed to occupational exposures at the smelter. The plant continues to offer further surveillance of pregnancy outcomes. These results illustrate previously documented examples of risk factors for miscarriage (alcohol) and premature birth (medical conditions in the mother). This study also demonstrates the challenges encountered in reproductive epidemiology in the workplace, such as dealing with recall bias and selecting an appropriate reference group for working women.

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Table 1

Characteristics of the Study Population, Including All Active Workers Who Completed the Survey and Reported One or More Eligible Pregnancies (N, SD for Continuous Variables and N, % for Categorical Variables)

		Male (N=343)		Female (N=76)	
Education					
	≤Highschool	185	53.9	28	36.8
	College	151	44	47	61.8
	≥Graduate	6	1.7	1	1.3
	Refused	1	0.3	0	0
Age (at time of survey)		43.7	6.3	42.6	7.3
Year started working at the plant		1992	3.4	1994	4.7
Years worked at the plant		13	3.4	12	4.7
Current job					
	Production	276	80.5	25	32.9
	Laboratory	14	4.1	13	17.1
	Administration	40	11.7	38	50
Unable to Determine		13	3.8	0	0

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Table 2

Description of the Pregnancies (N, SD for Continuous Variables and N, % for Categorical Variables)

	Male				Female			
	Before Employment (N=414)		During Employment (N=321)		Before Employment (N=116)		During Employment (N=68)	
Age at conception	26.7	3.8	29.5	4.3	25.5	4.9	31	4.5
Number of pregnancies	2.1	0.9	2.3	1	2.4	1	2.5	1.3
Health problems during pregnancy								
Hypertension	13	3.1	6	1.9	2	1.7	2	2.9
Diabetes	11	2.7	20	6.2	1	0.9	3	4.4
Pre-eclampsia or eclampsia	9	2.2	8	2.5	1	0.9	1	1.5
Thyroid disorder	5	1.2	9	2.8	1	0.9	0	0
Systemic lupus	0	0	0	0	0	0	0	0
Other medical condition	22	5.3	32	10	8	6.9	12	17.6
Smoking during pregnancy	87	21	34	10.6	30	25.9	6	8.8
Cigarettes smoked	14.1	6.1	12.6	6	13.4	5.7	9.3	4.5
Drinking during pregnancy	22	5.3	9	2.8	6	5.2	3	4.4
Drinks consumed	2.7	2.4	4.7	6.8	2.3	4.8	0.7	1.2

Table 3

Multivariate Analysis of Adverse Pregnancy Outcomes Among Female Workers

	N	Miscarriage		Premature birth		Congenital anomaly	
		OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Age	184	1.08	0.98, 1.18	1.14	0.89, 1.46	1.04	0.87, 1.23
Education							
High school (reference)	74	1.0 (reference)		1.0 (reference)		1.0 (reference)	
College	110	0.93	0.38, 2.31	0.37	0.04, 3.55	1.10	0.22, 5.37
Year of conception							
< 1999 (reference)	141	1.0 (reference)		1.0 (reference)		1.0 (reference)	
>=1999 (vs < 1999)	43	2.76	0.89, 8.57	1.09	0.04. 33.23	0.74	0.12, 4.42
Employment area							
Before employment (reference)	116	1.0 (reference)		1.0 (reference)		1.0 (reference)	
Production	22	0.42	0.10, 1.71			3.43	0.44, 26.97
Lab	26	0.38	0.09, 1.59			**7.89**	**1.16, 53.77**
Administration	19	0.94	0.26, 3.39			1.85	0.15, 22.14
Medical condition during pregnancy*							
No (reference)	176	1.0 (reference)		1.0 (reference)		1.0 (reference)	
Yes	8	**		**		1.80	0.17, 19.32
Smoked during pregnancy							
No (reference)	148	1.0 (reference)		1.0 (reference)		1.0 (reference)	
Yes	36	0.70	0.21, 2.38	**		1.17	0.18, 7.43
Drank alcohol during pregnancy							
No (reference)	175	1.0 (reference)		1.0 (reference)		1.0 (reference)	
Yes	9	0.85	0.09, 7.66	8.90	0.57, 139.86	**	

* Hypertension, diabetes,eclampsia,thyroid disorder, or systemic lupus

** Unable to calculate due to small number of cases

Table 4

Multivariate Analysis of Adverse Pregnancy Outcomes Among Male Workers

	N	Miscarriage		Premature birth		Congenital anomaly	
		OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Age	725	1.03	0.97, 1.09	0.87	0.79, 0.96	1.04	0.94, 1.15
Education							
High school (reference)							
College	332	1.11	0.66, 1.86	1.61	0.76, 3.44	1.22	0.52, 2.84
Year of conception							
< 1999 (reference)							
>=1999 (vs < 1999)	117	**2.00**	**1.05, 3.80**	0.97	0.33, 2.90	1.24	0.34, 4.50
Employment area*							
Before employment (reference)	426	1.0 (reference)		1.0 (reference)		1.0 (reference)	
Production	263	1.19	0.66, 2.13	**2.85**	**1.25, 6.49**	0.74	0.27, 1.99
Lab	20	2.48	0.74, 8.31	1.43	0.17, 12.42		
Administration	26	1.13	0.33, 3.91	1.35	0.15, 12.47	0.86	0.09, 8.47
Medical condition during pregnancy*							
No (reference)							
Yes	66	0.35	0.11, 1.16	**3.62**	**1.50, 8.70**	1.34	0.38, 4.70
Smoked during pregnancy							
No (reference)							
Yes	124	0.97	0.49, 1.91	1.26	0.49, 3.25	1.35	0.48, 3.77
Drank alcohol during pregnancy							
No (reference)							
Yes	20	**3.24**	**1.07, 9.84**		None		None

* Hypertension, diabetes, eclampsia, thyroid disorder, or systemic lupus

Table 5

List of Congenital Anomalies Reported by Female Workers

Congenital Anomaly	Before/During Employment	Birth type	Year work started	Year of the pregnancy	Job category
Musculoskeletal	During	Live (single)	1991	1994	Laboratory
Ocular *	During	Live (single)	1992	1994	Production
Trisomy 9	During	Live (single)	1992	1996	Laboratory
Renal	During	Live (single)	1991	1997	Laboratory
Renal *	During	Live (single)	1992	1997	Production
Cardiovascular	During	Live (multiple)	1991	1999	Production
Trisomy 18	During	Live (multiple)	1991	2003	Laboratory
Musculoskeletal	Before	Live (single)	1991	1988	
Trisomy 21	Before	Stillbirth	2002	1998	
Genito-urinary	Before	Live (single)	2002	1999	

* same employee

Table 6

Mean Time Weighted Average Levels of the Different Agents Measured in the Smelter and Laboratory

Agents (unit of measurement)	Number of Samples	Standard Deviation	Minimum	Median	Maximum	Mean	ACGIH TLVs	Mean/ LTLV
Aluminum oxide (mg/m3)	31	0.0947	0.02	0.044	0.411	0.091	10	0.009
Aluminum (mg/m3)	9	3.1932	0.073	1.1	8.3	2.8226	10	0.28
Asbestos (f/cc)	6	0.0044	0.0066	0.016	0.019	0.0146	0.1	0.15
Ammonia (ppm)	4	1.0886	0.1	0.135	2.3	0.6675	25	0.0267
Carbon Monoxide (ppm)	189	1.6863	0.001	0.17	14.63	0.8609	25	0.034
Chromium, metal and trivalent (mg/m3)	9	0.031	0.0014	0.009	0.094	0.0208	0.5	0.042
Coal tar pitch volatiles as BSM (mg/m3)	97	0.0364	0.01	0.02	0.2	0.037	0.2	0.185
Copper (mg/m3)	30	0.002	0.0004	0.002	0.012	0.0019	0.2	0.01
Cyanide (as CN) (mg/m3)	6	0.037	0.038	0.0395	0.13	0.0545	2	0.0275
Cyclohexane (PPM)	3	14.0678	0.9	21	28	16.6333	100	0.16
Dust, respirable (mg/m3)	82	1.7701	0.035	0.295	16	0.6605	3	0.22
Dust, total (g/m3)	953	18.1914	0.007	1.12	176.22	5.7555	10	0.57
Fluorides (Total) (mg/m3)	378	5.8147	0.001	0.1275	62.21	1.0522	2.5	0.42
Fluoride (particulate) (mg/m3)	377	5.7748	0.001	0.078	62	0.959	2.5	0.38
Fluoride gas as HF(mg/m^3)	391	0.2678	0.001	0.02	2.639	0.1066	0.4	0.267
Magnesium (mg/m^3)	31	0.0099	0	0.002	0.04	0.0059	10	0.0006
Manganese, metal & compounds (mg/m^3)	57	0.0994	0.0004	0.003	0.51	0.0343	0.2	0.17
Methanol (ppm)	1		14	14	14	14	200	0.07
Naphthalene (ppm)	11	0.3293	0.003	0.082	0.905	0.2675	10	0.0267
Nickel (mg/m^3)	17	0.0218	0.001	0.005	0.094	0.0108	1.5	0.007
Nickel Compound (mg/m^3)	31	0.0026	0.0004	0.002	0.016	0.0026	0.1	0.03
RCF (f/cc)	8	0.1273	0.006	0.177	0.358	0.1516	0.2	0.76
Silica, crystalline, (mg/m^3)	12	0.012	0.011	0.022	0.048	0.0232	0.025	0.92
Sulfur dioxide (ppm)	3	0.0012	0.011	0.013	0.013	0.0123	2	0.006
Electromagnetic radiation (EMF) (mT)	39	2.7838	1.62	5.11	13.83	5.8697	60	0.096