

**The Effect of Arsenic Exposure on Semiconductor Workers at the AXT Plant****Jill Collins**

**Abstract** The exposure of American Xtal Technology (AXT) workers to gallium arsenic created concern for former and current employees of the company. When gallium arsenic enters the body the compound breaks down into gallium and arsenic. Arsenic is known to have carcinogenic qualities. Exposure to arsenic might have unnoticed health effects at first, however, possible long term effects such as cancer (Bates 1992) and reproductive illnesses (Swan 1995) have been known to be caused by arsenic exposure. For these reasons if a person has been continuously exposed to arsenic, long term health monitoring would be helpful to make sure the long term effects of the carcinogen are not appearing. This study begins the monitoring process by collecting surveys of former and current AXT employees analyzing this set of data to understand trends in the data including common health complaints and correlation of place of work and problems reported. It is found that there does not appear to be a significant difference between areas of work with high gallium arsenic levels of exposure and areas with lower levels. It is still recommended, however, to continue the medical monitoring for those that were exposed because effects of a carcinogen can appear years later and capturing those effects early is important for treatment.

**Introduction**

American Xtal Technology Inc. (AXT) is a semiconductor manufacturing firm which specializes in the development of high-tech semiconductors, or computer chips. These chips are built on a base of gallium arsenide and as a result hold up better than the well-known silicon microchip when exposed to high levels of radiation (Izakson 2002). The semiconductors are used in a variety of technologies including solar cells, fiber optics, satellites and cell phones (Thompson 2004).

The gallium arsenide crystals are grown and melted into ingots, a bar or block of semiconductor material. The ingots are then sliced into wafers which are used to create circuits and then cut into microchips. The chips are polished and cleaned and chemicals are used to clean and dry the circuit. The workers then count, sort, and weigh the semiconductors.

Slicing and polishing the chips be harmful, but because gallium arsenic crystals are particularly brittle a large amount of dust is produced from the cutting and processing of the crystals (Thompson 2004). This dust exposes workers throughout the plant to gallium arsenide particles, which, when inhaled, break down to gallium and arsenic in the body. While gallium is not harmful, arsenic is known to be both toxic and have carcinogenic qualities which can have numerous adverse health effects in the long term such as cancer. Cancer (Bates 1992) and reproductive illnesses resulting in birth defects or miscarriages (Swan 1995) are among the threats associated with arsenic exposure. Wafers are therefore supposed to be manufactured in clean rooms in which air is circulated and filtered so that dust and particles are kept to a minimum while the wafers are processed. Workers in these areas are usually required to wear smocks, booties, gloves, and facemasks.

In the spring of 2000, the state Division of Occupational Safety and Health (Cal-OSHA) shut down the company AXT Inc, due to unsatisfactory worker conditions. After the four day shut down, 42 citations were issued and the company was fined almost \$200,000. The company, with headquarters located in Fremont, California, was charged with knowingly exposing their workers to gallium arsenide without taking the proper precautions and providing necessary training (Cal-OSHA 2000). According to

government documents, internal company documents, and employee testimonials, this exposure had gone on for a prolonged period of at least five years (Thompson 2004).

Instead of complying with Cal-OSHA's requirements, however, the company moved the manufacturing operations to China in September 2002. This was a better economic option for AXT because the company is able to avoid the laws requiring environmental and health precautions for their workers. As a result, hundreds of Bay Area AXT workers were laid off over a four year time span. Most of these workers had been exposed to arsenic during their work at AXT and now are jobless with the possible threat of cancer or reproductive sickness in the future due to prolonged arsenic exposure.

In the AXT plant, workers were exposed to numerous other chemicals such as indium phosphide, sulphuric acid, ammonium hydroxide, hydrogen peroxide, ethanol, hydrogen fluoride, perchloroethene, bromine, hydrochloric acid, zinc, sulphur, nitric acid, sodium hypochloride, iodine, and methanol (China Labour E-Bulletin 2004). Without proper precautions such as protective clothing, proper ventilation, and masks, exposure to such chemicals can cause neurological (Lagerkvist 1995), respiratory (McElvenny 2001), and reproductive problems (Swan 1995).

In the case of AXT, the ingot slicers were provided with smocks but not masks (Izakson 2002). AXT was also cited by government regulators for allowing ventilation systems to degrade, subjecting the workers to exposure anywhere from 4 to 21 times the maximum permissible limit (Thompson 2004). Because of these lapses some workers were exposed to arsenic up to 31 times the maximum permissible level (Cal-OSHA 2000). In 1999, AXT's own air monitors recorded levels of arsenic 21 times the maximum permissible level (Cal-OSHA 2000). It is concluded that AXT knowingly exposed their workers to high levels of arsenic for a time period of at least five years (Cal-OSHA 2000). Continuous exposure over a period of time to a carcinogen such as arsenic increases health risks compared to exposure over a limited time (supposed to blend with other horrors).

Other charges by investigators included failure to provide proper training to employees handling or exposed to gallium arsenide, failure to provide proper preventative equipment and clothing, and failure to inform workers of the risk they were subjected to when exposed to gallium arsenide (Thompson 2004).

In June 2004 a preliminary survey of 133 former AXT workers revealed that half the workers reported dizziness, breathing difficulties, and/or eye irritation during the period they were exposed to gallium arsenide (Cal-OSHA 2000). Only three percent of workers surveyed reported that they were aware of risk of cancer and reproductive complications associated with gallium arsenide exposure (Cal-OSHA 2000). Of these only 10% reported that they had been trained in how to properly handle the toxic material (Cal-OSHA 2000). The workers dealing with wastewater in the AXT manufacturing plant reported that no fans or ventilation systems were used. They reported that the safety glasses were provided did not completely cover the worker's eyes. And the paper coveralls did not prevent chemicals from touching the skin (Focus Group 8-19-04). Workers also reported that they were not informed of the carcinogenic qualities of gallium arsenide. They were not trained in worker health and safety (Focus Group 8-19-04).

It is required by law that companies dealing with compounds such as gallium arsenide provide proper training and information to the workers to lessen their potential health risks. Shower and changing facilities are also required for the workers so that they do not bring the toxic compound back to their homes. These facilities were not provided for the AXT workers (Cal-OSHA 2000). As a result, dust and particulates from the facility were most likely transported to the workers home exposing children and other family members to arsenic.

Workers in semiconductor plants have a high prevalence of work related illnesses (Wald 1987). Previous studies tracking the health of other semiconductor workers have found an increase in the rate of spontaneous abortions among female clean room workers (Swan 1995); (Pastides 1988). Another study by the British government in 2001 looked at cancer rates among semiconductor workers at a particular plant in Scotland and found a statistically significant rise in cancer rates among the workers (McElvenny *et al.* 2001).

Often these workers are immigrants with limited local language ability and lack of knowledge of their rights and available resources who are sought out because they are able to be easily exploited and do not complain about working conditions due to fear of loosing their job and their difficulty in communicating with their employer because of their limited English skills (Thompson 2004). This appears to be the pattern at AXT. Of

the 220 workers surveyed in this study, only 2.4% of the people reported they spoke English; the rest spoke Mandarin, Cantonese, or both.

A limited number of studies have examined the effect of arsenic exposure on factory workers. Most of the research on arsenic exposure has been done regarding arsenic in drinking water; airborne exposure to inorganic arsenic has not been heavily studied. Like ingested arsenic, inhaled arsenic increases the systemic level of arsenic in a person to levels comparable to ingestion as seen by urine samples (Hopenhayn-Rich 1993). Ingested arsenic can increase rates of cancer including skin, bladder, kidney, liver, and lung (Bates 1992). It has also been associated with causing diabetes mellitus (Lai 1994); (Rahman 1995) and peripheral vascular and cardiovascular disease (Engel 1994). The few studies that have explored the effect of airborne inorganic arsenic exposure have found a significantly increased risk of lung cancer (Lee-Feldstein 1989).

The University of California at San Francisco's Community Occupational Health Project (COHP) in Oakland has carried out health screenings of AXT workers and previous workers. These screenings consisted of a survey and physical exam, and laboratory tests (Bridges 2004) and began in July 2004 and continued until February 2005. This information will be helpful in analyzing trends in the health of current and former AXT workers as well as provide data for comparison in long term monitoring.

The purpose of this research is to identify any trends in the data collected from the completed surveys, and to analyze whether or not a correlation between the area of work and medical problems is present. Without monitoring health effects of workers exposed to toxics, the health concerns would not be known, policies would not be made, and lawsuits could not be pursued in the interests of the workers. Through health surveys and medical screenings the health of the workers can be monitored allowing problems that arise to be dealt with accordingly. Because arsenic is a carcinogen, problems might take years to develop. Without proper monitoring these conditions could go untreated and cause even more serious health concerns. Monitoring and surveys are also important to hold AXT accountable for the medical problems of their previous employees who were knowingly exposed to arsenic without proper precautions or information provided. Through screening and surveys, data can be provided to create concrete evidence to hold AXT accountable to their workers.

**Methods**

The Community Occupational Health Project (COHP) of Oakland was responsible for conducting the screenings and surveys used in this study. Former AXT workers, organized through the help of Asian Pacific Environmental Network (APEN), were encouraged to participate in a survey and medical screening. Surveys and medical exams were collected between July 2004 and February 2005. The surveys elicited demographic information, questions about the participants work at AXT, and questions regarding personal health (Appendix A). Translating services provided by COHP volunteers were used to contact the participants, assist during medical screenings, and support while answering the survey.

Two hundred twenty surveys in total were entered into SPSS 11.5 software by a volunteer for the Community Occupational Health Project. I then transferred this data into the program JMP IN 3.2.6. Frequency charts and graphs of demographics, areas of work, and medical problems were administered on the data to better understand the dynamics of the group surveyed. Because this research is focusing on whether the area an employee worked was correlated with any reported health problems, the data regarding area of work was compared to health problems the worker reported. Correlation between the factors was determined by a chi-squared analysis. If the p-value of the chi-square test was 0.15 or lower the correlation was recorded. Both positive and negative correlations were recorded between area of work and health related problems. The positive correlations showed that in a particular area of work more employees had a particular medical problem. The negative correlation demonstrated that in a particular area of work less of the workers had a particular medical problem.

The types of jobs that subjected the workers to a higher risk of gallium arsenine exposure were also grouped in the category of high risk and not high risk. High risk areas of work were determined by the level of arsenic detected using wipe samples ( $\text{ug}/100\text{cm}^2$ ) found in the Cal OSHA report. The departments and activities with the highest arsenic levels were polysynthesis, slicing, ingot, and crystal growth. Polishing, planning, edge rounding, quality control, shipping, cleaning, inventory, leaning, and

lapping, were all categorized as low risk jobs. Workers in these low risk departments were still exposed to gallium arsenic but to lower levels of the toxin.

It was common for workers to work in multiple departments during their time at AXT. If that was the case, multiple places of work were marked on the survey. There is no way of determining the length of time the worker worked in a particular area given the results of the survey, and consequently length of time in the high risk area could not be addressed. Therefore, any worker who at one time worked in a high risk area was included as working in a high risk area for the purposes of this study. High risk areas of work were compared to medical problems using a chi-square analysis to better understand the relationship between the variables. Again, comparisons with p-values of 0.15 and lower were recorded as possibly correlated.

In order to address confounding factors I used a two-factor chi-squared test with interaction. The confounding factors I identified and accounted for were gender, age, and whether the worker was a smoker at the time he or she completed the survey. Running the two-factor chi-squared tests with interactions enabled me to determine whether a medical problem was correlated with a particular job because of the job itself or as a result of these confounding factors.

Some data from the survey was not used. For example, the section of the survey dealing with fertility was not used in the analysis because due to the high age of the workers (median of 52 years) and the low mean amount of months worked with AXT (34.5). Therefore most of the workers were not dealing with issues related to pregnancy.

Individual interpretation of the survey questions could result in a potential pitfall. With the use of a translator the questions are more difficult to keep in their purest form. This was considered when conducting the surveys through the use of simple questions. As always during a surveying process, individuals misunderstanding or inaccuracy of information is possible. A large enough sample size can help to alleviate these complications.

## **Results**

All of those surveyed were Asian. The surveyed group of 220 had slightly fewer males than females (48 % and 52 % respectively). Only 2.4 % of those surveyed reported

that they spoke English. There was a relatively normal distribution of ages with a median age of 52 years. The median number of months worked was 34.5 months. The amount of time worked at AXT was skewed: most respondents worked for a shorter time making the distribution heavy on the right and with a tail on the left. Sixty percent of those surveyed were not currently employed. Of the 220 surveyed, 25 of the workers filed a claim for injury. Common complaints included contact with chemicals, and hand injuries (specifically cuts by broken crystal or ingot chips).

Thirty six percent of the former workers surveyed lived in Oakland, 19 % lived in Fremont, and 14 % were from San Leandro. Fourteen percent of the participants worked in polysynthesis, 19 % worked in slicing, 5 % worked in ingot, and 20 % worked as crystal growers, the four jobs described as high risk occupations meaning the workers have a high chance of arsenic exposure. About 37 % of the workers surveyed had at one time worked in a high risk area when working for AXT.

Seventy-three percent of the respondents rated their health as poor or fair. Multiple factors could contribute to this health report including smoking and aging. Twenty four percent reported that they had smoked at one time in their lives. Only 12 % said that they smoked at the time of the survey.

Ingot and lapping workers reported higher than expected frequencies of skin problems; their p-values were 0.007, 0.074 respectively. Polishing and lapping workers had a correlation with sinus problems (p-value = 0.007 and 0.037 respectively). Polysynthesis and polishing workers had a significantly more reported chest pain (p-value of 0.054 and 0.010 respectively).

Numbness or tingling in fingers or toes was reported as a problem for more edge rounding workers (p-value = 0.042). Cleaners reported more bone and muscle pain than other workers (p-value = 0.042). Muscle weakness was reported by slicing workers more than other workers (p-value = 0.042). The planning workers, on the other hand, had significantly lower reported problems with muscle weakness than other workers (p-value = 0.043). Planning workers also had significantly less problems with their joints than other workers (p-value = 0.004). Balance problems were reported by more slicing workers (p-value = 0.142) and edge rounding workers (p-value = 0.133) than other workers. In contrast, less crystal growers reported balance problems (p-value = 0.078).



Unusual weight loss or gain was reported by more polysynthesis workers than other workers (p-value = 0.110). Problems with bowel movements were reported by significantly more shipping workers (p-value = 0.057). Quality control workers reported more problems with abdominal pain than the rest of the workers (p-value = 0.077). Polishing and lapping workers experienced significantly more headaches than other workers (p-values of 0.011 and 0.030 respectively). Planning workers, on the other hand, had significantly less problems with headaches (p-value = 0.085).

Feelings of dizziness were experienced by more ingot, edge rounding, and quality control workers with p-values of 0.120, 0.037, 0.111. A significantly higher amount of cleaning workers than other AXT workers surveyed experienced problems with miscarriages (p-value = 0.029). The cleaners also reported higher levels of problems with their menstrual cycles than other workers (p-value = 0.071).

Polishing workers had a significantly higher rate of heart disease (p-value = 0.006) than other workers surveyed. Polysynthesis workers, on the other hand, had a significantly lower rate of heart disease than other workers surveyed (p-value = 0.030).

Quality control workers and edge rounding workers had a higher rate of high blood pressure than other workers surveyed (p-values of 0.043 and 0.113 respectively). High cholesterol was a problem for polishing and shipping workers, who had a significantly higher rate of high cholesterol (p-values of 0.033 and 0.015 respectively). Planners and cleaners, in contrast, had a significantly lower rate of high cholesterol (p-values of 0.038 and 0.019).

Edge rounding workers had a significantly higher rate of asthma than other surveyed workers (p-value = 0.019). The polishers had a significantly higher rate of diabetes (p-value = 0.026) and shipping workers had a significantly lower rate of diabetes (p-value = 0.053) than the other workers surveyed. Polysynthesis workers experienced more nerve problems than other surveyed workers (p-value = 0.024). Ingot workers and crystal growers had a higher rate of anemia than other workers surveyed (p-values of 0.146 and 0.070 respectively). Polishing workers had significantly higher rates of skin growths (p-value = 0.054) than other surveyed workers.

Planning and Inventory workers reported significantly lower rates of problems with depression than other AXT workers (p-values of 0.093 and 0.025 respectively).

Inventory, shipping and quality control workers all had significantly less reported incidence of painful or swollen legs (p-value of 0.106, 0.083 and 0.106 respectively). Ingot and Planning workers had significantly less complaints (0.006 and 0.027 respectively) about having trouble sleeping than the other workers. Significantly less crystal growth workers had problems with breathing (p-value = 0.087) as with edge rounding workers (p-value = 0.087) and leaning workers (p-value = 0.066) who also reported significantly less problems with breathing than other jobs. Less ingot workers reported problems with bowel movements (p-value = 0.057).

People working in high risk areas had significantly more reported chest pains than low risk workers (p-value = 0.080). They reported less painful legs than low risk workers (p-value = 0.092) as well as less sinus problems than low risk workers (p-value = 0.077).

X-square results (p<0.15)	Polysynthesis	Slicing	Ingot	Crystal Growth
heart disease	-			
high blood pressure				
high cholesterol				
Asthma				
Diabetes				
nerve problems	+			
Anemia			+	+
skin cancer				
lung cancer				
skin problems			+	
skin growths				
eye problems				
Sinuses				
Breathing				-
persistent cough				
chest pain	+			
decreased sensation in fingers or toes				
numbness or tingling in fingers or toes				
bone or muscle pain				
muscle weakness		+		
Joints				
movement or coordination			-	
Balance		+		-
unusual weight loss or gain	+			
eating, swallowing				
Digestion				
bowel movements				
urination problems				
abdominal pain				
Headaches				
Dizziness			+	
miscarriages				
trouble having children				
menstrual cycle				
painful or swollen legs				
trouble sleeping			-	
Depression				

Table 1: Positive (+) and Negative (-) correlations between medical problems and high risk jobs (p<0.15).

Medical Problem	Polysynthesis	Slicing	Ingot	Crystal Growth	Polishing	Planning	Ed Ro
heart disease	<b>0</b>	7	0	7	<b>15</b>	0	
high blood pressure	19	21	25	16	25	25	
high cholesterol	23	19	8	19	<b>33</b>	<b>0</b>	
asthma	6	14	8	14	8	13	
diabetes	6	17	17	7	<b>18</b>	13	
nerve problems	<b>13</b>	7	8	7	3	0	
anemia	10	7	<b>17</b>	<b>12</b>	<b>2</b>	0	
skin problems	29	33	<b>67</b>	<b>40</b>	37	13	
skin growths	3	5	8	5	8	0	
eye problems	45	45	<b>25</b>	40	38	38	
sinuses	16	19	17	14	<b>32</b>	13	
breathing	35	33	25	<b>23</b>	42	25	
persistent cough	29	24	8	14	23	<b>0</b>	
chest pain	<b>45</b>	36	25	28	<b>43</b>	13	
decreased sensation in fingers or toes	19	14	8	12	13	<b>0</b>	
numbness or tingling in fingers or toes	35	38	17	33	37	<b>0</b>	
bone or muscle pain	42	40	33	30	42	<b>0</b>	
muscle weakness	29	<b>31</b>	33	23	23	<b>0</b>	
joints	45	36	25	33	47	<b>0</b>	
movement or coordination	0	2	0	<b>0</b>	3	0	
balance	<b>0</b>	<b>7</b>	0	<b>0</b>	5	0	
unusual weight loss or gain	<b>13</b>	5	0	2	7	0	
disgestion	6	10	8	12	13	13	
bowel movements	10	<b>7</b>	<b>0</b>	12	13	13	
abdominal pain	6	10	0	<b>23</b>	8	0	
headaches	48	38	42	37	<b>53</b>	<b>13</b>	
dizziness	35	40	<b>58</b>	28	43	25	
miscarriages	0	0	0	0	1	0	
menstrual cycle	6	7	8	7	3	0	
painful or swollen legs	10	5	8	5	5	0	
trouble sleeping	32	19	<b>0</b>	23	20	<b>0</b>	
depression	16	17	8	16	18	<b>0</b>	

Table 2: Percentages of workers in a particular area with a medical problem (the bold means there are significantly more or less reported cases).

**Discussion**

Workers in high risk areas did not seem to have more medical conditions or physical problems than the workers in low risk areas. However, there were correlations between medical problems and specific areas of work. Particular jobs experienced more physical problems than others and some jobs had significantly less physical problems than others. Table 1 shows the positive and negative correlations between high risk areas of work and medical problems. Table 2 shows the percentages of people in a specific job that had a specific medical problem. The bold numbers are the comparisons that had either a positive or negative correlation between the medical problem and the area of work. Workers in planning, inventory, and leaning had no significant correlation with having physical problems but instead those workers experienced significantly less problems than other jobs. These jobs seem to be less physically demanding and do not expose the workers to chemicals and toxins.

Most of the physical problems that were correlated with particular jobs were due to the nature of the job and not necessarily exposure to gallium arsenic. For example, polishers and edge rounders were not jobs categorized as high risk jobs for gallium arsenic exposure; however the analysis shows that workers in these areas suffer from more physical problems than workers in other areas. Polishers had sinus problems, chest pain, headaches, heart disease, high cholesterol, diabetes, and skin growths. Edge rounders reported numbness, balance problems, dizziness, high blood pressure and asthma.

While the workers that were exposed to gallium arsenic might not appear to have more physical problems than workers in other areas, this could be due to the fact that arsenic is a carcinogen and problems related to arsenic exposure would not necessarily immediately show. Many of the reported problems have to do with what the job required rather than exposure to arsenic. For example, bone and muscle pain might be due more to the physical requirements of a specific job rather than carcinogen exposure.

Many of the other jobs, such as cleaning, are physically demanding and so having significantly more bone and muscle pain is not surprising due to the nature of the job. Also, 68% of the cleaners were female compared to 52% of the workers over all. Because

of the high representation of females in the cleaning jobs, female problems such as miscarriages and menstrual problems are not surprisingly over represented and therefore reported as significantly higher occurrences.

Although 220 surveys were collected when those surveys were split into thirteen different categories the sample size greatly shrinks. Also over representation of gender, smokers, age, etc. in a specific area of work can skew the results so that one area of work can look to be correlated with a physical problem when really the reason for that correlation has to do with the gender ratio in that specific job. People surveyed marked all the areas they had worked in at one time or another so there is no way to know how long each person worked in a specific area. This means that someone that worked in an area for only a couple of weeks is counted the same as someone that worked in that area for years. The person who has worked for a longer time obviously had more exposure to that area and therefore would better reflect the effects of that exposure but this study is not able to take length of time in a specific area into account.

Therefore although this study does not show that high risk areas are associated with more physical problems this is because the effects of gallium arsenic exposure will appear over time if they do appear. For this reason it is important to monitor the health of the exposed workers. If problems come up due to the exposure early detection and treatment would be beneficial to the worker. This study did show that specific jobs are associated with certain physical problems. Most of these problems are probably due to the physical demands of the job or the chemicals or toxins used in that specific area. Other jobs seemed to have fewer problems associated with that specific occupation such as people that worked in planning, inventory, and lapping.

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