HEALTH ISSUES IN THE GLOBAL SEMICONDUCTOR INDUSTRY

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ABSTRACT

The microelectronics industry began in the United States less than 50 years ago. It quickly spread to Japan and to a number of European countries and, in recent years, to much of the remaining world. The experience of US manufacturers is that some serious occupational and environmental problems occur, in particular, with the production of semiconductor devices. But before the occupational and environmental problems were adequately addressed, the industry had migrated to many countries around the world, especially to East Asia and Southeast Asia. This paper summarizes the limited number of studies of the health of semiconductor workers conducted thus far in the United States. It is also a call for further research and for caution in the development of the microelectronics industry in areas of the world that lack sufficient regulation and enforcement of laws to protect workers from occupational hazards and the community from environmental hazards that have occurred wherever microelectronics companies have been established.

Introduction

Microelectronics is a major international industry. Its explosive growth has resulted in a world market for semiconductor devices alone that is valued at more than $60 billion. The microelectronics industry workforce may number as high as half a million workers. Until a few years ago, we thought of semiconductor manufacturing as the activity of only a few regions such as Silicon Valley (Santa Clara County in Northern California), Route 128 outside Boston, Kyushu Island in Japan, and a few areas of Western Europe. Today, the pre-eminence of American and Japanese technologies is being challenged by that of many countries; there are now many active Asian and European producers of microelectronic devices[1]. The most dynamic of these international developments occurred in Malaysia.

Malaysia's electronics industry was begun by the Japanese firms Toshiba and Matsuchita. These companies, through a 1967 joint venture, sought to develop black and white television sets for the domestic sector. Pleased with the formation of a new manufacturing activity, the Malaysian government enacted the Free Trade Zone (FTZ) Act of 1971, hoping to stimulate an otherwise sluggish economy. Transnationals, seeking access to low cost production facilities in areas with limited environmental legislation and enforcement and few problems with union representation, responded in one of the most massive influxes of new companies in recent history [2]. The semiconductor firm, National Semiconductor Corporation (NSC), led the American microelectronics relocation to Singapore and Malaysia in 1968 and 1971. The early success of American firms such as NSC and Advanced Microdevices (AMD) in Malaysia was quickly followed by more Japanese and West European firms such as Hitachi and Philips.

The Malaysian government was interested in alleviating poverty and redressing ethnic inequalities. The government program known as the New Economic Policy of 1971 was designed to attract foreign investment through tax exemptions and subsidized infrastructure, such as land, water, electricity and property protection[3]. Although unionization was not banned, it was not allowed in any of the early companies that arrived to take advantage of the hospitable industrial climate of Malaysia. Figure 1 demonstrates the requirement for obedience and conformity that high-technology companies impose on their workers. The cleanroom discipline is rewarded with salaries of under $0.50 per hour from which is deducted the cost of the meal provided during the work shift. For women workers, there is virtually no hope of advancement.

The Japanese yen and currencies from newly industrialized countries (NICs) in Asia appreciated in the 1980s creating large new local markets for consumer goods. There followed a massive influx into Malaysia of Japanese and other Asian consumer electronics companies. Thus, by 1992, Malaysia had become the largest semiconductor exporting country in the world and the world's third largest producer of integrated circuits. In little more than a decade, Malaysia had produced a skilled workforce that was assuming leadership roles in production planning and direct marketing of one of the world's most dynamic industries. For example, Malaysian managers run all phases of the Intel and Northern Telecom (US and Canadian companies) subsidiaries.

This story of industrial success is reminiscent of the early days of semiconductor manufacturing in Silicon Valley. Rapid growth of hundreds of new companies was followed by a period of intense manufacturing competition, driving the majority of local companies into at least some offshore production. Regional disappointment with the declining job market was

exacerbated by the discovery that underground chemical storage tanks were contaminating the area's underground water tables, leading to Silicon Valley's unenviable distinction of being home to more Environmental Protection Agency (EPA) Superfund cleanup sites than any other county in the United States [4]. Moreover, as governmental agencies became aware of the use of large quantities of organic solvents by this industry, air pollution agencies began aggressively to control the behavior of semiconductor companies .

Many critics of the massive migration of microelectronics manufacturing companies to countries such as Malaysia point out that NICs have few if any environmental protection laws and little enforcement capability when the laws do exist. It can be argued that developed countries such as the United States and Japan are passing their environmentally damaging industries to the NICs, and along with them the long-term costs of environmental remediation which, by the American experience, is quite significant. In effect, to provide near term jobs and industrial development, developing countries are assuming long-term costs that they are poorly equipped to meet.

Malaysia, for example, is attempting to export many of the industrial wastes from its burgeoning electronics industry to such countries as the Philippines and Thailand. Many companies are stockpiling thousands of drums of hazardous waste because the country does not have waste treatment facilities to handle the level of production common to semiconductor manufacture. Informed observers tell of illicit dumping of hazardous wastes into rivers and streams and of illegal land filling. There is no investigative reporting of such incidents, and there would be no useful purpose for public discussion given the level of environmental protection offered by the Malaysian government. The dangers are going to be more ominous before proper attention is paid to the impending occupational and environmental problems created by the microelectronics industry in Asia.

Occupational Health

In the early years of the California microelectronics industry, occupational health was seldom discussed. The companies typically hired nurses to create the illusion that the health of workers was being carefully monitored and assured. Only two US companies had full-time physicians, and fewer than ten had part time physicians on their staffs.

The safety reports sent to the California Division of Industrial Accidents reflected the fact that semiconductor manufacture is a light industry with a low incidence of industrial injury. It was not until the past decade that occupational illnesses were separated from occupational injuries, and, for the first time, recognized for their unusually high incidence rate.

California's manufacturing industries include all the light and heavy industries found in any large industrial country. The incidence of occupational illness as a percentage of total workloss cases (the worker misses a complete work shift because of the illness) varies between 7-9 percent on an annual basis. For California's electronics industry, however, this figure is considerably higher, varying between l4 and 20 percent. For the semiconductor workers who make up about one-quarter of the electronics workers, the incidence of occupational illness is the highest segment, representing a range between l8 and 26 percent (Table 1).

The California Bureau of Labor Statistics and Research categorizes illness resulting from exposure to toxic materials as "systemic poisoning." The employer submits a form when the worker is referred to a physician indicating that the illness is the result of a hazardous chemical exposure. The systemic poisoning rate for electronics workers is consistently greater than other manufacturing industry workers, and semiconductor workers have the highest rates among electronics workers (Table 2). Whereas the manufacturing industry rate never exceeds 20 percent of occupational illnesses resulting from a hazardous chemical exposure, the figure can approach 40 percent for electronics workers and exceed 40 percent for semiconductor workers.

The chemically-intensive manufacturing processes of microelectronics products can be demonstrated by the data in Table 3. Systemic poisoning of electronics workers is 3-4 times more likely in electronics workers than in other manufacturing industries, and is higher than workers in the chemical industry, even those in pesticide manufacture. Semiconductor workers have, again, a consistently greater problem with systemic poisoning resulting in occupational illness than do other manufacturing workers.

Occupational illness data may reflect the widespread use of toxic materials in the semiconductor industry, which has developed process applications for many metals, chemicals, and toxic gases in a wide variety of combinations and plant settings [5-7]. The technology underlying this industry is continually changing. This fast-paced change, as well as the stringent security precautions of the industry, have added to the difficulty of instituting proper health and safety measures in the microelectronics industry. Many companies report that they keep Material Safety Data Sheets (MSDSs) in conformity with US law on literally thousands of chemicals.

Research on Occupational Health

In 1988, a reproductive study was conducted by the University of Massachusetts among semiconductor workers at the Digital Equipment Corporation (DEC). Personal interviews were conducted with workers and controls eliciting the finding of an elevated spontaneous abortion rate among semiconductor workers. The relative risks of spontaneous abortion for women working in "diffusion" was 2.18 and those in "photolithography" was 1.75. Analysis of potential confounders did not substantially alter the findings [8].

The impact of this study was immediate and profound. Television and other media coverage prompted some companies to inappropriately begin to take women of childbearing age out of production facilities, without clear demonstration of any greater safety for male workers and without any real understanding of the cause of the reproductive effects. The investigators and the study were criticized harshly for conclusions drawn from such a small study. But the industry was on notice that a scientific study had demonstrated statistically significant reproductive hazards associated with semiconductor manufacture and that the findings would have to be verified or disproved for the controversy to be settled.

IBM, then the largest US manufacturer of integrated circuits, engaged the School of Public Health at Johns Hopkins University to conduct a similar study with IBM employees. IBM decided to forego participation in a study proposed by the Semiconductor Industry Association to be conducted in a number of its member companies. The retrospective portion of the IBM study, conducted at facilities in New York and Vermont, were preliminarily reported in late 1992 as

showing an increased spontaneous abortion rate for women workers in two specific cleanroom areas. Although other workers exposed to glycol ethers (diethylene glycol dimethyl ether and ethylene glycol monoethyl ether acetate) were not found to have similar increases in abortion rate, the association of glycol ether exposure and spontaneous abortion in the retrospective portion of the study caused IBM to notify its employees worldwide of the findings and to announce to the media that the study will lead to more restrictive handling of glycol ethers at IBM facilities. The final study report from Johns Hopkins is available in two documents (Gray, 1993; Corn and Cohan, 1993). The overall rate of spontaneous abortions per 100 pregnancies in the retrospective study was 15.9%. The rate of spontaneous abortion was 16.7% among women working in cleanrooms and 15.1 % among women working in non-cleanroom areas. This difference was not statistically significant. The rate of spontaneous abortion was lower among women working in other- manufacturing areas (11.6%), as compared to women working in the cleanrooms (16.7%) or non-manufacturing areas (17.9%). The pattern of lower spontaneous abortion rates among women who worked in the other-manufacturing group was observed in both plants. When women who worked in the other-manufacturing group were used as a common reference group, multivariate statistical procedures estimated that the risk of spontaneous abortion was increased by 70% for pregnancies conceived by women working in the cleanrooms, and 60% for pregnancies conceived by women working in non-manufacturing areas. Thus, the risk among cleanroom workers was similar to that among employees working in non-manufacturing areas. The authors stress that these results are inconclusive, and that self selection of women at low risk of miscarriage into other manufacturing jobs cannot be ruled out.

The prospective study of IBM employees analyzed work functions assuming significant ethylene glycol ether exposures with some jobs. The study lacked personal sampling data on the exposed workers, and like the University of California study, failed to study urine metabolites of the glycol ethers even though the urine samples were collected for other purposes. Another similarity with all other studies of semiconductor workers is the small sample size. It is not possible to demonstrate an association of reproductive outcomes with exposure to a group of chemicals with so few pregnancies among exposed workers as occurred in the Johns Hopkins study. There were only six pregnancies among women who worked with processes that required any use of ethylene glycol ether-based Photoresists and solvents. Even though four of these six pregnancies resulted in spontaneous abortion (66.6%), when compared to the rate of pregnancy loss among women in non-cleanroom areas (43.8%), the relative risk of spontaneous abortion of 1.5 (associated with work requiring EGE) was not statistically significant.

The SIA study was conducted by researchers at the University of California, Davis, with participation of California's Department of Health Services personnel. Its study report is completed and provides the most compelling demonstration to date that there is a reproductive risk associated with semiconductor manufacturing work[11]. The relative risk of spontaneous abortion among semiconductor workers compared with controls in the retrospective portion of this study was l.45. Women working in semiconductor manufacturing jobs were l.45 times as likely to have a spontaneous abortion as women working in non-manufacturing jobs.

The SIA announced at a press conference that women working in areas with exposure to glycol ethers and to fluorides were at an increased risk of spontaneous abortion. The industrial

hygiene portion of the study failed to demonstrate any significant glycol ether exposure. Moreover, the experience of industrial hygienists who have looked at glycol ethers in this setting is that these chemicals are not likely explanations of this marked increase in spontaneous abortion risk. The same can be said for fluoride exposure which is typically not measurable in plant surveys.

The prospective reproductive study demonstrated an increased risk of spontaneous abortion with a relative risk of l.34. Here, in a similar methodology followed by the Johns Hopkins researchers, a group of women workers submitted daily urine specimens to be analyzed for human chorionic gonadotropin (hCG) levels that would detect abortions that might otherwise be missed even by the woman worker. The study was conducted only six months so pregnancy outcomes such as birth weight and birth defects were not observed. The sample size was too small to support or reject any of the chemicals associated with abortion in the retrospective portion of the study. There were only 20 pregnancies in the fabrication worker group during the study period. Unfortunately, no attempt was made to analyze the urine specimens for glycol ether metabolites to document exposure in these workers. Here, again, as with the IBM study, there was an immediate attempt by the industry to point to glycol ethers as the cause of the reproductive problem and to assure the public and its workers through press releases that member companies would phase out the dangerous materials.

The prospective portion of the SIA study also showed a diminished probability of conception among semiconductor workers after correction for birth control practices. Although the methodology of this phase of the study was improved over former studies, it is disappointing that yet another small study population was reported when there was every indication from the SIA and the University of California researchers that a large and definitive study was underway.

Indeed, the study has been touted since 1987 as a large and definitive study of all aspects of health of semiconductor workers. The actual study of other health measures than reproductive health was conducted solely by questionnaire. The three areas of complaint about health that workers shared in their questionnaires were pulmonary symptoms, skin rashes and joint pain of the upper extremities. There was a suggestion of an occupational stress problem derived from a single question about stress on the questionnaire. There were no examinations and no biologic monitoring of workers for health measures other than the small sample of women workers participating in the prospective reproductive study.

The SIA study provides little additional information on the causes of its reproductive findings, and no information at all on the complaints of workers regarding pulmonary symptoms, skin rashes and joint pain. It is increasingly clear that a reproductive risk exists in semiconductor manufacture, even though the Johns Hopkins study raises some doubts. But there is no obvious cause that can be identified from any of the studies conducted thus far. Indeed, it appears that press releases from IBM and the SIA indicating that glycol ethers will be phased out of their plants in the near future are little more than attempts to mollify workers and to have the public believe that the cause of the problem is known and will be corrected. It is prudent to discontinue using glycol ethers in this and other industries. It is also justifiable to advise women contemplating pregnancy or already in the first trimester that they should seek work in non high risk assignments in the same company or to find another job entirely.

IBM and the SIA have an obligation to provide their workers with a reliable explanation of the cause of the miscarriage risk. This will require further funding of research and further cooperation of many companies. One important continuation of the SIA study would be to blend its data with those of the Johns Hopkins study, and to analyze all the urine samples for glycol ether metabolites.

It would not be difficult to compare the incidence of spontaneous abortion in semiconductor companies that use glycol ethers and those that do not. Many companies have already phased out the use of these solvents. If our concern is for glycol ethers, there are industries that would provide a much larger population under more easily measured exposure situations to the glycol ethers. The preoccupation of semiconductor companies with glycol ethers continues to suggest that it is but a convenient excuse to explain away a more serious problem with cleanroom work and reproductive health.

The reproductive findings in semiconductor industry studies indicate that other health problems should be evaluated, including cancer and a variety of chronic illnesses. The SIA and IBM studies hardly close the book on the health issue in this industry. Indeed, they show how important it is to open this industry to further health research both in the United States and in Japan, Germany, Malaysia and the many other countries where this high risk manufacturing process is now being conducted.

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