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OCCUPATIONAL HEALTH IN THE MICROELECTRONICS INDUSTRY

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Many governments offer incentives to microelectronics companies to locate in their regions. Most semiconductor chip manufacture is taking place in Asia where occupational health research, protective standards, and enforcement are at unacceptably low levels. Moreover, the printed circuit board industry is now largely concentrated in Asia. Some American and European companies have expanded microelectronics manufacture in Central and Eastern Europe where it is hoped that higher standards of occupational health and safety can be achieved.

Occupational illnesses occur at a high rate in electronics workers, particularly among semiconductor workers. Microelectronics manufacture is done in cleanrooms where air is recirculated after dust is removed by particulate filters. Many different chemicals, metal dopants, and other materials are used in the semiconductor industry. The chemical fumes and vapors that are not removed by air filtration are recirculated with continuous worker exposure. The industry also presents problems of radiation exposure as well as a variety of occupational stressors, including ergonomic issues.

Keywords: microelectronics, electronics, semiconductor, printed circuit board, cleanroom

Semiconductor Industry

Semiconductor chip manufacture is a major international industry. The rapid growth of the semiconductor chip industry has resulted in a world market that is valued at more than \$200 billion per year. These high-technology devices are crucial to the manufacture and sales of about \$1 trillion in electronic products each year. The microelectronics industry workforce exceeds a million workers. The semiconductor industry is complex and diverse, with many technologies and manufacturing processes. The manufacturing settings share many characteristics, but no two are exactly the same. What was once thought to be a «clean» industry is actually one of the most chemical-intensive industries ever conceived. There has been a serious public misunderstanding of the difference between the meaning of «clean» as required for dust-free cleanroom manufacturing and what is required to protect the health of workers.

Many of the older technologies are exported to newly industrialized countries as newer technologies are installed in the more highly developed industries of Japan, the United States, and Europe. Thus there is particular concern about the many workers, mostly in countries that do not enforce occupational health and safety regulations, who have inherited jobs that use chemicals, technologies, and equipment that are no longer acceptable in developed countries. Central and Eastern European countries should be aware of this practice.

Occupational Health

Thousands of different chemicals, dopant metals, toxic gasses, and other materials have been used in the semiconductor industry over the past fifty years. The

industry also presents problems of radiation exposures as well as a variety of occupational stressors, including some unresolved cleanroom ventilation and ergonomic issues [1]. However, because of the rapid development of this industry, and its penchant for secrecy, the semiconductor industry is poorly understood.

Semiconductor chip making is a light manufacturing industry where workers have fewer injuries than do workers in heavier manufacturing. Nonetheless, workers have high rates of musculoskeletal pain and injuries. A cross-sectional study assessed the prevalence of specific musculoskeletal symptoms and their association with possible ergonomic risk factors. A total of 3,175 persons from eight manufacturing sites across the United States completed the survey. Overall, seven of 12 musculoskeletal outcomes were significantly more prevalent among fabrication workers. Upper-extremity symptoms were more common among fabrication workers and showed a dose-response effect with hours of work per day [2].

In a study in Malaysia, pain and musculoskeletal injuries occurred in the majority of semiconductor workers [3]. Significant associations were found between prolonged standing and leg pain, between prolonged sitting and neck and shoulder pain, and between prolonged bending and shoulder, arm, back, and leg pain. The study showed a clear association between work-related musculoskeletal pain and prolonged hours spent in particular postures and movements [4].

Occupational illnesses occur at a high rate in electronics workers, particularly among semiconductor workers. The U.S. Bureau of Labor Statistics reported occupational illness serious enough to cause a reportable work loss, averaged across all manufacturing

industries, accounted for 6.3 percent of all workloss cases in 2001. The rate in the electronics industry was higher, 9.5 percent, and the rate in the semiconductor component of electronics workers was higher yet, 15.4 percent (Table 1) [5].

While these rates are somewhat distorted by the low rates of injury, they are high enough to make it likely that there were real increases in illness. Moreover, a study of the reporting of occupational illnesses in California found that semiconductor companies properly reported less than half of all cases that should have been reported by OSHA criteria [6].

The BLS data for 2001 showed that 2.4 percent of workloss cases for workers in all manufacturing industries were the result of «exposure to caustic, noxious, or allergenic substances». The corresponding rate for the electronics industry was much higher, 6.2 percent, and for semiconductor workers it was 8.5 percent (Table 2) [5].

The BLS data for 2002 were presented in a different format, so they cannot be compared with prior years. Nonetheless, the data showed that 2.2 percent of workloss cases for workers in all manufacturing industries were the result of «exposure to caustic, noxious, or allergenic substances.» The corresponding rate for the electronics industry was much higher, 4.2 percent, and for semiconductor workers it was 5.9 percent [5]. These occupational illness data may reflect the widespread use of toxic materials in the semiconductor industry. The manufacture of integrated circuits requires the use of many metals, chemicals, and toxic gases in a wide variety of combinations and plant settings.

BLS now reports poisoning disorders for workers with ingestion or absorption of toxic substances in a new and different format. In 2003, the first year that BLS used NAICS worker code data, reported that the

rate of occupational illnesses caused by poisoning was 0.4 (per 10,000 full-time workers) for all private industry, and slightly higher at 0.5 for all manufacturing industry. The rate of poisoning disorders for semiconductor and other electronic components manufacturing (NAICS code 3341) was 3.0, and it was 6.0 for semiconductor and related device manufacturing (NAICS code 334413). Skin disorders and respiratory conditions also occur at elevated rates in the semiconductor industry [5].

These occupational illness data may reflect the widespread use of toxic materials in the semiconductor industry. The manufacture of integrated circuits requires the use of many metals, chemicals, and toxic gases in a wide variety of combinations and plant settings. Many developing countries begin to manufacture high-technology products before they have instituted national programs to regulate and enforce occupational and environmental health standards [7]. When they do so, they unwittingly assume long-term costs of workers' compensation and environmental remediation their countries can hardly afford. Whether this leap into high-technology manufacture by developing countries provides a net benefit to society is not at all clear at this point.

Reproductive Studies

Since a high proportion of semiconductor workers are women of childbearing age, the risk of adverse reproductive outcomes was examined among workers at a Massachusetts semiconductor company. Personal interviews were conducted with manufacturing workers, spouses of male workers, and an internal comparison group of non-manufacturing workers. Elevated rates of spontaneous abortion were observed for women

Table 1
Occupational Illnesses as Percent of All Injuries and Illnesses

	1997	1998	1999	2000	2001
All Manufacturing Industries	6.1	5.9	6.1	6.1	6.3
Electronic Components and Accessories (367)	8.4	7.5	10.0	8.3	9.5
Semiconductor and Related Devices (3674)	12.3	9.2	14.9	9.9	15.4

Source: Bureau of Labor Statistics, U.S. Department of Labor, 2004

Table 2
Percent of All Injuries and Illnesses Involving Exposure to Caustic, Noxious, or Allergenic Substances

	1997	1998	1999	2000	2001
All Manufacturing Industries	2.6	2.5	2.4	2.2	2.4
Electronic Components and Accessories (367)	5.1	7.3	6.0	7.6	6.2
Semiconductor and Related Devices (3674)	8.4	8.6	9.7	7.7	8.5

Source: Bureau of Labor Statistics, U.S. Department of Labor, 2004

working in clean rooms (31.3 abortions per 100 pregnancies for photolithographic workers, 38.9 for diffusion workers, and 17.8 for unexposed women) [8]. The authors stressed the tentative nature of their findings and called for more definitive studies.

IBM, then and now one of the largest semiconductor manufacturers in the world, engaged the School of Hygiene and Public Health at Johns Hopkins University to study reproductive problems among IBM employees. The retrospective portion of the study, conducted at facilities in New York and Vermont, was reported in 1992. It showed an increased rate of spontaneous abortion among women who worked in two specific cleanroom areas [9]. Birth defects, cancer, and other health outcomes were not studied. The small prospective reproductive study included few abortions and had low statistical power.

The Semiconductor Industry Association (SIA) sponsored researchers in California to conduct a retrospective cohort study of 6,088 women. In this group there were 904 eligible pregnancies ascertained by completion of a detailed telephone interview and 113 of these resulted in a spontaneous abortion eligible for inclusion in the analysis. The crude risk ratio for women working in fabrication areas vs. non-fabrication areas was 1.45 (95% CI 1.02–2.05). This reduced slightly to 1.43 (95% CI 0.95–2.09) after adjustment for various potential confounders [10]. This study provides the most compelling demonstration to date that a reproductive risk is associated with semiconductor manufacturing work.

Thus, an ostensibly «clean» work environment has been found to be associated with miscarriages in three separate studies. The SIA and IBM studies show how important it is to open this industry to further health research in the United States and many other countries where these manufacturing processes are now in general use. This excess risk of miscarriage occurred in settings where industrial hygiene air measurements were in compliance with current occupational standards. This suggests several possibilities, none of them welcome: that present standards are inadequately protective, that routes of exposure not included in the standards are important, that the relevant agents were not measured, or that agents are acting in unexpected synergy.

Cancer Studies

Semiconductor workers may be subject to a risk of occupational cancers in parallel with the risks of occupational reproductive effects. A 1983 report evaluated the general cancer incidence pattern in the electronics

industry. The total risk estimates were 1.15 for men and 1.08 for women, but the relative risk estimates for lung, bladder, and malignant melanoma were significantly increased to 1.52, 1.22, and 1.35, respectively [11]. A subpopulation of workers in the electronics industry was further examined with regard to cancers of the mouth, pharynx, and respiratory system. Among males the incidence of lung tumors was moderately but significantly elevated ($RR=1.36$). There were 13 cases of pharyngeal cancers giving a risk estimate of 3.0. In a subgroup composed of workers who largely held assembly jobs, there were five nasal cancers, representing a risk increase of more than fourfold.

IBM commissioned a study of its Cancer Mortality File to assess the risk of cancer among its workers. The study had severe limitations prompting the authors to state that, «Information about specific exposures in the work environment, such as EMF, ionizing radiation, or chemical agents, was not available. Some of the observed associations are difficult to interpret because exposure information pertaining to division and job groups is lacking» [12].

The IBM study found that mortality from brain cancer among male electronics workers increased as duration of employment lengthened. This is consistent with trends previously reported in the scientific literature: namely, that the risk of dying from brain cancer is highest among electrical and electronics workers with long-term work histories — 10 years or more — and with probable exposure to solders and organic solvents [13]. This study found that the risk of astrocytic tumors among electronics manufacture and repair workers was increased tenfold among those employed for 20 or more years. The authors pointed out that, «Numerous solvents used throughout the electrical and electronics industry are known neurotoxins, causing peripheral neuropathy, central nervous system depression, and neurobehavioral dysfunction.»

Clapp and Johnson studied the IBM Corporate Mortality File and found patterns of mortality in the IBM workforce consistent with occupational exposures to solvents and other carcinogenic materials. The files contained data on decedents between the years 1969 and early 2001. The final number of records used for analysis was 31,941 and comprised 27,272 males and 4,669 females. There were 7,697 cancer deaths and 7,206 were expected ($PMR=106.8$; 95% CI=104.8, 108.8). The Proportionate Mortality Ratios for all sites were significantly elevated when comparing the IBM workers to the U.S. population. There was excess mortality in IBM males due to cancers of the large intestine, pancreas, melanoma, kidney, testis, thyroid, and central nervous system, and

all lymphatic and hematopoietic tissues. In females, there was excess mortality due to cancer of the lungs and bronchus, breast, other female organs, and central nervous system, and all lymphatic and hematopoietic tissues. The types of cancer that are most increased are consistent with the findings of other studies of semiconductor workers and with studies of workers in other industries exposed to the same chemicals. The most important findings are the excess deaths due to brain cancer, kidney, lymphatic, hematopoietic, and melanoma [14].

In 2001 the Health and Safety Executive (HSE) in the United Kingdom announced the results of its study of cancer rates in a small sample of workers (71 deaths) at the National Semiconductor (NSUK) plant at Greenock in Scotland. That study found that the overall mortality rate from all causes of death was lower among work force members than it was for Scotland as a whole, though the total incidence of cancer cases was about the same as for Scotland as a whole. However, HSE identified a higher than expected incidence of lung, stomach, and breast cancer among women, and brain cancer among men [15].

The results of these studies suggest a work-related cause for several kinds of cancer in the semiconductor industry. Though the findings are not conclusive, it is clear that more detailed studies are needed to determine whether or not there is a workplace risk, and if so to determine its specific nature and size.

All of these results have come from studies of the semiconductor industry in its most advanced form as found in the United States and the United Kingdom. It is important to study cancer risks in the industry in countries that have inherited older, environmentally unfriendly technologies and possibly defective equipment, and tend to employ workers who may be less educated about, or less able to control, the health hazards associated with their employment.

The HSE inspected 25 plants operated by 22 different companies in Britain. Twenty-two percent of the plants failed to meet «minimum legal requirements» for health provision, ventilation, and health surveillance. Only five plants complied with minimum legal requirements for every issue inspected. As a result, the HSE issued 13 improvement notices and one prohibition notice to five of the companies. HSE inspectors were critical of the standard of occupational health services. Many of the plant physicians and nurses used by the companies were part time and were employed by outside entities, not by the companies. Most of the doctors were general practitioners, some of whom had never even visited the plants [16]. One very significant oversight was that in the case of arsenic, a carcinogen widely used by British semicon-

ductor companies, «there was virtually no keeping of health records. This is particularly worrying given that the industry has consistently disputed that the cancers suffered by its workers are work-related» [17].

Printed Circuit Boards

Printed circuit boards (PrCBs) are fundamental to the operation of virtually all electronics products. The PrCB is the platform upon which components such as semiconductor chips and capacitors are mounted. It provides the electrical interconnections between components. PrCB manufacturing is highly complicated, requiring large equipment investments and over 50 process steps [18].

The most advanced PrCB technologies now require a cleanroom manufacturing environment similar to that required in the semiconductor industry. This complicates the issue of occupational health by introducing recirculation of cleanroom air and the longer term exposure of workers to chemical fumes and vapors. Potential hazards could arise from decomposition of chemical compounds or from chemical product incompatibilities with other chemicals, other materials, or even water.

The two basic types of PrCB substrates are flexible and rigid. Among base materials used for rigid PrCBs, epoxy resin with a woven glass laminate surface predominates. The main processes, common to all PrCBs, are drilling, image transfer, and electroplating. Holes are drilled into PrCBs to provide layer-to-layer interconnections on double-sided and multi-layer circuits. These holes are subsequently «plated through» or made conductive by plating copper onto the hole barrels (the vertical, cylindrical surface of the hole).

Image transfer is the process by which an image of a circuit layer is transferred from film, from glass, or directly from image data files to the copper foil of the PrCB material. For inner layers, this includes the application of a photo-resist (a photosensitive film which also serves as the etch resist), imaging, developing, and etching. For outer layers, image transfer may include the electroplating of copper, tin, tin-lead, or nickel/gold coatings.

Occupational Health

In 1997, the U.S. EPA entered into a limited joint effort with the PrCB industry to identify and assess environmentally safer alternatives to chemical and process technologies that pose potential hazards to workers and communities [19]. The project with the industry was limited to a study of only one of the many

processes necessary to the production of PrCBs, the «making holes conductive» process. As an example of the complex and chemically-intensive nature of the industry, more than 170 different chemical products reported to the EPA were identified with the making-holes-conductive process.

Chemical products utilized in the electroless copper process contain formaldehyde or dimethylformamide, two of many occupational carcinogens to be found in the PrCB industry. When heated, chemicals used in the electroless copper bath can generate formaldehyde vapors. The EPA study resulted in a recommendation that the industry end its widespread reliance on the electroless copper process, to remove formaldehyde and other suspected carcinogens from the workplace.

Vincent and colleagues measured the urinary metabolites of glycol ethers in workers at two PrCB factories in France. Ambient glycol ether levels (EGME, EGEE, EGBE, and PGME) and their acetates were recorded at levels significantly above TLV (threshold limit value) and PEL (permissible exposure level), the commonly used exposure limits in the United States. Thirteen workers were studied for pre- and post-shift urinary glycol ether metabolite levels. The levels were significantly increased over the course of the work shift reflecting both respiratory and skin absorption of glycol ethers and their acetates [20].

In Taiwan and other Asian countries, EGME is used as the major solvent in the copper PrCB industry. Annual use of EGME in Taiwan is more than 3000 tons. Large quantities of hazardous chemicals such as EGME, acetone, and dimethyl formamide are used as raw materials. The Taiwanese PrCB industry accounts for more than 90% of the total use of EGME in that highly industrialized country [21]. The main raw materials used in these plants include epoxy and phenolic resins, hardeners (dicyanamide), catalyst (2-methyl imidazole), antimony oxide, aluminum oxide, silica dioxide, titanium oxide, pigments, acetone, and EGME.

Shih and colleagues studied 53 impregnation workers in two PrCB factories in Taiwan that make copper clad laminate with EGME as a solvent. Some workers, especially impregnation and mixing workers, were exposed to as much as 30 ppm EGME. Hemoglobin, packed cell volume, and red blood cell count in the male workers exposed to EGME were significantly lower than in the controls. The frequency of anemia in the exposed group (26.1%) was significantly higher than in the control group (3.2%) [22]. A significant correlation was also found between the weekly increase of urinary MAA (Friday after the shift minus Monday before the shift) and the weekly mean exposure to

EGME [23].

In a follow-on study, the frequency of anemia in the group exposed to very high glycol ether levels (42%) was significantly higher than that in the comparison group (3%). The hematological effects had returned to normal in the first follow up survey 2.5 months later, as a result of a reduction in the EGME exposure. The mean airborne exposure of EGME in the three surveys dropped from 35.7 to 2.65 ppm, then to 0.55 ppm [24].

Chang and colleagues in Taiwan further characterized the PrCB workplace based on the intensity and frequency of exposure to EGME. Environmental monitoring results showed that the average airborne EGME concentration for the workers in special operations was 8.13 ppm, higher than the permissible exposure limit of EGME in Taiwan, and significantly higher than the exposure level in regular operations, 2.14 ppm. Similar to the airborne EGME monitoring finding, EGME metabolite levels for the workers in special operations were significantly higher than levels in regular operations. The average metabolite concentrations for special operations were about 13 fold greater than those found in regular operations [25].

Chang and colleagues studied the possible association between the cancer risk and exposures to chlorinated organic solvents in workers in an electronics factory, including some PrCB workers. The proportionate cancer morbidity ratio (PCMR) for breast cancer in the exposed female employees was significantly elevated when compared with the two comparison groups. However, there was no dose-response relationship between female breast cancer risk and duration of employment [26]. These findings are consistent with the results of studies by Steenland, Stayner, and Deddens who present evidence of a positive exposure-response for breast cancer mortality in a large study of workers exposed to solvents. They also found a similar result with lymphoid tumors in male workers [27].

Glycol ethers have been implicated as causes of reproductive outcomes such as spontaneous abortion and diminished fertility in electronics industry workers [9, 10, 28]. The semiconductor industry began to phase out the use of low-molecular-weight glycol ethers in the 1980s, when the manufacturer reported the reproductive toxicity of the chemicals. There is no evidence that the PrCB industry is phasing out the use of glycol ethers.

Environmental Protection

Billions of electronics products have been discarded in every region of the world. Lead is one of the most signifi-

cant hazardous materials found in electronics waste. Efforts to substitute lead use with less hazardous materials are moving slowly. Lead is ubiquitous in electronics products. It is present in solder, finishes, batteries, paints, piezoelectric devices, discrete components, sealing glasses, and cathode-ray-tube glass. Lead is also used as a stabilizer for plastics such as PVC (polyvinyl chloride), commonly used in cable assemblies. Lead is only one of many pollutants found in discarded electronics products.

Regulatory initiatives are emerging that require the electronics industry incorporate environmental, health, and safety considerations into design and manufacturing decisions. Moreover, regulations governing the use, storage, transportation, and disposal of hazardous materials are beginning to influence the manufacturing process. It is hoped that by addressing environmental management issues, electronics manufacturers can reduce both hazardous materials and the generation of hazardous waste. This effort may also lead to improvements in operating efficiencies, reducing procurement costs of raw materials.

The electronics industry is preparing to comply with a number of restricted materials laws. In 2003, the European Union (EU) enacted the Restriction on Hazardous Substances (RoHS) Directive that bans the use of lead, mercury, cadmium, hexavalent chromium, and certain brominated flame retardants (BFRs) in most electronics products sold in the EU market beginning July 1, 2006 [29]. Both business-to-business and consumer products are covered. Although there are some exemptions to the Directive's chemical restrictions, this Directive, by banning the use of critical materials in electronics products sold in key world markets, may result in a significant change in the way products are designed for global sale.

The European Parliament and the European Council is considering legislation, Regulation, Evaluation, and Authorization of Chemicals (REACH), that will require industry to prove that chemicals being sold and produced in the European Union are safe to use or handle [30]. REACH policy will require registration of all substances that are produced or imported into the European Union. The amount of information required for registration will be proportional to the chemical's health risks and production volumes. Companies will also need to seek authorization to sell and produce problematic chemicals, such as carcinogens, mutagens, and teratogens. Toxic chemicals that persist in the environment or that bioaccumulate will also need authorization. The policy is slated for enactment in 2006.

California recently enacted the nation's first law that establishes a funding mechanism for the collection and recycling of computer monitors, laptop computers, and

most television sets sold in the state. That law, the Electronic Waste Recycling Act of 2003 (SB20) [31] also contains a provision that prohibits a covered electronics device from being sold or offered for sale in California if the device is prohibited from being sold in the European Union by the RoHS Directive.

The electronics industry also is beginning to take responsibility for its products at the end of their useful life. This responsibility also forms the basis for «take-back» legislation which is being implemented in the European Union under the Waste Electrical and Electronic Equipment (WEEE) Directive, beginning in August, 2005 [32]. The Directive encourages the design and production of electronics equipment to take into account and facilitate dismantling and recovery, in particular the reuse and recycling of electronics equipment, components, and materials necessary to protect human health and the environment.

In the European Union, since July 1, 2003, materials and components have not been allowed to deliberately contain lead, mercury, cadmium, or hexavalent chromium [33]. Lead was classified as Category 1, toxic to reproduction (embryotoxic), and as a precaution, the EU classified lead chromate pigments as category 3 carcinogens [34].

Conclusion

Because of the rapid development of the microelectronics industry and its penchant for secrecy, the issue of occupational health has not received adequate attention. Thousands of different chemicals, metal dopants, and other materials have been used in the semiconductor industry. The industry also presents problems of radiation exposure as well as a variety of occupational stressors, including ergonomic issues. The very nature of the cleanroom manufacture, with its recirculation of air with fumes and vapors not removed by dust filters, has not been subjected to thorough study.

Many governments offer generous incentives to semiconductor companies to locate in their regions. One common incentive is the government promise that it will not fund research studies that may be antithetical to the interests of the companies. Another inducement to migration is the promise that workers will not be allowed to organize. Moreover, governments have failed to exercise regulatory control over the microelectronics industry, despite the fact that this vital industry may have a significant impact on public health. It is little wonder that most chip manufacture is taking place predominantly in Asia where occupational health research, protective standards, and enforcement are at unacceptably low levels.

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ГІГІЕНА ПРАЦІ В ЕЛЕКТРОННІЙ ПРОМИСЛОВOSTІ

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Уряди багатьох країн пропонують стимулювати розташування компаній мікроелектронної промисловості в своїх регіонах. Більшість компаній з виробництва напівпровідникових мікросхем розташовано в Азії, де гігієнічні дослідження, стандарти з захисту умов праці та використання прав перебувають на неприйнятно низькому рівні. Крім того, виробництво печатних монтажних плат зараз теж сконцентровано в Азії. Деякі американські та європейські компанії розширили виробництво мікроелектроніки у Центральній та Східній Європі, де можуть бути досягнуті більш суворі стандарти з гігієни та охорони праці.

Професійні захворювання досягають високого рівня у працюючих з електронікою, особливо у тих, хто працює з напівпровідниками. Виробництво мікроелектроніки проходить у чистих приміщеннях з рециркуляцією повітря після видалення пилу за допомогою фільтрів для уловлювання мікрочасток. У хімічній промисловості використовують багато різних хімічних речовин, металевих домішок та інші матеріали. Хімічні дими та пари, що не видаляються після фільтрації повітря, рециркулюють і мають постійний вплив на працюючого. Ця промисловість також створює проблему радіаційного впливу і різних професійних стресів, включаючи ергономічні проблеми.

Ключові слова: мікроелектроніка, електроніка, напівпровідники, печатні монтажні плати, чисте приміщення

ГИГИЕНА ТРУДА В ЭЛЕКТРОННОЙ ПРОМЫШЛЕННОСТИ

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Правительства многих стран предлагают стимулировать размещение компаний микроэлектронной промышленности в своих регионах. Большинство компаний по производству полупроводниковых микросхем располагается в Азии, где гигиенические исследования, стандарты по защите труда и использование прав находятся на недопустимо низком уровне. Кроме того, промышленное производство печатных плат в настоящее время сконцентрировано главным образом в Азии. Некоторые американские и европейские компании расширили производство микроэлектроники в Центральной и Восточной Европе, где, возможно, могут быть достигнуты более высокие стандарты по гигиене и охране труда.

Профессиональные болезни часто имеют место у рабочих, занятых в электронной промышленности, особенно среди тех, кто работает с полупроводниками. Производство микроэлектроники осуществляется в чистых помещениях, где происходит рециркуляция воздуха после удаления пыли с помощью фильтров для улавливания микрочастиц. В электронной промышленности используются различные химические вещества, металлические примеси и другие материалы. Химические дымы и пары, которые не удаляются при фильтрации воздуха, рециркулируют, оказывая постоянное воздействие на рабочего. Эта промышленность также создает проблемы радиационного воздействия и разнообразные профессиональные стрессы, включая эргономические проблемы.

Ключевые слова: микроэлектроника, электроника, полупроводник, печатная монтажная плата, чистое помещение

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