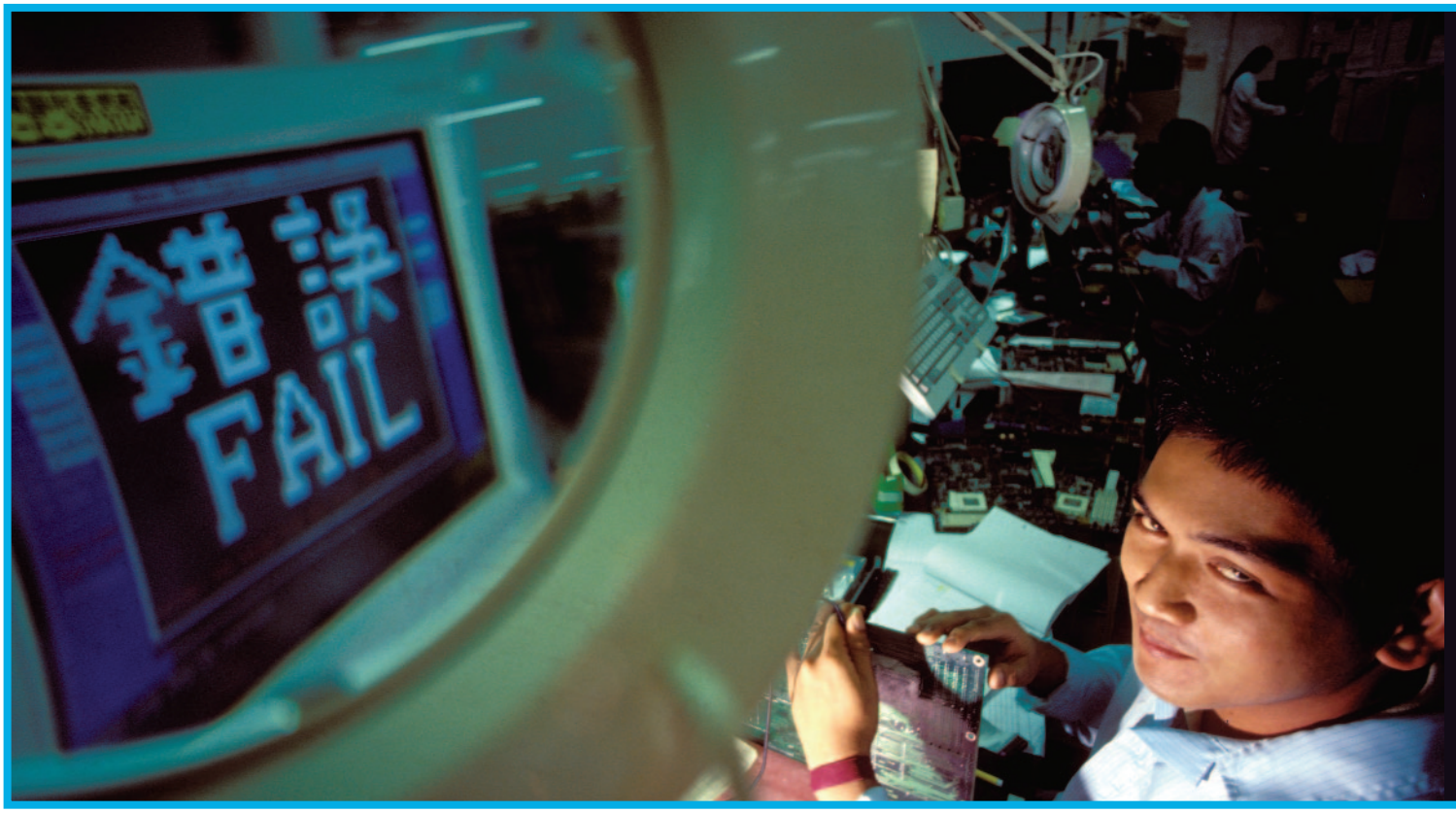

Despite the recent slowdown in computer sales, factories making computer chips as well as those that make other electronics products based on chips continue opening new facilities in Asian-Pacific nations, primarily in Taiwan, South Korea, Singapore, and Malaysia. In 2002, for the first time, more chips were made in the Asian-Pacific region than in North America, according to a 23 September 2002 article in *BusinessWeek Online* citing the Semiconductor Industry Association (SIA—the leading U.S. trade group).

In late 2001, separate reports on worker health from the government of the United Kingdom and the SIA examined cancer risk in chip production, raising the concern—but finding no clear proof—that working in the chemical-intensive industry is injurious to worker health. (Both studies called for more research.) Also in the past year, the groundwater pollution that plagued the industry in its birthplace, Silicon Valley, California, has appeared near shut-down semiconductor factories in Taiwan.

As the computer and semiconductor industries continue moving to Asia, they face a renewed focus on occupational and environmental health. The biggest unknowns are in the developing world.

Eastward Progression

According to the *BusinessWeek Online* article, Asian-Pacific production reached 28.7% of the world total in 2002, eclipsing North America's 25.7% share. The eastward movement of chip fabricators continues. Taiwan, which remains a key player in world chip production, bought 20% of all semiconductor equipment purchased in 2000, according to an August 2001 article on the website of *Semiconductor Magazine* titled "Asia-Pacific: Taking Over the World (Carefully)." China is also determined to rapidly increase chip production.

Industry insiders cite many reasons for moving to Asia, including remaining competitive in a global market, the large market potential that countries such as China have to offer high-tech companies, lower import tax rates, and skilled and technically trained workers. The surging demand for chips in Asia is another powerful incentive. "National [Semiconductor] currently sells over 45% of our products in Asia, so it is a huge—and growing—market for us," says company spokeswoman LuAnn Jenkins. According to an article in the 6 February 2003 edition of the *South China Morning Post*, China is expected to buy $16.1 billion worth of chips in 2003, and its demand is growing 29% per year. Jenkins adds, "There is a cost advantage, too, in that China provides a greater rebate to companies [in value-added tax] if products are manufactured there. We are also closer to our customers by locating a facility in that region."

But some critics charge that part of the move into Asia stems from what they say are the region's loose standards for protecting the environment and worker health. Joe LaDou, a clinical professor of occupational medicine at the University of California at San Francisco and a longtime critic of the semiconductor industry,

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Short-Circuiting Environmental Protections?

directs the International Center for Occupational Medicine. LaDou, who has been observing the semiconductor industry since 1969, says occupational health remains unstudied in Asia. "There has never been, even in Japan, an Asian study of the health and safety of semiconductor workers," he alleges. "One of the benefits of Asian manufacture is that environmental disease and occupational illness are simply unobserved."

Was National Semiconductor's decision to locate a facility overseas partly motivated by lower costs for worker and environmental health? "Absolutely not," says Jenkins. "We follow stringent guidelines for worker health and safety no matter where we do business. In Suzhou [a new plant in China], for example, we are implementing the same environmental health and safety management systems and programs we have in our other plants worldwide. This will be a state-of-the-art facility outfitted with new equipment." She adds that National Semiconductor does not have any clean rooms in Asia, which are the focus of many of LaDou's comments and allegations.

Some information about occupational health in the Asian-Pacific chip-making countries comes from *Beyond Good Deeds*, a July 2002 report on global corporate behavior produced by the California Global Corporate Accountability Project, a collaboration of several nongovernmental organizations. The report cited a 2000 survey of 136 high-tech companies in Malaysia showing that 22 had not established a committee on occupational safety and health. Of the remaining committees, 45 were "barely active," and 11 were "inactive." Information on how many of these companies produce chips is not available, but Malaysia is a major producer of products that use semiconductors.

A Repeat of Silicon Valley?

When the focus shifts to environmental health, there are indications that Asian chip-making countries may be repeating the problems of groundwater contamination that plagued Silicon Valley, where a variety of organic solvents, including 1,1,1,-trichloroethane and 1,1-dichloroethane, contaminated municipal wells. In 1986, Fairchild Semiconductor paid undisclosed sums to more than 500 claimants in the contaminated area. During the 1980s, a series of groundwater pollution incidents were blamed on Japan's high-tech industry, wrote Fumikazu Yoshida, a professor in the economics department of Hokkaido University, Japan, in his 2002 book *The Economics of Waste and Pollution Management in Japan.*

In Taiwan, a giant of semiconductor manufacture, problems have surfaced at the Hsinchu Science-Based Industrial Park (HSIP), the nation's largest zone of semiconductor production. In 1997, local residents began complaining about pungent smells and polluted water in the vicinity, says Shenglin Chang, a Taiwan native who is an assistant professor in the Department of Natural Resource Sciences and Landscape Architecture at the University of Maryland at College Park. When a nun at the nearby bible college fainted because

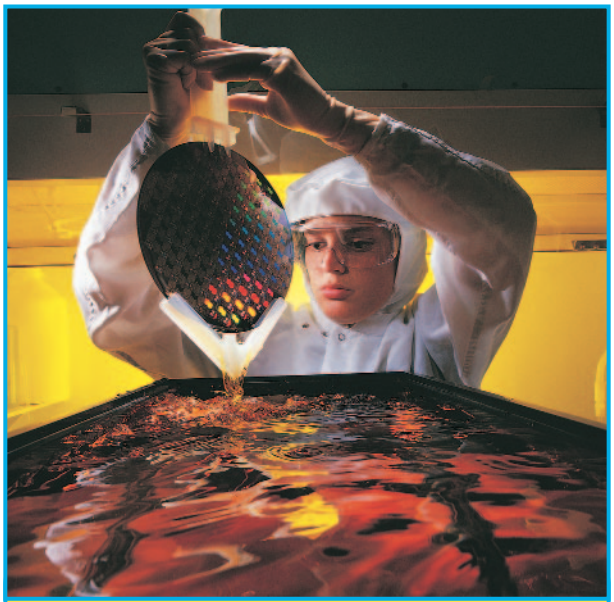
of the smell, "residents got really outraged," Chang says. Chang led an investigation under the auspices of the nonprofit Taiwan Environmental Action Network and found "many headaches, chest pains, [and] muscle pains among residents and bible college students," she says. The pollution was traced to mixed wastewater from the industrial park that was dumped into rivers and streams from which vapors outgassed. "There's no way to identify which company or which step caused the incident," says Chang.

Old world, new growth. Chip manufacturing is rapidly concentrating in Asia due to factors such as large market potential, lower import taxes, skilled workers—and possibly less strict environmental health regulations.

In 2000 the Hsinchu Department of Health tested the blood and urine of 255 local residents. Although Chang was told that 56% of the subjects had "abnormal" blood tests and 41% had "abnormal" urine tests, she says the health department refused to release the results. Chang admits that the data are inconclusive, and it's not possible to conclusively attribute the abnormalities to the same factors that caused the polluted water and pungent smell. "You need further research on that . . . but it's very difficult to get funding inside Taiwan," she says, due to the economic and political power of the semiconductor industry.

Taiwanese studies also indicate that past industry practices are harming human health. Jung-Der Wang, a professor at the Institute of Occupational Medicine and Industrial Hygiene of National Taiwan University Hospital, studied the site of a semiconductor factory that operated from roughly 1970 to 1992. Even after groundwater remediation, a variety of volatile organic compounds (VOCs), including vinyl chloride, tetrachloroethylene, and trichloroethylene, were still present in groundwater. In the 8 February 2002 issue of *Journal of Toxicology and Environmental Health Part A*, Wang reported on a health risk assessment that used U.S. Environmental Protection Agency methods to show that residents, during showers and while washing, were inhaling and dermally absorbing unsafe amounts of VOCs (residents were already boiling their drinking water to disperse VOCs, so ingestion was not a part of the study). In a separate study published in the same issue of the same journal, Wang and colleagues exposed mice to chlorinated organic solvents used in chip fabrication and found in the groundwater—including chloroform, 1,1 dichloroethane, trichloroethylene, and tetrachloroethylene—and detected significant increases in cancer. The researchers concluded that the mixture of alkenes may be harmful to humans.

The HSIP has enlarged its wastewater treatment facilities, says Jih Shao, deputy director of the science division of the Taipei Economic and Cultural Representative Office in Washington, D.C. However, he does not specify whether the wastewater is being treated to remove chemical contamination or simply undergoing standard sewage treatment. Regarding worker health in Taiwan, Shao says, "Every manufacturer has to follow labor health protective rules. For people who work with solvents, they need to check their health every year."



Dangerous work. Despite improvements in the semiconductor industry, chip making still requires the use of hazardous materials such as toxic solvents and metals, and few companies have adopted international occupational safety standards.

Mixed Regulatory Picture

One problem facing global semiconductor workers is that local or national health regulations may be inadequate, and few mandatory international regulations seem to apply to the industry. The Basel Convention, often raised as a possible barrier to the transportation of used computers (which are often "recycled" under hazardous conditions in developing countries; see "e-Junk Explosion," *EHP* 110:A188–A194 [2002]), prohibits the export of hazardous waste from rich countries to poor ones. The United States, however, continues to refuse to ratify the Basel Convention, and the agreement doesn't address health issues for workers in manufacturing anyway.

A second possible source of regulation is the 1990 Chemicals Convention of the United Nations International Labour Organization, which has been ratified by only 10 countries. The convention requires that all chemicals be evaluated for hazards, that workers be informed about chemicals in the workplace, and that appropriate preventive measures be used. However, literature searches and interviews produced no mention of the convention, so its effectiveness is questionable.

Lead, which is used in solder to join electronic parts and is a neurotoxicant, would be phased out of electronics under the European Union's proposed Restriction on Use of Hazardous Substances. In a 2001 report called the *Lead Free White Paper*, however, the World Semiconductor Council, a trade group, observed that electronic devices account for only a small percentage of lead in landfills, and that because 200,000 types of electronic products

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use lead solder, any replacement solder would have to be shown to be an effective and safe replacement, and this could take considerable testing.

Some corporations have opted for voluntary self-regulation under the International Organization for Standardization (ISO). ISO 14000, a group of standards designed to improve environmental management techniques, is described at the ISO's website as "a wide-ranging portfolio of standards for sampling and test methods to deal with specific environmental challenges" such as maintaining the quality of air, water, and soil. ISO standards, however, are not a prescription for specific practices but rather a system of management to foster improvement, and they are no guarantee of clean operations. Lyuba Zarsky, who codirected the California Corporate Global Accountability Project, noted that the culprit in a river pollution incident at the HSIP was ISO 14000–certified.

OHSAS 18001 is a counterpart of ISO 14001 that focuses on occupational health. Written by safety and standards organizations in Australia, Ireland, South Africa, Norway, Malaysia, and elsewhere, the standard was designed to replace conflicting local standards and help corporations establish an occupational health and safety management system to eliminate or minimize risk to employees and other interested parties who may be exposed to occupational health and safety risks, according to the OHSAS website (**http://www.osha-bs8800-ohsas-18001-health-and-safety.com/**). A few semiconductor makers, including National Semiconductor and Fairchild Semiconductor, have adopted OHSAS 18001. In January 2003, Fairchild announced that it had become the first company within the Philippine Visayan Islands to be OHSAS 18001–certified.

The new Silicon Valley? In Taiwan, suspected toxic releases into air and water from semiconductor manufacturing facilities have been anecdotally linked to adverse health effects, although there is no definitive evidence they are related. This points to a huge controversy surrounding the industry—the lack of adequate occupational and environmental health studies.

A Sign of Improvement?

Despite the paucity of scientific studies on the occupational health and environmental health impact of the semiconductor industry and the lack of clear international regulatory authorities over them, the industry has made improvements. By 1995, a group of major chip makers including IBM and Intel had eliminated ozone-depleting chlorofluorocarbons from cleaning processes. The industry found replacements for glycol ethers. Industry experts, government officials, and nongovernmental organizations worked together to create a procedure for handling and storing waste. Underground tanks were upgraded in Silicon Valley to include double containment and monitoring, reducing the threat to groundwater. And the increasing use of both automation and sophisticated chemical sensors now provides the mechanism to sound alarms and automatically shut down chemical delivery to minimize exposure to employees.

Yet it's difficult to know whether these technological changes will help in the countries that are the site of new chip factories. LaDou contends that many workers in developing countries use machinery removed from old plants in developed countries. "Semiconductor plants never die," he says. "They just move to the developing countries," where old equipment is installed in new buildings—a charge that industry spokespersons firmly deny.

Another driver of change in the industry, at least in the United States and the United Kingdom, could be lawsuits filed by former workers against IBM, National Semiconductor, and several other companies that supplied chemicals to the chip makers. Amanda Hawes, a lawyer in San Jose, California, who represents about 250 former IBM workers and their heirs in cases in New York and California, says, "The claim is that their work in the electronics industry has caused cancer, birth defects, and some other chronic diseases." Such lawsuits may encourage companies to tighten their occupational health protections to avoid hefty settlements.

Zarsky says the potential cost of lawsuits could explain the industry's reticence regarding research: "I think it's an extremely worrisome issue for the industry because of the potential for liability." Citing a recent SIA decision to proceed cautiously with scientific recommendations to perform a full epidemiology study of cancer among semiconductor workers [see box insert, p. A282], she says, "It's very slow, and you have to wonder if they are reluctant to proceed down that path—because of what they might find."

The course the SIA takes in future research endeavors will play a major role in the quest to document the occupational and environmental health effects of chip production. Ted Smith, director of the Silicon Valley Toxics Coalition, a nonprofit group that has long tracked the effects of chemicals used in the industry, says that during a 2001 meeting with members of the Taiwan Semiconductor Industry Association "we asked them if they had any plans for conducting any health studies in Taiwan, and they told us that they did not. . . . They were waiting for the U.S. headquarters of the SIA to take the lead."

David J. Tenenbaum

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The Cleanroom: How Clean?

Making chips has always required a long list of toxic solvents and heavy metals. Despite continual changes in processes, certain requirements remain, says Bruce Fowler, a professor of toxicology at the University of Maryland School of Medicine, who has studied the toxic effects of the heavy metals involved in chip production. He says, "You still have to have clean chips," and that means the use of various metals and a host of solvents. Heavy metals are needed later during the process that changes the electronic properties of silicon.

At the heart of the concern about occupational health is the dust-free cleanroom. Although semiconductors require the absence of dust, critics charge that cleanrooms are unclean in some other respects. "The cleanroom was designed . . . by engineers for the single purpose of lowering the particulate dust content of the cleanroom air," says Joe LaDou, a clinical professor of occupational medicine at the University of California at San Francisco and director of the International Center for Occupational Medicine. "Virtually all cleanroom air is recycled air, and you have a dozen or more solvents in the cleanroom at any time. The fumes and vapors are constantly entering the cleanroom and not being filtered out." The result, LaDou says, is "a chemical exposure lab with human subjects."

Not so, says Molly Tuttle, communications director of the Semiconductor Industry Association (SIA). "The semiconductor manufacturing process is designed to ensure that any chemicals or gasses which pose significant potential hazards are isolated from contact or unsafe exposure to workers. . . . Where trace—and safe—amounts of chemicals can enter the cleanroom environment, they are rapidly diluted and exhausted . . . resulting in an indoor air environment which enjoys a much higher level of fresh air turnover than the vast majority of indoor manufacturing."

Although some observers suspect that larger semiconductor firms may have examined occupational health, outside scrutiny and peer-reviewed reports are rare. In 1992, several studies, including one sponsored by the SIA and conducted by researchers at the University at California, Davis, found increases in miscarriages among cleanroom workers, who are predominantly female. Blame was assigned to chemicals known as glycol ethers, used as solvents in chip production, and the U.S. industry soon began phasing out these chemicals (see "Where the Chips Fall: Environmental Health in the Semiconductor Industry," *EHP* 107:A452–A457 [1999]).

Since then, there has been little or no epidemiology work in the industry. David Wegman, chairman of the Department of Work Environment at the University of Massachusetts at Lowell, who directed the SIA Science Advisory Committee (SAC) on cancer in the workplace, says, "We could not find any studies directly related to cancer risk in the industry in our literature search." The SAC was initiated in 1999 to "evaluate possible cancer risk among wafer fabrication workers in the semiconductor industry from a review of available information," according to the executive summary of the committee's October 2001 report *Cancer Risk Among Wafer Fabrication Workers in the Semiconductor Industry*. The committee concluded that there "is no affirmative evidence" that working in wafer fabrication does increase the risk of cancer. However, the report continues, "There is insufficient evidence at the present time to conclude that workplace exposures . . . have not or could not result in measurably increased risk of one or more cancer types."

Wegman says the SAC recommended that the SIA move immediately to planning a full study of cancer among semiconductor workers, with both feasibility and full epidemiologic phases. The SIA, however, has opted for a feasibility study before making any further plans, according to Tuttle. "We are conducting a feasibility study to see if data can support and/or warrant a full epidemiologic study. Our primary concern is to make sure the health and safety of our workers is the best available." Tuttle also says, "We are not being dictated by cost, but it's certainly an important factor." This decision disappointed the SAC, which felt that uncoupling the two phases would delay the startup of the proposed study and deter researchers from competing to conduct the study.

The second new study of cancer in the semiconductor industry came from the United Kingdom Health and Safety Executive (HSE), which is responsible for maintaining health and safety in workplaces. Like the SIA study, it called for further study but did not prove injury. In December 2001, the HSE issued *Cancer Among Current and Former Workers at National Semiconductor (UK) Ltd, Greenock*. The report cited excess rates of four types of cancer in former workers at National Semiconductor's plant in Greenock, Scotland. Of the four types of cancers identified in the report, only one was statistically significant—lung cancer in women. Researchers, however, did not evaluate whether or not these women smoked, a factor known to contribute to 90% of lung cancers. Although the HSE could not confirm that the increases were due to workplace exposures, the report states that the results "reinforce the concerns that prompted [the] investigation. The findings, particularly those relating to lung cancer, need to be treated very seriously."

National Semiconductor saw the primary finding in the report as good news. "We are encouraged [by the fact that] the HSE did not find scientific evidence of increased cancer risk for employees in Greenock," says company spokeswoman LuAnn Jenkins.

But the study did not satisfy Jim McCourt, coordinator of the Phase II injured semiconductor workers' support group in Greenock. Beyond failing to investigate lifestyles, he charges, the investigators left out the cleaners, who often had the dirtiest jobs but who worked for

subcontractor cleaning companies and were excluded from the study because they were not National Semiconductor employees. (Jenkins contradicts this, saying that cleaners, a large portion of whom were employees rather than subcontractors, actually were included in the HSE study.) Still, McCourt calls the HSE study "a step forward, and the results [indicating excess cancer rates] were quite alarming."

Many political, economic, and scientific reasons may combine to explain the scarcity of research and the ambiguity of the findings. The industry increasingly outsources production to contract manufacturers that may be largely unknown to the public and relatively immune to public pressure over occupational health issues. The lack of unions removes a potential source of data about occupational health issues. As a critical industry in developing countries, semiconductor manufacturers have political clout, which, critics say, impairs scientific investigation.

Fowler, for example, says there have been "improvements in occupational health [in the individual], but you have to discriminate between this country, where we have some standards regarding occupational exposures, and developing countries, where they don't have anything like the Occupational Safety and Health Administration. What [the industry has] done is shifted the fab process to the developing countries."

Dirty work in a clean room. The source of the most health concern are the cleanrooms where workers come in close contact with toxic chemicals on a routine basis.

The research task itself is complex. Whereas the British and SIA studies concentrated on cancer, some chemicals used in the industry may have neurological and reproductive toxicity. Although the industry ranks high in traditional manufacturing safety measures, occupational illness is another story. LaDou cites figures that compare the number of occupational illnesses to all reported injuries and illnesses: In 2000, according to the U.S. Bureau of Labor Statistics, occupational illnesses comprised 12.7% of all reported illnesses and injuries in all manufacturing industries. In semiconductor and related device industries, the rate was 22.5%. Exposures are also unusually complex. "If you look at the semiconductor industry, you are basically writing a textbook of occupational medicine and toxicology," says LaDou. "There is hardly a traditional exposure problem that's not found. It's everything from ergonomics and lighting, to ionizing and nonionizing radiation; it runs the gamut of solvent fumes and vapors, dopant gases . . . with a number of known carcinogens and reproductive toxicants."

The recent SAC study found that 26 of the hundreds of chemicals used in the industry—including arsenic and hexavalent chromium—are definite, probable, or possible carcinogens. The real issue, from an occupational health point of view, is whether these chemicals are injuring worker health.

The SAC researchers concluded that a standard agent-by-agent risk assessment would not "adequately answer questions of cancer risk in wafer fabrication." Yet risk assessments on multiple agent exposures are extremely difficult. Furthermore, says Wegman, because of the large number of potential chemical exposures and the previous discovery of work-related miscarriage risk, the SAC thought cancer should not be the only subject of study. They therefore recommended the development and support of ongoing health surveillance activities as early warning systems for occupational disease.

Some critics suggest that the paucity of studies may reflect an unwillingness to look for problems in an industry that has settled on a production technique that was not built with a focus on occupational health. "They have designed state-of-the-art manufacturing facilities and ignored the health and safety of the workers inside them," charges LaDou. "The only way out of this box is to export manufacturing to developing countries and contract out production to less-regulated, almost underground manufacturers. That explains how so few studies have been published." On the contrary, says Tuttle, "The SIA works hard to develop and incorporate environmental, safety, and health solutions early in the design of future processes, equipment, and cleanrooms."

One can only hope that someday a rigorous, accepted study of the environmental and occupational health aspects of chip making will come to fruition. Slowly, that day seems to be approaching. Until then, however, expect the sharp and acrimonious debate between the semiconductor industry and its critics to continue. **–David J. Tenenbaum**

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