

Mortality Among Semiconductor and Storage Device-Manufacturing Workers

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Problem: We evaluated mortality during 1965 to 1999 among 126,836 workers at two semiconductor facilities and one storage device facility. **Method:** We compared employees' cause-specific mortality rates with general population rates and examined mortality patterns by facility, duration of employment, time since first employment, and work activity. **Results:** Employees had lower-than-expected mortality overall (6579 observed deaths, standardized mortality ratio [SMR] = 65; 95% confidence interval [CI] = 64–67), for all cancers combined (2159 observed, SMR = 78, 95% CI = 75–81) and for other major diseases. Central nervous system cancer was associated with process equipment maintenance at one of the semiconductor facilities (10 observed, SMR = 247, 95% CI = 118–454). Prostate cancer was associated with facilities/laboratories at the storage device facility (18 observed, SMR = 198, 95% CI = 117–313). **Conclusions:** Further evaluation of workplace exposures or independent investigations of similar occupational groups may clarify the interpretation of associations observed in this study (J Occup Environ Med. 2005;47:996–1014)

Only a few epidemiologic studies of workers in semiconductor fabrication and related occupations have examined mortality and cancer incidence.^{1–4} These studies were conducted in the United Kingdom and included in total approximately 6200 employees. We conducted a study of mortality among employees at three facilities owned by International Business Machines (IBM) and a study of cancer incidence among employees at two of these facilities. This article presents the results of the mortality study. We will report cancer incidence results separately because the latter were subject to temporal and geographical restrictions that did not affect the mortality results.

We have described the three facilities in detail elsewhere.⁵ At two of the facilities, East Fishkill, New York (NY) and Burlington, Vermont (VT), the main operations were semiconductor manufacture, masking, and packaging. The East Fishkill and Burlington facilities opened in 1963 and 1957, respectively. They differed in several aspects over the course of their operating histories. East Fishkill had a more prominent semiconductor research and development role than Burlington and may have used materials in early phases of research and development that were not used in manufacturing processes. Although masking operations began at both facilities, over the course of time all production-scale masking migrated to Burlington. The presence of extensive packaging development and manufacturing operations at East Fishkill and the es-

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sential lack of packaging manufacturing at Burlington constitutes a major difference between the two sites.⁵ The third facility, in San Jose, California (CA), opened in 1956 and manufactured products such as hard disk drives, tape drives, network servers, and microdrives, none of which was produced at East Fishkill or Burlington. The processes and chemicals used at San Jose were different from those at the other two facilities.⁵

Materials and Methods

The time period of follow-up was from January 1, 1965, through December 31, 1999. Follow-up ended in 1999 because this was the most recent year for which data were available from national sources when we conducted record linkages to determine vital status and causes of death. Subjects were IBM employees who worked for at least 1 day at any of the three facilities during this period, who were not foreign citizens on temporary assignment at the facilities, and who had records containing information on birth date, gender, race, social security number (SSN), IBM hire date, and facility start date.

To identify subjects, we used IBM's electronic year-end files (YEFs) and the Corporate Employee Resource Information System (CERIS) history file. YEFs, available for each year from 1965 to 1999, contained identifying information and data on IBM employees' work assignment (facility, division, department, position) as of the end of the year. Some jobs, beginning and ending within the same calendar year, may have been omitted from YEF records. Most subjects employed during or after 1984 had CERIS records that identified all jobs, regardless of length of assignment, beginning in 1984.

From YEF and CERIS records, we developed data on each IBM position held by an employee since 1965 or since the IBM hire date. The job data included the start and end dates, location (facility) code, division

code, division name, department code, department name, job code, and job title. In compiling work histories, we used YEF data for jobs before 1984 and CERIS records for 1984 and later years.

From the job data, we developed facility-specific lists of unique combinations of division code, division name, department code, department name, job code, and job name (DDJs). We assigned each combination to a workgroup that consisted of DDJs with similar work activities.⁵ Operations at the semiconductor facilities in East Fishkill and Burlington comprised 15 workgroups at each of the two facilities; at San Jose, there were 19 workgroups. We further classified each DDJ as "potentially exposed" (ie, entailing any type of work other than offices) or "unexposed" (ie, entailing office work only). From workgroup descriptions developed for each facility, we determined whether activities would have been performed in cleanrooms. Two of the 15 workgroups at East Fishkill and Burlington had operations conducted always or frequently in cleanrooms, and eight had occasional cleanroom activities. At San Jose, work occurred always or frequently in a cleanroom for three workgroups and occasionally for eight workgroups.

We identified three manufacturing eras, during each of which workplace environments were judged to have been relatively stable.⁵ Although reconstruction of historical exposures was not part of this study, information on process changes and the evolution of exposure controls over the course of time indicated that the potential for exposure to chemical and physical agents may have been higher in the earliest manufacturing era.

We classified subjects into three categories of socioeconomic status (SES) based on the longest held job, using information on educational background and salary range associated with each job. SES group 1 (highest) consisted of professionals (engineers, scientists, systems analysts, managers, physicians etc.) and

programmers, SES group 2 of technicians, and SES group 3 of production, maintenance, clerical, and other employees. All work history information was developed without knowledge of subjects' vital status or causes of death.

Information on vital status as of December 31, 1999, came from linkages with the Social Security Administration, the National Death Index (NDI), and the Departments of Motor Vehicles (DMV) in NY and CA and from IBM records. For subjects who died before 1979, we retrieved death certificates, and a nosologist coded the underlying cause of death using the International Classification of Diseases (ICD) code in effect at the time of death. For subjects who died in or after 1979, NDI furnished causes of death, coded using the ICD revision in effect at the time of death.^{6,7}

Mortality analyses considered all employees and subgroups specified by facility, years since hire, years worked, potential exposure, workgroup, and job group. External analyses compared employees' mortality rates with the rates of the general population of the state where their facility was located (NY minus NY City, VT, or CA), with one exception. We were not able to use VT state rates for nonwhites because the rates were based on very small numbers and frequently were reported as being equal to zero. For nonwhite Burlington subjects, we used comparison rates from NY State minus NY City. We also conducted analyses using as the referent the general populations of the county and surrounding counties where each facility was located. Results were similar to those of analyses using state populations as the referent and are not presented.

External analyses used the standardized mortality ratio (SMR) as the measure of association.⁸ Person-year accumulation began on the date of a subject's first record of employment at a study facility (on or after January 1, 1965) or on the date of

entry into a particular category of an employment factor, whichever was later, and ended on the death date, on the date of loss to follow-up or on December 31, 1999, whichever was earliest. When there were at least five observed or expected deaths, we computed exact 95% confidence intervals (CIs) of the SMRs. In facility-specific analyses, employees who worked at more than one facility contributed person-years and deaths to each facility where they worked. If an employee transferred from one study facility to a second study facility, person-year accrual at the second facility began on the transfer date.

Internal analyses used Cox regression to estimate cancer rate ratios (RRs) for employees with potential exposure compared with unexposed employees and for employees ever, compared with those never, in a particular workgroup at a facility. We also used Cox regression to evaluate the relation between years of work in potentially exposed workgroups and specific forms of cancer. In all Cox regression analyses, age was the time variable; all exposure variables were time-dependent; and the models controlled for year of birth, gender (except when analyzing gender-specific cancers), race, SES and, for analyses of workgroups, employment (ever vs. never or years) in other workgroups. We evaluated the proportionality assumption of the Cox regressions using Wald tests for interaction terms between the exposure variables and age. Results from models in which the assumption was violated were not reported.

To decide which results to describe in detail from analyses of the overall group of employees and subgroups specified on the basis of years worked, years since hire and potential exposure category, we focused on associations having at least five observed or expected deaths and an SMR of at least 120. In presenting results for workgroups, we used a more conservative inclusion criterion to minimize the role of chance in producing positive results and fo-

cused on associations having at least five observed deaths, an SMR of 150 or higher, and an RR of at least 1.5.⁹

Results

The total number of employees in the study was 126,836 (Table 1). Of these, 45,492 had worked at East Fishkill, 29,962 at Burlington and 54,455 at San Jose; these numbers do not sum to 126,836 because 3027 employees had worked at more than one of the facilities. Among employees at all three facilities combined, 65% were men, and 35% were women. The proportion of subjects who were white was 67% among women and 75% among men. Men and women were distributed differently by SES group: 45% of men compared with 20% of women were in SES group 1, 14% of men compared with 5% of women were in SES group 2, and 42% of men compared with 76% of women were in SES group 3. Median values were 1984 for first recorded year of work at the study facilities, 2.3 for years worked and 15.5 for years since first recorded work. As of the end of the study in 1999, 91% of employees were alive, 5% were deceased, 4% were lost to follow-up, and employees' median age was 44 years. Person-years of follow-up were 2,055,328 in total, 813,961 at East Fishkill, 464,390 at Burlington and 816,895 at San Jose.

Overall Mortality Patterns

At the three facilities combined, employees had 6579 observed and 10,072 expected deaths from all causes (SMR = 65, 95% CI = 64–67), indicating that their overall mortality rate was 35% lower than the mortality rates of NY, VT, or CA general populations after adjusting for age, gender, race, and calendar time (Table 2, panel 1). The all-causes SMR was 68 both for East Fishkill and for Burlington employees and was 61 for employees at San Jose. Cancer mortality was lower than expected overall (2159 observed, SMR = 78, 95% CI = 75–

81) and at each facility. Results were similar for subgroups of employees with many (15+ or 20+) years since first record of employment and long duration of employment (5+ or 10+ years). Employees' mortality rates for major causes of death other than cancer were markedly lower than expected overall, at each facility and in subgroups with many years since hire and long duration of employment.

Mortality rates were lower than general population rates for most forms of cancer (Table 2). There were deficits of deaths from cancers associated with smoking and alcohol. Men had a large deficit of lung cancer (442 observed, SMR = 61, 95% CI = 55–67). The SMR for this cancer was higher for women than for men, but women employees had a lung cancer rate about the same as their general population counterparts (127 observed, SMR = 98, 95% CI = 82–117). Lung cancer was the only form of cancer for which there were reasonably large numbers of deaths both for women and for men, for which gender was clearly an effect modifier and for which results are, therefore, displayed separately by gender.

Employees with 15+ years since first recorded work and 5+ years worked or with 20+ years since first recorded work and 10+ years duration of employment also had large deficits of deaths from smoking and alcohol-related cancers, except for lung cancer among women. For other cancers, these employee groups did not have any large deficits or excesses of specific cancers that were based on substantial numbers; small increases occurred for several cancers, including ovarian, central nervous system, non-Hodgkin lymphoma and multiple myeloma.

Analyses of specific cancers by facility were largely consistent with results described previously. In employee subgroups with many years since hire and long duration of employment, the SMRs were between

TABLE 1
Number of Subjects by Selected Characteristics for Each Facility and for All Subjects Combined

	East Fishkill n (%)	Burlington n (%)	San Jose n (%)	Total* n (%)
Total	45,492 (100)	29,962 (100)	54,455 (100)	126,836 (100)
Gender/race or ethnicity				
Men, total	30,290 (100)	19,676 (100)	35,443 (100)	82,845 (100)
White, non-Hispanic	25,347 (84)	18,414 (94)	20,245 (57)	61,878 (75)
Hispanic	727 (2)	214 (1)	3770 (11)	4667 (6)
Asian	1942 (6)	660 (3)	8907 (25)	11,196 (13)
African American	2197 (7)	315 (2)	2342 (7)	4776 (6)
American Indian	38 (0)	44 (0)	134 (0)	215 (0)
Unknown	39 (0)	29 (0)	45 (0)	113 (0)
Women, total	15,202 (100)	10,286 (100)	19,012 (100)	43,991 (100)
White, non-Hispanic	11,470 (75)	9714 (94)	8723 (46)	29,540 (67)
Hispanic	494 (3)	86 (1)	3517 (18)	4090 (9)
Asian	656 (4)	251 (2)	4853 (26)	5698 (13)
African American	2511 (17)	184 (2)	1799 (9)	4423 (10)
American Indian	28 (0)	32 (0)	110 (1)	168 (0)
Unknown	43 (0)	19 (0)	10 (0)	72 (0)
Vital status				
Alive	41,063 (90)	27,562 (92)	48,990 (90)	114,718 (91)
Deceased	2906 (7)	1288 (4)	2516 (5)	6579 (5)
Unknown	1523 (3)	1112 (4)	2949 (5)	5539 (4)
Age at end of follow-up (yrs)				
<40	16,018 (35)	11,745 (39)	20,898 (38)	47,921 (38)
40–49	10,939 (24)	8029 (27)	12,822 (24)	30,888 (24)
50–59	9278 (21)	5921 (20)	11,623 (21)	26,014 (21)
60+	9257 (20)	4267 (14)	9112 (17)	22,013 (17)
Median	45	43	44	44
Gender and SES group				
Men				
Professionals	14,580 (48)	7354 (37)	16,600 (47)	36,941 (45)
Technicians	4955 (16)	3640 (25)	3293 (9)	11,333 (14)
Production/clerical/other	10,755 (36)	8682 (44)	15,550 (44)	34,571 (42)
Women				
Professionals	2875 (19)	1500 (15)	4512 (24)	8660 (20)
Technicians	1155 (8)	491 (5)	515 (3)	2106 (5)
Production/clerical/other	11,172 (73)	8295 (80)	13,985 (73)	33,225 (76)
Year first at facility				
<1965	4035 (8)	1237 (4)	3914 (7)	9186 (7)
1965–1969	6241 (11)	3786 (13)	5690 (10)	15,620 (12)
1970–1979	8759 (19)	5888 (20)	9940 (18)	23,758 (19)
1980–1989	18,002 (40)	9369 (31)	14,592 (27)	41,347 (33)
1990–1999	8455 (19)	9682 (32)	20,318 (37)	36,925 (29)
Median	1982	1984	1984	1984
Years worked at facility				
<1	14,457 (32)	10,732 (36)	21,455 (39)	45,709 (36)
1–<5	13,039 (29)	7473 (25)	16,748 (31)	35,606 (28)
5+	17,996 (40)	11,757 (39)	16,252 (30)	45,521 (36)
Median	2.9	2.6	1.7	2.3
Years since first record of employment at facility				
<15	18,772 (41)	14,960 (50)	28,540 (52)	60,391 (48)
15+	26,720 (59)	15,002 (50)	25,915 (48)	66,445 (52)
Median	16.3	15.0	14.5	15.5
Person-years	813,961	464,390	816,895	2,055,328

*Total is less than the sum of the number of employees at each facility because 3027 worked at more than one facility: 2058 at East Fishkill and Burlington, 672 at East Fishkill and San Jose, 251 at Burlington and San Jose, and 46 at all three facilities.

TABLE 2

Observed Number of Deaths, SMR* and 95% CI for All Subjects, for All Subjects With 15+ Years Since First Recorded Employment, and 5+ Years Worked and for All Subjects With 20+ Years Since First Recorded Employment and 10+ Years Worked, by Facility

Facility and Cause of Death†	Total			15+ YSF, 5+ YRS			20+ YSF, 10+ YRS		
	Obs	SMR	95% CI	Obs	SMR	95% CI	Obs	SMR	95% CI
Panel 1. East Fishkill, Burlington, and San Jose									
All causes	6579	65	64–67	3125	70	67–72	1921	71	68–75
All cancer	2159	78	75–81	1094	79	74–84	704	81	76–88
Oral cavity, pharynx	28	42	28–60	11	35	17–62	6	32	12–69
Esophagus	41	53	38–71	23	53	34–80	19	67	41–105
Stomach	62	72	55–92	33	79	54–111	17	67	39–107
Colorectum	237	88	77–100	119	84	70–101	80	91	72–114
Liver, biliary passages	45	60	44–81	20	52	32–80	10	41	20–75
Pancreas	127	92	77–110	70	96	75–121	48	103	76–137
Larynx	11	36	18–64	4	24	7–62	3	29	6–83
Lung, men	442	61	55–67	260	64	56–72	177	68	58–78
Lung, women	127	98	82–117	47	90	66–120	25	85	55–125
Breast	137	95	80–112	45	100	73–134	23	102	65–154
Cervix	13	61	32–104	0	[4.8]	—	0	[2.1]	—
Endometrium and uterus NOS	7	50	20–103	3	58	12–169	2	[2.9]	—
Ovary, other female genital	42	106	76–143	16	117	67–190	11	152	76–272
Prostate	116	93	77–112	83	100	80–124	57	102	78–133
Testes	7	68	28–141	0	[2.0]	—	0	[1.1]	—
Melanoma of skin	54	90	67–117	21	82	51–125	13	84	45–144
Bladder	36	71	50–98	23	77	49–115	11	57	29–103
Kidney	59	85	64–109	33	92	63–129	20	87	53–135
Central nervous system	97	107	87–131	42	112	81–151	26	117	76–171
Brain	93	108	87–132	42	114	82–154	26	119	77–174
Non-Hodgkin lymphoma	116	99	82–119	70	125	98–158	43	122	88–165
Hodgkin lymphoma	13	64	34–109	3	[4.2]	—	1	[2.1]	—
Leukemia	91	85	69–105	45	95	69–127	30	103	69–147
Multiple myeloma	45	104	76–139	23	97	61–145	19	125	75–195
Other cancer	206	80	70–92	100	81	66–98	63	80	62–103
Benign neoplasms	20	58	36–90	7	50	20–103	5	61	20–142
Diabetes	100	49	40–60	62	61	47–78	39	60	42–81
Cerebrovascular disease	248	63	55–71	130	67	56–79	78	67	53–83
Heart disease	1925	66	64–70	1031	70	66–74	617	70	64–75
NMRD	347	56	50–62	212	62	54–71	134	61	51–73
Cirrhosis of liver	134	41	34–48	70	57	45–72	40	60	43–82
Nephritis and nephrosis	26	41	27–60	15	47	27–78	7	36	14–74
External causes	736	53	49–57	154	56	48–66	75	55	44–70
AIDS	76	29	23–36	13	20	11–34	9	27	13–52
Other known causes	683	61	57–66	309	65	58–73	200	70	61–80
Unknown	125			28			13		
Panel 2. East Fishkill and Burlington									
All causes	4122	68	66–71	1997	72	69–75	1229	73	69–77
All cancer	1352	78	74–82	688	78	72–84	452	82	74–89
Oral cavity, pharynx	17	42	25–68	7	36	15–75	2	18	2–63
Esophagus	22	43	27–65	13	45	24–77	12	64	33–112
Stomach	34	69	48–96	16	64	37–104	6	40	15–86
Colorectum	143	81	68–96	68	73	57–92	47	81	59–108
Liver, biliary passages	27	71	47–103	14	67	37–112	9	67	31–127
Pancreas	85	98	78–121	49	104	77–137	38	126	89–172
Larynx	7	34	14–69	2	18	2–64	1	14	0–77
Lung, men	274	59	53–67	160	61	52–71	107	63	51–76
Lung, women	88	106	85–131	33	97	67–136	19	98	59–153
Breast	82	92	73–114	26	91	59–133	15	102	57–168
Cervix	11	85	42–151	0	[3.0]	—	0	[1.4]	—
Endometrium and uterus NOS	6	75	28–163	3	[3.5]	—	2	[1.9]	—
Ovary, other female genital	26	102	67–150	11	122	61–219	7	146	59–300
Prostate	64	84	65–107	46	91	66–121	28	81	54–118

(Continued)

TABLE 2
(Continued)

Facility and Cause of Death†	Total			15+ YSF, 5+ YRS			20+ YSF, 10+ YRS		
	Obs	SMR	95% CI	Obs	SMR	95% CI	Obs	SMR	95% CI
Testes	4	63	17-162	0	[1.3]	—	0	[0.7]	—
Melanoma of skin	41	110	79-150	15	93	52-153	11	112	56-201
Bladder	29	87	58-124	17	86	50-138	8	63	27-124
Kidney	42	95	69-129	25	108	70-159	16	107	61-174
Central nervous system	55	102	77-133	22	97	61-146	15	111	62-183
Brain	52	101	75-132	22	98	61-148	15	112	63-185
Non-Hodgkin lymphoma	75	102	80-127	46	128	94-171	29	128	85-183
Hodgkin lymphoma	8	58	25-115	3	[2.7]	—	1	[1.3]	—
Leukemia	60	91	70-118	29	98	65-140	22	119	75-180
Multiple myeloma	28	105	70-152	16	108	62-175	13	137	73-234
Other cancer	124	78	65-93	67	86	67-110	44	89	65-120
Benign neoplasms	16	71	40-115	6	63	23-138	4	71	19-181
Diabetes	69	55	43-69	43	67	48-90	24	58	37-86
Cerebrovascular disease	150	68	57-79	81	73	58-91	46	69	50-92
Heart disease	1257	69	65-73	691	73	68-79	404	71	64-78
NMRD	218	58	51-67	128	62	51-73	87	66	52-81
Cirrhosis of liver	77	50	40-63	44	72	53-97	26	78	51-114
Nephritis and nephrosis	19	44	27-69	11	50	25-89	5	36	12-84
External causes	428	58	53-64	94	62	50-76	54	71	53-92
AIDS	37	33	23-46	5	20	6-46	2	17	2-60
Other known causes	421	61	56-68	189	63	54-73	119	65	54-78
Unknown	78			17			6		
Panel 3. East Fishkill									
All causes	2906	68	66-71	1396	73	69-77	829	74	69-79
All cancer	948	77	73-82	471	78	71-85	302	83	74-93
Oral cavity, pharynx	11	37	19-67	4	30	8-76	2	26	3-95
Esophagus	13	35	19-60	8	40	17-79	7	57	23-116
Stomach	26	68	44-99	12	64	33-112	6	55	20-119
Colorectum	102	79	64-96	54	81	61-106	35	88	61-122
Liver, biliary passages	21	73	45-111	12	79	41-138	7	74	30-153
Pancreas	65	103	80-131	37	113	79-155	28	140	93-202
Larynx	5	34	11-79	2	26	3-96	1	[4.5]	—
Lung, men	200	60	52-69	109	60	50-73	70	63	49-80
Lung, women	53	98	73-128	18	79	47-125	10	76	36-139
Breast	56	93	70-121	14	71	39-119	9	88	40-167
Cervix	6	79	29-172	0	[1.8]	—	0	[0.8]	—
Endometrium and uterus NOS	5	93	30-216	3	[2.4]	—	2	[1.4]	—
Ovary, other female genital	16	97	55-157	7	118	47-243	5	156	51-363
Prostate	48	85	63-113	32	89	61-126	18	77	46-122
Testes	3	[4.4]	—	0	[0.9]	—	0	[0.5]	—
Melanoma of skin	32	137	94-194	11	113	56-202	7	124	50-255
Bladder	22	88	55-133	11	77	39-138	7	79	32-162
Kidney	28	93	62-135	17	112	65-180	10	109	52-200
Central nervous system	40	111	79-151	18	122	72-192	13	152	81-260
Brain	38	110	78-151	18	124	73-196	13	155	82-262
Non-Hodgkin lymphoma	59	116	88-149	34	144	99-201	20	139	85-215
Hodgkin lymphoma	5	50	16-116	3	[2.0]	—	1	[1.0]	—
Leukemia	37	80	56-110	18	88	52-139	12	98	50-170
Multiple myeloma	21	113	70-172	12	120	62-210	9	146	67-276
Other cancer	74	69	55-87	35	71	49-98	23	72	46-108
Benign neoplasms	13	84	45-144	4	62	17-159	3	[3.7]	—
Diabetes	43	53	39-72	26	66	43-97	13	54	29-93
Cerebrovascular disease	113	69	57-83	58	74	56-95	33	72	50-101
Heart disease	897	66	62-71	483	72	65-78	272	69	61-78
NMRD	166	63	54-73	99	70	57-85	65	74	57-95
Cirrhosis of liver	60	65	41-70	35	87	61-122	18	86	51-136
Nephritis and nephrosis	18	54	32-86	10	60	29-111	4	39	11-101

(Continued)

TABLE 2
(Continued)

Facility and Cause of Death†	Total			15+ YSF, 5+ YRS			20+ YSF, 10+ YRS		
	Obs	SMR	95% CI	Obs	SMR	95% CI	Obs	SMR	95% CI
External causes	266	61	54–68	59	68	52–88	35	83	58–116
AIDS	31	34	23–48	5	25	8–58	1	11	0–60
Other known causes	289	59	52–66	135	67	56–79	79	67	53–84
Unknown	62			11			4		
Panel 4. Burlington									
All causes	1288	68	64–72	595	68	63–74	389	71	64–79
All cancer	427	78	71–86	219	78	68–89	148	81	69–95
Oral cavity, pharynx	6	51	19–112	3	52	11–151	0	[3.7]	—
Esophagus	9	59	27–112	5	56	18–130	5	82	27–190
Stomach	8	64	28–127	4	64	17–163	0	[4.0]	—
Colorectum	43	85	61–114	15	55	31–91	13	74	40–127
Liver, biliary passages	6	58	21–127	2	34	4–123	2	[3.9]	—
Pancreas	21	80	50–122	12	83	43–145	10	102	49–187
Larynx	2	30	4–109	0	[3.7]	—	0	[2.6]	—
Lung, men	79	56	45–70	52	62	46–81	36	63	44–87
Lung, women	35	119	83–166	15	134	75–221	9	147	67–279
Breast	28	94	62–136	11	123	62–220	6	135	49–293
Cervix	5	89	29–209	0	[1.2]	—	0	[0.5]	—
Endometrium and uterus NOS	1	[2.7]	—	0	[1.1]	—	0	[0.6]	—
Ovary, other female genital	10	110	53–202	4	[3.1]	—	2	[1.6]	—
Prostate	17	78	45–124	14	93	51–156	10	93	45–171
Testes	1	[2.1]	—	0	[0.4]	—	0	[0.2]	—
Melanoma of skin	10	68	32–124	4	62	17–159	4	[4.0]	—
Bladder	7	76	30–156	6	107	39–234	1	[3.7]	—
Kidney	14	92	50–155	8	99	43–195	6	109	40–237
Central nervous system	15	78	44–128	4	50	14–128	2	[4.8]	—
Brain	14	76	42–128	4	50	14–128	2	[4.8]	—
Non-Hodgkin lymphoma	19	77	47–121	13	106	56–181	8	99	43–196
Hodgkin lymphoma	3	[3.9]	—	0	[0.7]	—	0	[0.3]	—
Leukemia	26	124	81–182	11	118	59–211	10	168	80–308
Multiple myeloma	8	93	40–184	4	[4.8]	—	3	[3.2]	—
Other cancer	54	98	74–128	32	116	79–163	21	124	77–190
Benign neoplasms	3	39	8–113	2	[3.0]	—	1	[1.9]	—
Diabetes	28	58	39–84	17	68	40–108	10	59	28–109
Cerebrovascular disease	39	63	44–85	23	71	45–107	13	64	34–109
Heart disease	387	76	68–83	203	75	65–86	128	75	63–90
NMRD	55	47	36–62	29	44	29–63	21	48	30–73
Cirrhosis of liver	17	36	21–58	9	44	20–83	8	68	29–133
Nephritis and nephrosis	1	9	0–51	1	18	0–99	1	[3.5]	—
External causes	168	54	46–63	34	53	37–74	19	58	35–90
AIDS	8	34	15–67	0	0	0–69	0	[2.6]	—
Other known causes	136	65	54–77	54	55	42–72	38	62	44–85
Unknown	19			4			2		
Panel 5. San Jose									
All causes	2516	61	58–63	1131	66	63–70	682	69	64–74
All cancer	830	78	72–83	407	81	73–89	250	82	72–93
Oral cavity and pharynx	12	42	22–74	4	32	9–81	3	41	9–120
Esophagus	20	72	44–111	9	62	28–117	7	76	30–156
Stomach	28	74	50–108	17	100	58–160	11	110	55–197
Colorectum	96	99	80–121	51	107	79–140	33	114	79–160
Liver and biliary passages	18	48	29–76	6	34	13–74	1	9	0–51
Pancreas	42	80	58–109	21	81	50–124	10	63	30–116
Larynx	4	39	11–99	2	39	5–139	2	[3.2]	—
Lung, men	169	62	53–72	100	69	56–84	70	78	61–99
Lung, women	41	87	62–118	14	77	42–129	6	59	22–128
Breast	56	101	76–130	19	118	71–184	8	105	45–207
Cervix	2	23	3–84	0	[1.9]	—	0	[0.8]	—
Endometrium and uterus NOS	1	[4.4]	—	0	[1.7]	—	0	[0.9]	—

(Continued)

TABLE 2
(Continued)

Facility and Cause of Death†	Total			15+ YSF, 5+ YRS			20+ YSF, 10+ YRS		
	Obs	SMR	95% CI	Obs	SMR	95% CI	Obs	SMR	95% CI
Ovary, other female genital	19	132	79–205	6	128	47–278	3	[2.4]	—
Prostate	53	107	80–140	38	118	83–162	29	138	93–199
Testes	3	[4.0]	—	0	[0.7]	—	0	[0.4]	—
Melanoma of skin	14	59	32–99	6	63	23–137	2	36	4–130
Bladder	7	39	16–80	6	59	22–129	3	47	10–137
Kidney	19	72	43–112	8	62	27–122	4	51	14–130
Central nervous system	42	113	81–153	20	136	83–210	11	128	64–230
Brain	41	115	83–156	20	139	85–214	11	131	65–234
Non-Hodgkin lymphoma	42	95	68–128	24	120	77–178	14	115	63–192
Hodgkin lymphoma	5	73	24–171	0	[1.5]	—	0	[0.8]	—
Leukemia	34	81	56–113	16	91	52–148	8	76	33–150
Multiple myeloma	17	98	57–157	7	78	31–161	6	107	39–232
Other cancer	86	80	64–99	33	72	50–101	19	70	42–109
Benign neoplasms	5	42	14–98	2	[4.6]	—	0	[2.5]	—
Diabetes	31	39	26–55	19	50	30–79	15	64	36–105
Cerebrovascular disease	99	56	46–68	49	58	43–77	32	65	44–92
Heart disease	684	62	58–67	338	64	57–71	209	67	58–77
NMRD	132	52	44–62	85	62	50–77	46	54	40–73
Cirrhosis of liver	61	34	26–44	28	46	30–66	13	40	22–69
Nephritis and nephrosis	7	33	13–68	4	42	11–107	2	35	4–127
External causes	315	47	42–52	60	49	38–64	21	37	23–56
AIDS	39	25	18–34	8	21	9–41	7	35	14–72
Other known causes	265	60	53–67	121	68	57–82	80	79	62–98
Unknown	48			10			7		

*The expected number is provided in brackets, without the SMR and the 95% CI, when the observed number and the expected number of deaths were both <5.

NOS indicates not otherwise specified; NMRD, non malignant respiratory disease.

120 and 170, for pancreatic cancer, ovarian cancer, central nervous system cancer, non-Hodgkin lymphoma, and multiple myeloma at East Fishkill; lung cancer among women, breast cancer and leukemia at Burlington; and prostate cancer, central nervous system cancer, and non-Hodgkin lymphoma at San Jose. None of these results was statistically significant at the 5% probability level.

Mortality by Potential Exposure Category

SMR analyses of all three facilities combined indicated that both potentially exposed employees (72% of all subjects) and unexposed employees had deficits of deaths from cancers associated with smoking and alcohol, except that both unexposed and potentially exposed women had lung cancer rates similar to general population rates (Table 3). SMRs and RRs

were elevated for ovarian cancer for all potentially exposed women (30 observed, SMR = 126, 95% CI = 85–180; RR = 2.1, 95% CI = 1.0–4.4) and for women with 15+ years since first potential exposure and 5+ years of potential exposure (12 observed, SMR = 157, 95% CI = 81–274; RR = 3.7, 95% CI = 1.4–9.3). Facility-specific analyses indicated that both SMRs and RRs for ovarian cancer were elevated among potentially exposed women at San Jose (Table 3, panel 5).

Mortality by Workgroup at East Fishkill and Burlington

The Appendix provides the number of subjects and person-years in each workgroup (see Appendix Table 1 online only) and results of SMR and Cox regression analyses for specific cancers for employees ever in each workgroup (See Appendix Table 2 online only). Table 4

presents summary data for workgroups associated with specific cancers and having at least five observed deaths from the cancer of interest, an SMR of 150 or higher and an RR of at least 1.5. For results meeting these criteria, we examined mortality patterns by years worked, years since starting and manufacturing era within workgroup.

Because East Fishkill and Burlington had certain operations in common during some time periods, analyses of mortality by workgroup were done for these two facilities combined, as well as separately. In the combined group of East Fishkill and Burlington employees, associations were seen for lung cancer among women in masking, breast cancer in masking, ovarian cancer in several workgroups, central nervous system cancer in process equipment maintenance, leukemia in the other manufacturing and multiple

TABLE 3

Observed Number of Deaths From Specific Forms of Cancer, SMR* and 95% CI For Unexposed, All Potentially Exposed, and Potentially Exposed With 15+ Years Since First Recorded Work and 5+ Years Worked and RR† for Exposed Compared With Unexposed‡, by Facility

Facility and Form of Cancer§	Unexposed			Exposed			Exposed, 15+ YSF, 5+ YRS			Ever exposed	Exposed, 15+ YSF, 5+ YRS
	Obs	SMR	95% CI	Obs	SMR	95% CI	Obs	SMR	95% CI	RR, 95% CI	RR, 95% CI
Panel 1. East Fishkill, Burlington, and San Jose											
	<i>n</i> = 42,065, PY = 628,006			<i>n</i> = 90,756, PY = 1,379,158			<i>n</i> = 24,650, PY = 254,760				
Oral cavity, pharynx	8	44	19–87	18	38	23–60	8	40	17–79	0.9, 0.4–2.1	0.9, 0.3–2.6
Esophagus	14	71	39–119	27	48	32–70	12	43	22–75	0.7, 0.3–1.4	0.7, 0.3–1.6
Stomach	11	47	23–84	49	82	60–108	21	80	50–122	1.9, 1.0–3.7	2.1, 1.0–4.4
Colorectum	59	82	63–106	166	87	74–101	73	81	64–102	1.2, 0.9–1.6	1.2, 0.8–1.7
Liver, biliary passages	9	43	20–82	34	66	46–92	13	54	29–92	1.5, 0.7–3.1	1.4, 0.6–3.5
Pancreas	34	91	63–128	89	92	74–113	46	99	73–133	1.0, 0.6–1.5	1.1, 0.7–1.8
Lung, men	126	69	58–82	295	57	50–63	153	59	50–69	0.8, 0.6–0.9	0.8, 0.6–1.0
Lung, women	46	98	72–130	77	98	77–122	28	95	63–137	1.0, 0.7–1.5	0.9, 0.6–1.5
Breast	59	109	83–141	74	86	67–108	26	106	69–155	0.8, 0.6–1.2	1.1, 0.7–1.9
Ovary and OFG	10	68	33–125	30	126	85–180	12	157	81–274	2.1, 1.0–4.4	3.7, 1.4–9.3
Prostate	23	77	49–115	89	98	79–121	54	102	77–133	1.5, 0.9–2.4	1.6, 1.0–2.7
Melanoma of skin	15	86	48–141	38	93	66–127	12	75	39–131	1.0, 0.5–1.9	0.7, 0.3–1.6
Bladder	8	62	27–123	25	69	44–101	14	73	40–123	1.0, 0.4–2.3	1.2, 0.5–2.9
Kidney	14	75	41–125	43	88	64–119	21	92	57–141	1.1, 0.6–2.1	1.3, 0.6–2.7
Central nervous system	28	106	71–154	68	111	86–141	29	126	84–181	1.0, 0.7–1.7	1.2, 0.7–2.2
Non-Hodgkin lymphoma	40	125	89–170	73	90	70–113	36	102	72–141	0.7, 0.5–1.0	0.8, 0.5–1.3
Leukemia	25	83	54–123	63	86	66–109	33	111	77–156	1.0, 0.6–1.6	1.4, 0.8–2.5
Multiple myeloma	17	146	85–234	26	85	56–125	16	106	61–173	0.6, 0.3–1.1	0.7, 0.3–1.5
Panel 2. East Fishkill and Burlington											
	<i>n</i> = 20,427, PY = 296,843			<i>n</i> = 56,468, PY = 926,286			<i>n</i> = 17,155; PY = 176,345				
Oral cavity, pharynx	4	53	14–135	11	35	18–63	5	37	12–87	—	—
Esophagus	8	86	37–170	14	35	19–58	7	34	14–71	0.3, 0.1–0.9	0.4, 0.1–1.2
Stomach	5	53	17–124	28	73	48–105	12	69	36–120	1.3, 0.5–3.3	1.4, 0.5–4.2
Colorectum	18	52	31–83	116	85	70–102	50	77	57–101	1.7, 1.0–2.8	1.6, 0.9–2.9
Liver, biliary passages	4	54	15–138	23	77	49–116	11	75	37–134	—	—
Pancreas	17	101	59–161	64	95	73–121	36	109	76–151	1.0, 0.6–1.7	1.2, 0.6–2.1
Lung, men	54	66	50–87	202	55	48–63	100	54	44–65	0.8, 0.6–1.0	0.7, 0.5–1.1
Lung, women	24	103	66–153	60	105	80–135	23	107	68–161	1.0, 0.6–1.7	1.0, 0.6–1.9
Breast	29	108	72–155	51	85	63–112	17	97	57–156	0.8, 0.5–1.3	1.0, 0.5–2.0
Ovary and OFG	5	67	22–157	19	110	66–172	8	143	62–282	1.5, 0.5–4.1	2.7, 0.8–9.2
Prostate	9	71	33–135	53	86	65–113	34	94	65–131	¶	¶
Melanoma of skin	8	105	45–206	32	113	77–159	11	98	49–176	1.2, 0.5–2.6	0.9, 0.3–2.2
Bladder	6	98	36–213	21	80	49–122	11	79	39–141	0.9, 0.3–2.2	1.0, 0.3–2.8
Kidney	7	83	33–171	33	96	66–135	17	105	61–168	1.2, 0.5–2.7	1.4, 0.6–3.7
Central nervous system	8	72	31–141	46	112	82–149	17	108	63–173	1.4, 0.7–3.1	1.5, 0.6–3.8
Non-Hodgkin lymphoma	17	115	67–185	57	100	76–130	27	108	71–157	0.8, 0.5–1.4	0.8, 0.4–1.6
Leukemia	11	82	41–146	46	92	67–122	23	111	71–167	¶	¶
Multiple myeloma	10	199	95–365	17	82	48–131	9	86	39–164	0.5, 0.2–1.1	0.6, 0.2–1.5
Panel 3. East Fishkill											
	<i>n</i> = 14,066, PY = 212,028			<i>n</i> = 33,515, PY = 585,654			<i>n</i> = 10,274, PY = 108,765				
Oral cavity, pharynx	3	51	11–149	8	35	15–69	3	32	7–94	—	—
Esophagus	5	70	23–163	8	28	12–54	5	36	12–83	0.4, 0.1–1.2	0.6, 0.2–2.1
Stomach	3	40	8–116	22	74	46–112	9	69	31–131	—	—
Colorectum	14	53	29–88	81	82	65–102	41	89	64–120	1.6, 0.9–2.8	1.8, 0.9–3.3
Liver, biliary passages	1	17	0–95	20	90	55–139	10	94	45–173	—	—
Pancreas	11	84	42–150	51	106	79–139	26	114	75–167	1.3, 0.7–2.6	1.4, 0.7–2.9

(Continued)

TABLE 3
(Continued)

Facility and Form of Cancer§	Unexposed			Exposed			Exposed, 15+ YSF, 5+ YRS			Ever exposed	Exposed, 15+ YSF, 5+ YRS
	Obs	SMR	95% CI	Obs	SMR	95% CI	Obs	SMR	95% CI	RR, 95% CI	RR, 95% CI
Lung, men	42	68	49–92	148	56	48–66	66	52	40–66	0.7, 0.5–1.0	0.6, 0.4–1.0
Lung, women	18	100	59–158	35	99	69–138	12	86	45–151	1.0, 0.6–1.8	¶
Breast	22	107	67–162	33	86	59–120	10	85	41–157	0.8, 0.5–1.5	0.9, 0.4–1.9
Ovary and OFG	4	70	19–179	11	104	52–187	4	[3.5]	—	—	—
Prostate	7	75	30–155	40	88	63–120	24	93	60–138	¶	¶
Melanoma of skin	7	131	53–271	24	138	88–205	7	106	43–218	1.1, 0.5–2.5	0.7, 0.2–2.0
Bladder	4	[4.8]	—	16	82	47–133	7	70	28–143	—	—
Kidney	4	64	18–165	23	100	63–150	13	124	66–211	—	—
Central nervous system	5	61	20–143	34	126	88–177	15	149	84–246	1.9, 0.7–5.0	2.1, 0.7–6.0
Non-Hodgkin lymphoma	13	118	63–202	45	116	85–156	20	122	75–189	0.8, 0.4–1.6	0.8, 0.4–1.7
Leukemia	9	89	41–169	27	77	51–113	14	99	54–166	0.9, 0.4–2.1	1.4, 0.6–3.3
Multiple myeloma	8	211	91–416	12	83	43–146	7	100	40–206	0.5, 0.2–1.3	0.6, 0.2–1.9

Panel 4. Burlington

	n = 7002, PY = 91,762			n = 24,458, PY = 358,199			n = 6880, PY = 66,652				
Oral cavity, pharynx	1	[2.0]	—	3	33	7–95	2	[4.1]	—	—	—
Esophagus	3	[2.5]	—	6	49	18–107	2	32	4–115	—	—
Stomach	2	[2.2]	—	6	62	23–134	3	[4.4]	—	—	—
Colorectum	4	46	12–117	37	93	65–128	10	53	25–97	—	—
Liver, biliary passages	3	[1.8]	—	3	37	8–108	1	[4.1]	—	—	—
Pancreas	7	158	64–326	13	63	33–107	10	98	47–179	0.3, 0.1–0.9	0.5, 0.2–1.5
Lung, men	14	59	32–99	57	51	39–66	35	60	42–83	0.8, 0.4–1.5	1.0, 0.5–1.9
Lung, women	6	108	40–236	25	112	73–166	11	145	72–259	1.0, 0.4–2.4	1.2, 0.4–3.6
Breast	8	124	54–245	19	87	53–136	7	122	49–252	0.8, 0.3–1.8	1.2, 0.4–3.7
Ovary and OFG	1	[1.8]	—	8	117	51–231	4	[2.1]	—	—	—
Prostate	2	[3.8]	—	14	81	44–136	10	97	47–178	—	—
Melanoma of skin	1	[2.6]	—	9	77	35–147	4	[4.5]	—	—	—
Bladder	2	[1.6]	—	5	69	22–160	4	[3.9]	—	—	—
Kidney	3	[2.6]	—	10	83	40–153	4	70	19–180	—	—
Central nervous system	3	[3.4]	—	12	79	41–138	2	36	4–129	—	—
Non-Hodgkin lymphoma	5	117	38–274	14	72	40–121	7	81	33–167	0.7, 0.2–2.0	0.8, 0.2–2.5
Leukemia	3	[3.8]	—	21	129	80–196	9	139	63–263	—	—
Multiple myeloma	2	[1.4]	—	6	88	32–192	1	[3.4]	—	—	—

Panel 5. San Jose

	n = 22,022, PY = 336,370			n = 34,880, PY = 462,628			n = 7528, PY = 77,954				
Oral cavity, pharynx	5	46	15–108	7	42	17–87	3	46	10–136	0.8, 0.2–2.5	—
Esophagus	6	56	21–122	14	85	47–143	4	53	14–136	1.5, 0.6–4.1	—
Stomach	6	42	15–91	21	94	58–144	9	102	47–194	2.6, 1.1–6.6	2.8, 1.0–8.2
Colorectum	41	107	77–145	52	93	69–121	23	94	60–141	0.9, 0.6–1.4	0.9, 0.5–1.6
Liver, biliary passages	5	36	12–84	11	49	24–87	2	22	3–78	1.3, 0.5–3.9	—
Pancreas	17	82	48–132	25	83	54–123	10	76	36–139	0.9, 0.5–1.8	1.1, 0.5–2.5
Lung, men	72	70	54–88	94	58	47–71	53	71	53–91	0.8, 0.6–1.0	0.9, 0.6–1.4
Lung, women	22	92	58–139	19	88	53–137	5	62	20–145	1.1, 0.6–2.1	0.7, 0.2–1.8
Breast	31	112	76–160	23	87	55–130	9	125	57–237	0.8, 0.4–1.4	1.2, 0.6–2.7
Ovary and OFG	5	68	22–160	14	211	115–353	5	242	79–566	3.8, 1.3–11.0	5.4, 1.4–20.7
Prostate	14	79	43–133	37	121	85–167	21	124	77–190	1.6, 0.9–3.1	1.7, 0.9–3.4
Melanoma of skin	7	70	28–144	7	54	22–112	1	[4.7]	—	0.8, 0.3–2.4	—
Bladder	2	29	4–105	4	38	10–97	3	58	12–168	—	—
Kidney	8	76	33–150	11	73	36–131	4	61	17–157	0.9, 0.4–2.4	—

(Continued)

TABLE 3

(Continued)

Facility and Form of Cancer§	Unexposed			Exposed			Exposed, 15+ YSF, 5+ YRS			Ever exposed	Exposed, 15+ YSF, 5+ YRS
	Obs	SMR	95% CI	Obs	SMR	95% CI	Obs	SMR	95% CI	RR, 95% CI	RR, 95% CI
Central nervous system	20	130	79–201	22	106	67–161	12	163	84–285	0.8, 0.4–1.5	1.2, 0.6–2.5
Non-Hodgkin lymphoma	23	130	82–195	17	67	39–108	9	88	40–168	0.6, 0.3–1.1	0.7, 0.3–1.6
Leukemia	15	89	50–147	19	79	47–123	9	101	46–191	0.9, 0.4–1.7	1.1, 0.4–2.6
Multiple myeloma	7	104	42–215	9	89	41–169	7	151	61–312	0.7, 0.3–2.0	1.1, 0.4–3.2

*The expected number is provided in brackets, without the SMR and the 95% confidence interval, when the observed number and the expected number of deaths were both <5.

†RR, adjusted using Cox regression for year of birth, SES, gender and race; computed when there were at least five deaths, both among the unexposed and among the exposed and when the Cox proportionality assumption was not violated.

‡Total numbers of exposed and unexposed employees exclude those who worked only in jobs that could not be classified according to exposure because of missing or uninterpretable DDJs or who worked in an unclassifiable job before moving to an unexposed job (772 employees at East Fishkill, 501 at Burlington, 827 at San Jose, and 1958 at all three facilities combined). The unexposed person-years are the sum of all person-yr contributed by employees who were always unexposed, plus the unexposed person-yr of employees who moved from an unexposed job to an exposed or unknown job. Data displayed only for cancers with at least 20 observed or expected deaths among all subjects combined.

§OFG indicates other female genital.

¶Results not reported because the Cox proportionality assumption did not hold.

myeloma in research and development (Table 4).

The associations between masking and lung cancer among women and between masking and breast cancer were limited to employees at Burlington, and the relation between research and development and multiple myeloma was limited to employees at East Fishkill. These results were each based on a small number of observed deaths, occurred among employees with fewer than five years in the workgroup and were not concentrated in employees with many years since hire or in the earlier manufacturing eras.

Ovarian cancer was associated with cleanrooms-occasional at East Fishkill and Burlington combined (14 observed, SMR = 152, 95% CI = 83–254; RR = 2.1, 95% CI = 0.9–4.5). The overall excess in this group was concentrated among employees who had 15+ years since starting and who spent 5+ years in cleanrooms-occasional (5 observed, SMR = 315, 95% CI = 102–735) and who started in the second manufacturing era (10 observed, SMR = 271, 95% CI = 130–499). Length of employment in cleanrooms-occasional

was associated positively with ovarian cancer (Cox regression coefficient (β) = 0.12, standard error (se) = 0.04, P = <0.01). There were more than expected deaths from ovarian cancer among employees in cleanrooms-occasional both at East Fishkill (7 observed, SMR = 115, 95% CI = 46–236; RR = 1.3, 95% CI = 0.5–3.6) and at Burlington (7 observed, SMR = 220, 95% CI = 88–453; RR = 4.4, 95% CI = 1.1–17.8). The excess was concentrated in different workgroups that comprise cleanrooms-occasional at the two facilities (packaging at East Fishkill: 6 observed, SMR = 163, 95% CI = 60–356; test/probe/dicing/slicing/die removal/wire bonding at Burlington: 6 observed, SMR = 239, 95% CI = 88–519; Table A2). These two workgroups differed in the tasks the workers performed, the processes and agents they used and the potential for exposure.⁵

Ovarian cancer also was elevated in other manufacturing at both facilities combined (7 observed, SMR = 269, 95% CI = 108–555; RR = 3.1, 95% CI = 1.3–7.8). Most subjects were short-term employees in this workgroup. The subgroup with 15+

years since starting and 5+ years worked had only 1 observed compared to 0.2 expected deaths; the trend in RRs for duration of employment with ovarian cancer was positive but not statistically significant (β = 0.20, SE = 0.11, P = 0.08). There were 5 observed (1.8 expected) ovarian cancer deaths at East Fishkill and 2 observed (0.8 expected) at Burlington in the other manufacturing workgroup.

The association between central nervous system cancer in process equipment maintenance (12 observed, SMR = 155, 95% CI = 80–270; RR = 1.8, 95% CI = 0.9–3.6) was concentrated in the subgroup with 15+ years since starting and 5+ years worked (5 observed, SMR = 295, 95% CI = 96–688) and in the earliest manufacturing era (7 observed, SMR = 187, 95% CI = 75–384). The association was limited to East Fishkill (10 observed, SMR = 247, 95% CI = 118–454; RR = 2.3, 95% CI = 1.1–5.0), whereas at Burlington there were 2 observed compared to 3.8 expected central nervous system cancer deaths in the same workgroup. At East Fishkill, the excess of central

TABLE 4

Summary of Results of Analyses of Specific Forms of Cancer by Work Group, Employees at East Fishkill or Burlington

Facility: Cancer, Work Group and Subgroup*	Obs	SMR, 95% CI	RR†, 95% CI	β‡, SE (P Value)
East Fishkill and Burlington				
Lung cancer among women in masking				
Ever in work group	8	151, 65–297	1.5, 0.7–3.1	–0.02, 0.10 (0.83)
15+ YSF, 5+ YRS	0	[0.2]		
Era 1	3	[1.4]		
Era 2	3	[3.1]		
Era 3	2	[0.8]		
Breast cancer in masking				
Ever in work group	8	161, 70–318	2.1, 1.0–4.3	0.08, 0.07 (0.21)
15+ YSF, 5+ YRS	0	[0.5]		
Era 1	2	[1.3]		
Era 2	4	[2.9]		
Era 3	2	[0.8]		
Ovarian cancer in cleanrooms, occasional				
Ever in work group	14	152, 83–254	2.1, 0.9–4.5	0.12, 0.04 (0.01)
15+ YSF, 5+ YRS	5	315, 102–735		
Era 1	4	[3.8]		
Era 2	10	271, 130–499		
Era 3	0	[1.7]		
Ovarian cancer in packaging				
Ever in work group	6	157, 58–343	1.8, 0.6–4.9	0.22, 0.055 (<0.01)
15+ YSF, 5+ YRS	4	[0.5]		
Era 1	2	[1.5]		
Era 2	4	[1.3]		
Era 3	0	[1.0]		
Ovarian cancer in test/probe/dicing/slicing/ die removal/wire bonding				
Ever in work group	9	186, 85–354	2.3, 1.0–5.3	–0.04, 0.12 (0.72)
15+ YSF, 5+ YRS	0	[0.7]		
Era 1	3	[2.2]		
Era 2	6	297, 109–647		
Era 3	0	[0.6]		
Ovarian cancer in other manufacturing				
Ever in work group	7	269, 108–555	3.1, 1.3–7.8	0.20, 0.11 (0.08)
15+ YSF, 5+ YRS	1	[0.2]		
Era 1	2	[1.6]		
Era 2	2	[0.8]		
Era 3	3	[0.3]		
Central nervous system cancer in process equipment maintenance				
Ever in work group	12	155, 80–270	1.8, 0.9–3.6	0.08, 0.04 (0.06)
15+ YSF, 5+ YRS	5	295, 96–688		
Era 1	7	187, 75–384		
Era 2	4	[3.3]		
Era 3	1	[0.8]		
Leukemia in other manufacturing				
Ever in work group	12	161, 83–281	2.2, 1.2–4.2	0.14, 0.07 (0.06)
15+ YSF, 5+ YRS	1	[0.6]		
Era 1	9	215, 99–409		
Era 2	3	[2.8]		
Era 3	0	[0.5]		
Multiple myeloma in research & development				
Ever in work group	7	205, 82–422	2.7, 1.0–7.0	0.18, 0.07 (0.01)
15+ YSF, 5+ YRS	2	[0.3]		
Era 1	2	[1.7]		
Era 2	4	[1.5]		
Era 3	1	[0.2]		

(Continued)

TABLE 4

(Continued)

Facility: Cancer, Work Group and Subgroup*	Obs	SMR, 95% CI	RR†, 95% CI	β‡, SE (P Value)
East Fishkill				
Central nervous system cancer in process equipment maintenance				
Ever in work group	10	247, 118–454	2.3, 1.1–5.0	0.11, 0.04 (0.01)
15+ YSF, 5+ YRS	5	681, 221–1588		
Era 1	6	330, 121–717		
Era 2	3	[1.8]		
Era 3	1	[0.4]		
Central nervous system cancer in test/probe/ dicing/slicing/die removal/wire bonding				
Ever in work group	10	168, 81–309	1.5, 0.7–3.1	–0.00, 0.07 (0.96)
15+ YSF, 5+ YRS	2	[1.0]		
Era 1	6	173, 64–377		
Era 2	3	[1.7]		
Era 3	1	[0.8]		
Non-Hodgkin lymphoma in test/probe/dicing/ slicing/die removal/wire bonding				
Ever in work group	15	171, 96–282	1.6, 0.9–2.8	0.03, 0.05 (0.60)
15+ YSF, 5+ YRS	2	[1.7]		
Era 1	7	136, 55–279		
Era 2	4	[2.5]		
Era 3	4	[1.1]		
Non-Hodgkin lymphoma in other manufacturing				
Ever in work group	9	161, 74–306	1.4, 0.7–2.9	0.05, 0.11 (0.69)
15+ YSF, 5+ YRS	0	[0.4]		
Era 1	1	[2.6]		
Era 2	6	245, 90–534		
Era 3	2	[0.5]		
Multiple myeloma in research & development				
Ever in work group	6	191, 70–416	2.2, 0.8–6.3	0.17, 0.07 (0.02)
15+ YSF, 5+ YRS	2	[0.3]		
Era 1	2	[1.6]		
Era 2	3	[1.4]		
Era 3	1	[0.2]		
Burlington				
Pancreatic cancer in masking				
Ever in work group	5	205, 67–478	3.4, 1.2–9.4	0.14, 0.05 (0.01)
15+ YSF, 5+ YRS	2	[0.4]		
Era 1	4	[1.3]		
Era 2	0	[0.9]		
Era 3	1	[0.2]		
Lung cancer among women in masking				
Ever in work group	6	229, 84–498	2.2, 0.9–5.4	–0.10, 0.22 (0.66)
15+ YSF, 5+ YRS	0	[0.2]		
Era 1	2	[0.9]		
Era 2	2	[1.3]		
Era 3	2	[0.4]		
Breast cancer in masking				
Ever in work group	7	294, 118–606	4.3, 1.8–10.3	0.13, 0.06 (0.04)
15+ YSF, 5+ YRS	0	[0.2]		
Era 1	1	[0.9]		
Era 2	4	[1.2]		
Era 3	2	[0.4]		
Ovarian cancer in cleanrooms occasional				
Ever in work group	7	220, 88–453	4.4, 1.1–17.8	0.05, 0.09 (0.61)
15+ YSF, 5+ YRS	1	[0.5]		
Era 1	2	[1.0]		
Era 2	5	274, 89–640		
Era 3	0	[0.4]		

(Continued)

TABLE 4

(Continued)

Facility: Cancer, Work Group and Subgroup*	Obs	SMR, 95% CI	RR†, 95% CI	β‡, SE (P Value)
Ovarian cancer in test/probe/dicing/slicing/ die removal/wire bonding				
Ever in work group	6	239, 88–519	3.8, 1.0–13.9	0.00, 0.13 (0.98)
15+ YSF, 5+ YRS	0	[0.4]		
Era 1	2	[0.8]		
Era 2	4	[1.4]		
Era 3	0	[0.0]		
Leukemia in other manufacturing				
Ever in work group	5	202, 65–471	2.2, 0.8–5.9	0.12, 0.10 (0.25)
15+ YSF, 5+ YRS	0	[0.3]		
Era 1	5	271, 88–632		
Era 2	0	[0.6]		
Era 3	0	[0.1]		

*YSF, yr since first record of employment in the work group; YRS, yr spent in the work group; era, manufacturing era (East Fishkill: 1, 1965–1973; 2, 1974–1983; 3, 1984–1999; Burlington: 1, 1965–1973; 2, 1974–1988; 3, 1989–1999). Criteria for inclusion of results for a work group in this table: for subjects ever in the work group, observed number of deaths \geq 5, SMR \geq 150, and RR \geq 1.5.

†Rate ratio for ever-compared to never-employed in the work group; Cox regression used to adjust for year of birth, gender (except for gender-specific analyses), race, socioeconomic status and ever-“exposed” in other work groups.

‡β, Cox regression coefficient for yr spent in the work group (continuous variable), adjusted for year of birth, gender (except for gender-specific analyses), race, SES, and years spent in other work groups entailing potential exposure; SE, standard error of the regression coefficient; P value of regression coefficient, equivalent to P value for linear trend.

nervous system cancer was concentrated in the subgroup with 15+ years since starting and 5+ years in process equipment maintenance (5 observed, SMR = 681, 95% CI = 221–1588) and in the two earliest manufacturing eras (era 1: 6 observed, SMR = 330, 95% CI = 121–717) (era 2: 3 observed and 1.8 expected). Length of employment in process equipment maintenance at East Fishkill was associated positively with central nervous system cancer (β = 0.11, SE = 0.04, P = 0.01).

Several other workgroups at East Fishkill had elevated SMRs and RRs for central nervous system cancer, but these associations were weaker than the association with process equipment maintenance. For example, employees in test/probe/dicing/slicing/die removal/wire bonding had 10 observed deaths from central nervous system cancer (SMR = 168, 95% CI = 81–309; RR = 1.5, 95% CI = 0.7–3.1); there was no duration-response relation for the latter workgroup (β = -0.00, SE = 0.07, P = 0.96).

The association between other manufacturing and leukemia at East Fish-

kill and Burlington combined (12 observed, SMR = 161, 95% CI = 83–281; RR = 2.2, 95% CI = 1.2–4.2) was concentrated in the earliest manufacturing era (9 observed, SMR = 215, 95% CI = 99–409). Eleven of the 12 leukemia decedents in other manufacturing had worked there for <5 years. There was only 1 leukemia death (0.6 expected) in the subgroup with 15+ years since starting and 5+ years worked (1 observed and 0.8 expected in the subgroup with 10+ years since starting and 5+ years worked). Results for other manufacturing and leukemia by facility indicated an association, based on small numbers, both at Burlington (5 observed, SMR = 202, 95% CI = 65–471; RR = 2.2, 95% CI = 0.8–5.9) and at East Fishkill (7 observed, SMR = 140, 95% CI = 56–289, RR = 2.0, 95% CI = 0.9–4.6).

Separate analyses of cancer mortality in workgroups at East Fishkill indicated that several workgroups had more than expected deaths from non-Hodgkin lymphoma. The largest increase occurred in test/probe/dicing/slicing/die removal/wire bonding (15 observed, SMR = 171, 95% CI = 96–282; RR = 1.6, 95% CI = 0.9–

2.8). There were 2 observed and 1.7 expected deaths among employees with 15+ years since starting and 5+ years in this workgroup (3 observed and 2.0 expected in the subgroup with 10+ years since starting and 5+ years worked), and no trend of increasing RRs with increasing time since starting or years worked was evident. At Burlington, employees classified as having worked in test/probe/dicing/slicing/die removal/wire bonding had fewer than expected deaths from non-Hodgkin lymphoma (4 observed, SMR = 59, 95% CI = 16–151).

Mortality by Workgroup at San Jose

At San Jose, associations were observed for pancreatic cancer in head fabrication, breast cancer in test/dice/slice, ovarian cancer in cleanroom occasional, other manufacturing, assembly, prostate cancer in facilities/laboratories, and central nervous system cancer in facilities/laboratories and in research and development (Table 5). The associations pertaining to pancreatic cancer, breast cancer, and ovarian cancer were concentrated among employees in the

TABLE 5

Summary of Results of Analyses of Specific Forms of Cancer by Work Group, Employees at San Jose

Cancer, Work Group and Subgroup*	Obs	SMR, 95% CI	RR†, 95% CI	β‡, SE (P Value)
Pancreatic cancer in head fabrication				
Ever in work group	8	156, 67–308	2.4, 1.0–5.3	0.15, 0.07 (0.03)
15+ YSF, 5+ YRS	1	[0.6]		
Era 1	4	[1.7]		
Era 2	4	[2.8]		
Era 3	0	[0.6]		
Breast cancer in test/dice/slice				
Ever in work group	6	163, 60–354	2.1, 0.8–5.2	–0.10, 0.28 (0.72)
15+ YSF, 5+ YRS	0	[0.1]		
Era 1	1	[1.0]		
Era 2	3	[2.2]		
Era 3	2	[0.5]		
Ovarian cancer in head fabrication				
Ever in work group	6	271, 99–590	2.3, 0.8–6.6	0.52, 0.11 (0.65)
15+ YSF, 5+ YRS	1	[0.3]		
Era 1	2	[0.7]		
Era 2	3	[1.2]		
Era 3	1	[0.3]		
Ovarian cancer in other manufacturing				
Ever in work group	5	378, 123–882	2.8, 1.0–8.4	0.15, 0.20 (0.46)
15+ YSF, 5+ YRS	0	[0.1]		
Era 1	2	[0.8]		
Era 2	3	[0.5]		
Era 3	0	[0.1]		
Ovarian cancer in assembly				
Ever in work group	7	254, 102–524	1.8, 0.6–5.0	0.16, 0.09 (0.08)
15+ YSF, 5+ YRS	1	[0.4]		
Era 1	5	347, 113–810		
Era 2	2	[1.1]		
Era 3	0	[0.2]		
Prostate cancer in facilities/laboratories				
Ever in work group	18	198, 117–313	2.3, 1.3–4.2	0.08, 0.03 (0.01)
15+ YSF, 5+ YRS	8	238, 103–468		
Era 1	14	235, 129–395		
Era 2	4	[3.1]		
Era 3	0	[0.1]		
Central nervous system cancer in facilities/laboratories				
Ever in work group	7	171, 69–353	1.6, 0.7–3.6	0.09, 0.04 (0.04)
15+ YSF, 5+ YRS	2	[0.9]		
Era 1	1	[2.2]		
Era 2	6	334, 123–728		
Era 3	0	[0.1]		
Central nervous system cancer in research & development				
Ever in work group	7	198, 80–408	1.5, 0.6–3.4	0.09, 0.05 (0.09)
15+ YSF, 5+ YRS	3	[0.5]		
Era 1	3	[1.7]		
Era 2	4	[1.8]		
Era 3	0	[0.1]		

*YSF, yr since first record of employment in the work group; YRS, yr spent in the work group; era, manufacturing era (1, 1965–1972; 2, 1973–1989; 3, 1990–1999). Criteria for inclusion of results for a work group in this table: for subjects ever in the work group, observed number of deaths ≥ 5 , SMR ≥ 150 , and RR ≥ 1.5 .

†Rate ratio, ever-compared with never-employed in the work group; Cox regression used to adjust for year of birth, gender (except for gender-specific analyses), race, SES, and ever-“exposed” in other work groups.

‡β, Cox regression coefficient for yr spent in the work group (continuous variable), adjusted for year of birth, gender (except for gender-specific analyses), race, SES, and years spent in other work groups entailing potential exposure; SE, standard error of the regression coefficient; P value of regression coefficient, equivalent to P value for linear trend.

earliest two manufacturing eras and among employees with fewer than five years in the workgroup; there was no or just one death from the cancer of interest in the subgroup with 15+ years since starting and 5+ years worked.

The excess of prostate cancer in the facilities/laboratories group at San Jose (18 observed, SMR = 198, 95% CI = 117–313; RR = 2.3, 95% CI = 1.3–4.2) was concentrated among, but not limited to, men who had 15+ years since starting and were employed 5+ years (8 observed, SMR = 238, 95% CI = 103–468) and who began working in the earliest manufacturing era (14 observed, SMR = 235, 95% CI = 129–395) and was limited to white men in facilities/laboratories (17 observed, SMR = 201, 95% CI = 117–322). There was a positive trend of increasing RRs with increasing years spent in this workgroup ($\beta = 0.08$, SE = 0.03, $P = 0.01$).

Central nervous system cancer deaths were elevated in the facilities/laboratories workgroup (7 observed, SMR = 171, 95% CI = 69–353; RR = 1.6, 95% CI = 0.7–3.6); this increase was concentrated in the second manufacturing era (6 observed, SMR = 334, 95% CI = 123–728). Although the trend in RRs by years worked was positive ($\beta = 0.09$, SE = 0.04, $P = 0.04$), there were only 2 deaths in the subgroup with 15+ years since starting and 5+ years worked. The research and development workgroup had an SMR for central nervous system cancer of 198 (7 observed, 95% CI = 80–408; RR = 1.5, 95% CI = 0.7–3.4). The increase was concentrated in the two earliest manufacturing eras. The trend in RRs by years worked was positive but not statistically significant ($\beta = 0.09$, SE = 0.05, $P = 0.09$).

Discussion

Our study is the largest investigation of the semiconductor industry and the only investigation of storage-device manufacturing workers conducted to date. Additional strengths

were low potential for differential information bias, in-depth analyses of mortality by potential exposure, workgroup, years worked and years since starting in an employment category and the use of both external and internal comparison groups.

The investigation also had limitations. Subjects tended to be young at the end of 1999, and data were sparse on subgroups with long potential disease induction time and long duration of employment. YEF records may have missed jobs lasting less than 1 year, and historical translations were unavailable for some DDJs. The impact of these limitations was likely to have been minor as short-term jobs are less likely to be associated with work-related health effects, and the proportion of subjects with DDJs that could not be classified by potential exposure and workgroup was small (1.5%). The semiconductor industry over the course of time has used several established and suspected carcinogens, including ionizing radiation, asbestos, arsenic and arsenical compounds, chromium compounds, sulfuric acid mist, ultraviolet light, trichloroethylene, carbon tetrachloride, nickel, and antimony trioxide.^{4,5,10} We did not develop estimates of employees' exposure to these or other specific agents. We also lacked information on nonoccupational factors that are potential confounders of some of the observed associations between employment factors and cancer. Our external analyses relied on comparisons of employees with general state populations, a suboptimal reference group because of the healthy worker effect;^{11,12} internal analyses, which may have minimized confounding by unmeasured factors, were imprecise because of small numbers. Nondifferential misclassification of subjects by potential exposure and workgroup probably occurred because information included in DDJs was sometimes nonspecific. Differential misclassification of causes of death and detection bias might have dis-

torted comparisons between IBM employees and the general population. Our analyses examined thousands of relationships, and some or all observed positive and negative associations may be due to chance.

The semiconductor and storage-device manufacturing workers in this study had mortality rates that, overall, were 30% to 40% lower than the rates of their general population counterparts. The deficit of mortality persisted among employees with many years since hire and long duration of employment. These results reflected the fact that many male employees were professionals and presumably were more educated, had more financial resources, and would have had better access to medical care than the general population at large. Because of these attributes, employees may have had less exposure to disease risk factors correlated with SES, as well as earlier diagnosis of certain cancers and other diseases and consequently better survival. SES is strongly inversely associated with overall and cancer mortality rates.^{13–18} Previous studies of white-collar workers or workers in technical jobs have reported all-cause SMRs in the range of 44 to 75 and all-cancer SMRs in the range of 50 to 88.^{19–32} The relation between SES and mortality varies by specific form of cancer. For example, SES is inversely associated with lung cancer mortality but is positively associated with breast cancer mortality.³³

There was no clear evidence of employment-related increased mortality from any form of cancer. Some subgroups of employees, specified on the basis of workgroup, had increased mortality from central nervous system cancer, prostate cancer and several other cancers. These associations could be attributable to workplace exposures, but confounding by nonoccupational factors, errors in work history classifications and chance are plausible alternative explanations.

Central Nervous System Cancer

Although we observed SMRs and RRs above the null for several workgroups at each facility, the most consistent association was with process equipment maintenance at East Fishkill. At both East Fishkill and Burlington, employees in process equipment maintenance are skilled technicians and engineers assigned to maintain and repair line equipment. This workgroup provided support to semiconductor fabrication and packaging operations at both facilities.

Ionizing radiation exposure during childhood is the only established cause of central nervous system cancer.^{34–38} Little is known about other causes of this cancer that could have been potential confounders in the present study.

It is not possible to conclude that the association between process equipment maintenance and central nervous system cancer at East Fishkill is causal. The observations that the association displayed a duration-response trend and was concentrated in subgroups with 15+ years since starting and 5+ years worked in this group and in the earliest two manufacturing eras indicate the need for assessing the relation, if any, to workplace exposures.

Prostate Cancer

This cancer was not associated with employment factors at East Fishkill or Burlington. At San Jose, men in the facilities/laboratories workgroup had a 2-fold increase in prostate cancer deaths. The facilities/laboratories workgroup at San Jose included jobs in facilities engineering, plant engineering, plant maintenance, environmental health and safety, laboratories and engineering and control. Duties included repairing and maintaining piping, ventilation systems, the deionized water plant, power distribution and conducting safety and quality audits of processes. Some studies have reported a possible link between expo-

sure to heavy metals and prostate cancer,^{39,40} but understanding of the etiologies of this cancer is limited.^{41,42} For reasons similar to those mentioned previously for process equipment maintenance and central nervous system cancer, we cannot conclude that the association between facilities/laboratories and prostate cancer is causal. Investigation of employees' exposure to specific agents may clarify the interpretation.

Other Cancers

At the three facilities combined, SMRs and RRs for ovarian cancer were elevated for potentially exposed women. Of several workgroup associations observed for this cancer, the strongest was with employment in cleanrooms-occasional at East Fishkill and Burlington. However, cleanrooms-occasional consists of diverse activities comprising five workgroups, and the excess of ovarian cancer occurred in a different workgroup within cleanrooms-occasional at the two facilities. The evaluation and interpretation of this and other results for ovarian cancer were difficult because of small numbers and the heterogeneity of work involved in the groups of interest. Occupational factors have not been identified as causes of ovarian cancer. Suspected factors include ionizing radiation, asbestos, talc, certain solvents and pesticides, and jobs in the health care, printing, agriculture, rubber manufacturing, and the pharmaceutical industry.^{43–45} Nonoccupational risk factors include family history, incessant ovulation and related factors, and possibly obesity and estrogen-replacement therapy.⁴³ Oral contraceptive use and high parity are protective.

At East Fishkill, mortality from non-Hodgkin lymphoma was weakly associated with several workgroups, particularly with test/probe/dicing/slicing/die removal/wire bonding. The associations were not statistically significant and did not display trends with amount of time spent in

the workgroups, and similar associations did not occur at Burlington. Occupational causes for this form of cancer have not been identified. Several facility-specific workgroups had increased mortality from pancreatic cancer, breast cancer, leukemia, and multiple myeloma. Detailed analyses of these results were either uninformative or did not suggest an occupational cause. The associations were, for the most part, based on small numbers and were not concentrated in long-term employees or subgroups with many years since beginning in a workgroup. It may be useful to evaluate these cancers further in future updates of the present study.

Comparisons between employees and the state general populations indicated that lung cancer mortality rates were low among men at all three facilities and, overall, were approximately the same as or lower than expected among women at East Fishkill and San Jose. At Burlington, women had more-than-expected lung cancer deaths overall, in subgroups with many years since starting and long duration of employment and with many years since starting and long duration of employment in potentially exposed workgroups. These associations were not statistically significant and were diminished in internal analyses that controlled for SES. Women employed in masking operations at Burlington had a 2-fold increase in lung cancer mortality rates, compared with the state general population or other women employees. Results for this workgroup were based on small numbers, years spent in the workgroup was not associated with lung cancer among women, and employment in masking was inversely associated with lung cancer among men at Burlington. We do not know the reason for the different results seen for women and men in masking. In view of the small numbers of lung cancer deaths among both women and men in this workgroup, chance may be the explanation. Examination of the gender-specific distribution of employ-

ees by job within masking indicated that the proportion working in production jobs was higher for women (82%) than for men (54%). We do not have any direct information on the extent to which exposure to chemical or physical agents varies by job type within masking.

Previous research on two small groups of semiconductor workers in the United Kingdom have not consistently reported positive results for any form of cancer.¹⁻⁴ Nichols and Sorahan³ found 3 observed and 3.6 expected brain cancer deaths, whereas McElvenny et al.⁴ reported 3 observed and 0.8 expected deaths. Nichols and Sorahan³ reported an SMR of 85 for lung cancer among women and men combined. In the study by McElvenny et al., there was no death from lung cancer among men, while women had 10 observed and 3.1 expected deaths from this cancer.⁴ The results of both studies were unremarkable or not reported for mortality from leukemia, non-Hodgkin lymphoma and cancers of the pancreas, breast and ovary. Storage device manufacturing workers have not been studied previously.

Conclusions

This study found that IBM employees at the three study facilities had substantial deficits of deaths from all major diseases when compared with general populations. Although there was no conclusive evidence that any form of cancer was associated causally with employment, mortality was increased in some subgroups of employees for central nervous system, prostate and several other cancers. These positive results emerged in the context of thousands of comparisons and may be due to chance. However, the associations warrant further investigation, with the highest priority for such investigation placed on central nervous system and prostate cancers because these two cancers appeared to be most consistently related to work factors. Further follow-up will permit a more informative analysis

of cancer mortality in the cohort. Detailed evaluation of employees' potential for occupational exposure to specific agents and of their non-occupational risk factors, as well as research on other groups of workers in the semiconductor and storage device manufacturing industries, may clarify the interpretation of the results.

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