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Elihu D. Richter, Tamar Berman, Eli Ben-Michael, Richard Laster & Jerome B. Westin

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Cancer in Radar Technicians Exposed to Radiofrequency/Microwave Radiation:

Sentinel Episodes

ELIHU D. RICHTER, MD, MPH, TAMAR BERMAN, ELI BEN-MICHAEL,
RICHARD LASTER, LL.D., JEROME B. WESTIN, MD, MPH, PHD

Controversy exists concerning the health risks from exposures to radiofrequency/microwave irradiation (RF/MW). The authors report exposure-effect relationships in sentinel patients and their co-workers, who were technicians with high levels of exposure to RF/MW radiation. Information about exposures of patients with sentinel tumors was obtained from interviews, medical records, and technical sources. One patient was a member of a cohort of 25 workers with six tumors. The authors estimated relative risks for cancer in this group and latency periods for a larger group of self-reported individuals. Index patients with melanoma of the eye, testicular cancer, nasopharyngioma, non-Hodgkin's lymphoma, and breast cancer were in the 20–37-year age group. Information about work conditions suggested prolonged exposures to high levels of RF/MW radiation that produced risks for the entire body. Clusters involved many different types of tumors. Latency periods were extremely brief in index patients and a larger self-reported group. The findings suggest that young persons exposed to high levels of RF/MW radiation for long periods in settings where preventive measures were lax were at increased risk for cancer. Very short latency periods suggest high risks from high-level exposures. Calculations derived from a linear model of dose-response suggest the need to prevent exposures in the range of 10–100 $\mu\text{W}/\text{cm}^2$. *Key words:* radiofrequency/microwave radiation; sentinel patients; cancer clusters; radar technicians.

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The health effects of non-ionizing (radio frequency/microwave; RF/MW) radiation have aroused interest in recent years, mainly as a result of the proliferation of cellular telephones and antennas in civilian settings, and the use of other communication equipment.^{1–6} Less attention has been devoted

to the health risks of radar technicians from occupational exposures. Accidental exposure to high levels of radar in air traffic controllers has been associated with chromosomal and hematologic changes.⁶ Long-term studies by Szmigielski et al.⁷ among Polish army personnel exposed to non-ionizing radiation have shown substantial increases in cancer compared with non-exposed personnel. Goldsmith's review⁶ suggests that there may be increased risks for cancer, reproductive effects, and other outcomes from exposures far below current regulatory levels. Goldsmith showed that in a cohort of U.S. diplomatic personnel exposed to RF/MW radiation, risks for cancer increased following exposures to levels as low as 5–18 $\mu\text{W}/\text{cm}^2$.

We report observations and estimate risks based on information collected from patients with sentinel tumors and high occupational exposures to RF/MW radiation from radar sources. The observations are of interest in view of the debate surrounding the possible carcinogenic effects of RF/MW radiation.^{8–10} This report states the case for precautionary measures to prevent exposure and for early detection of signs for increased risk and increased susceptibility.

METHODS

Six patients came to us during the period 1992–1999 for evaluation of eligibility for compensation. All were highly trained and knowledgeable concerning the nature of their work, the types of equipment they worked with, and the source, power, and frequency spectrum of the radiation they were exposed to. We estimated exposures to RF/MW radiation based on self-reports by the patients, information from manuals containing specifications of the equipment they used and repaired, and results of sporadic measurements from their work and medical records. Where possible, we produced job-exposure matrices for index patients. We used the index patients' medical records to verify diagnosis.

We gathered information about illnesses of the patients' co-workers through interviews with the sentinel patients, the co-workers themselves, or mutual colleagues. In three cases, we obtained the co-workers' medical records. When this documentation was pro-

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Address correspondence and reprint requests to: Elihu Richter, MD, MPH, Unit of Occupational and Environmental Medicine, Hebrew University–Hadassah Medical School, Jerusalem 91120, Israel; telephone: 972-2-6758147; fax: 972-2-6437219; e-mail: <elir@cc.huji.ac.il>.

vided, we found that it agreed with the information we had received from all three non-medical sources.

In addition, we gathered 27 responses to a questionnaire from persons with past occupational exposures to radar and antennas who later developed tumors. The questionnaire included information about job-related exposures, working conditions, and medical history. We calculated median, minimum, and maximum latency periods from the data from our original sentinel patients and the 27 questionnaires.

RESULTS

Episode 1: Melanoma of the Eye in a Naval Electronics Technician

Patient 1 had worked on radar equipment and electronic transmitters aboard ships from 1969 to 1989. His exposures were to power sources in frequency range 7.5–18 GHz, estimated, based on sporadic measurements, to reach 20–40 mw/cm² in the range of 10 GHz. Measurements at typical worksites were reported to be in the range of 0.1–7 mw/cm², with exposures from leaks in the range of 1.2–3 mw/cm². Documents in his employment record refer to a permitted exposure level of 10 mw/cm². He reported that his work exposures exceeded those of 500–600 co-workers.

During this period, he suffered from frequent episodes of eye irritation and repeated respiratory infections. In 1989, he was found to have retinal detachment and a choroidal melanoma of the right eye, which required enucleation. A co-worker developed cataracts.

Episode 2: Seminoma in an Electronics Technician

Patient 2 was a 22-year-old electronics technician. During his first year of work as a radar operator, in 1988, he was exposed to 20–21 watts, frequency 11 GHz. During a five-month period, he was exposed to a leak of unspecified strength from a wave guide for a work period of two hours a day. During a two-month period between October and December 1989, he was involved in a mishap and exposed to leakage from a wave guide transmitting Mw at 10.7 to 11.7 MHz from a power source ranging from 20 to 110 watts. Radiation was emitted into an enclosed room where he alternated work with five other workers, providing coverage 24 hours daily, six days a week. We estimated that the source of his cumulative work exposures ranged between 26,000 and 137,000 watt hours.

One year later (2.5 years following onset of exposure) he developed a seminoma. He underwent chemotherapy and whole-body irradiation, and was cured.

Episode 3: Carcinoma of the Nasopharynx in a Radar Technician

Patient 3 worked as radar technician and repairman. In 1968, he had begun studies as an electronic technician

in a vocational high school. His work involved radar equipment. Thereafter, he held many jobs as a maintenance and repair technician. He worked with equipment emitting radiation in the frequency ranges 1,250–1,350 MHz and 2,700–2,900 MHz at average power levels between 6 and 3.6 Kw and pulsed transmission.

He reported frequent leaks, lapses, or breakdowns in the linear beam tubes (klystrons), in the oscillators (magnetrons), and from the wave-transmission guides or amplification components of the station, which can produce intense exposures in the MW range and exposures to ionizing radiation (IR). During these repair activities, workers would test the transmission of the oscillator with its cover open—a situation involving high concentrated exposure risks. The patient was directly in the field of transmission for periods lasting several minutes. He reports sticking his head and neck into openings for close looks into “hot spots.” There was no routine or sporadic monitoring of his exposures.

He worked in a setting where there were severe episodes of air pollution from oil refineries. During these episodes, he experienced throat irritation and frequent colds. In the mid- and late 1970s, he experienced episodes of dizziness and headache, ringing in the ears, inability to equalize the air pressure between the ears, hearing problems, sore throat, and runny nose, which he associated with cold drinks or exposure to winds in the afternoons. Various physicians treated him with antibiotics for what was considered tonsillitis and allergies.

In September 1993, at age 43, he was diagnosed as having metastatic carcinoma of the nasopharynx (squamous-cell carcinoma) after presenting with a right-sided neck mass and stuffed right-sided nasal passage. He had no familial history of increased tumor risk.

Episode 4: Pituitary Tumor in a Radar Technician

Patient 4 was a radar technician between the years 1983 and 1993. In 1983–86, he was directly exposed to 18 GHz at power intensities ranging from 10 mw to 10 w, as well as possible exposures to ELF radiation from main-frame computers.

During 1987–90, he repeatedly sustained exposures in the MHz to GHz range from operating computers and communication equipment, with power sources in the order of magnitude of 0.01 to 1 w (10 μ w to 1,000 μ w). In 1990–93, he was exposed to RF/MW radiation at very low frequency (30–88 MHz) at very high transmission power, up to 300 w (300,000 μ w) at a distance of 300 meters for many hours a day for a year and a half. From the outset, he suffered from headaches, dizziness, and fatigue, but did not seek medical help.

In 1995, the patient, at age 42, and 12 years after his first exposures, began to feel numbness of the left side, especially in the hand and face, with slight dizziness when walking. CT scan in July 1996 showed a large in-

TABLE 1 Sex, Age First Exposed to RF/MW, Dates of Employment, and Onset and Outcome of Cancer for Four Workers in a Team of 50

Sex, Age First Exposed	Employment Dates	Date First Ill	Diagnosis
F, 18	1991-99	1996	Ductal carcinoma, left breast
M, 22	1989-90	?	Cancer of brain, died late 1990s
F, senior	Preceded her employment	90	Cancer of foot, died of osteosarcoma? melanoma?
M, senior	1980-90	89?	No longer employed

vasive non-secretory pituitary tumor, and right frontotemporal transcranial resection was done in 1996.

The patient reported that an individual sitting in the next room during years 1987-92 had been diagnosed as having a neurocytoma in a foramen in the brain in 1994. We are tracing other individuals from the same work setting who also developed brain tumors.

Episode 5: Breast Cancer in an Electronics Technician

Patient 5 was a radar technician from 1991 through 1996. From age 18, the patient worked as a radar technician in enclosed settings, and outside near an actively operating radar transmitter. Her work involved computers and a screen (60-Hz electrical power source) 15 hours a day for the first two years and nine hours a day for the subsequent three years. In 1991-93, she worked 5 m away from an actively operating radar dish for a period of 20-30 days. Radon levels were reported as "close to normal values."

During her years of service, neither she nor her co-workers were protected by Faraday netting, either on themselves or on the equipment, or with special clothing. She did not receive periodic blood tests or any other examination, and she was not aware that measures of environmental exposure were carried out.

In 1996, at age 23, she came to us with a history of radical mastectomy, chemotherapy, and radiotherapy for ductal carcinoma, Stage III (lump 6.4×7.5 cm) in her left breast. She was tested normal for Brca1 and Brca2 genes. At age 5, she had received treatment for bilateral ureteral reflux, which had required many KUB x-rays, without shielding of the chest.

There were other cases of cancer in her unit. Table 1

summarizes the best available information about three persons among a team of 50 who, during her five years of work, developed special tumors, and a fourth who retired because of illness (unspecified).

Episode 6: Non-Hodgkin's Lymphoma in an Electronics Technician

Patient 6 was an electronics technician. His job was to operate, maintain, and repair equipment. Major exposures came from maintenance work with antennas that produced pulsed transmissions. Specifications indicated transmission from a power source with a band frequency of 16-16.5 GHz, 1-kw peak-to-peak beams, 4,000 pulses/s, 1 watt in average. He frequently worked within a few meters of a radar dish or even on the dish during periods of transmission. Sporadic measurements indicated exposures in the work area at levels of 5 mw/cm² 300 cm from the source and 10 mw/cm² 20 cm from the source. His total cumulative exposure to various sources of RF/MW radiation, including the radar dishes and portable equipment, was estimated to be 29,780 person-hours. Table 1 presents data on tumors in other workers in his unit of 25 technicians. At age 26, eight years after onset of exposure, he came to us with a medical history of non-Hodgkin's lymphoma.

Table 2 presents data on tumors in the other workers in his unit of 25 technicians. Based on interviews with this worker's superior, their individual employment periods were also approximately eight years. We estimated cumulative work exposure as 200 person-years.

We were unable to obtain information about the age of onset and duration of exposure of another worker with brain cancer in this unit of 25 workers. We could

TABLE 2 Tumor Types, Ages Exposed/Diagnosed, and Survival (December 31, 1997) of Seven Workers with Tumors in 25 Workers (Est: 200 Person-years)

	Age (Years)		Status Alive/Dead (Age at Death)
	First Exposed	Onset of Disease	
Non-Hodgkin's lymphoma	18	26	A
Melanoma and lymphoma	18	23	D (25)
Leukemia	?	45	?
Leukemia in arm	18	28	A
Lymphoma	30	50	D (50)
Liver (benign)	18	33	A
Brain	18	19	A

TABLE 3 Observed-Expected Ratios (O/E) for Workers Exposed to Radiofrequency Radiation

	Cancer Cases in Male Jews Aged 20-54 (1989) (No.)	Crude Annual Incidence/100,000 Male Jews Aged 20-54 (1989)*	Radar Technician Unit (N = 25) 1988-1998†: O/E, Relative Risks and Poisson Probability‡
All tumor sites	769	46.0	7/0.09 RR > 50 P < 0.001
Hematolymphatic	139	8.3	5/0.02 = RR = 250 P > 0.001
Lymphoma only	92	5.5	4/0.01 = RR = 400 P < 0.001

*Israel Cancer Registry; Israel population of Jewish males aged 20-54 in 1989 was 1,680,000.

†Person-years follow-up was 200 (25 workers × 8 years follow-up).

‡Poisson probability (rate is expected incidence) $P(r) = (e^{-u})(u^r/r!)$.

not obtain information about another worker, aged 19, with cancer in the head/neck one year after exposure, among 500 workers with shorter (< 3 years) job assignments and lesser exposures who were located in the vicinity of the transmission site. He is not included in this cohort.

Based on available data on the incidence of tumors in this unit of 25 workers, we calculated observed-expected ratios for workers exposed to RF/MW radiation (Table 3).

Figure 1 presents data on latency periods (median) between onset of exposure and diagnosis of cancer in 33 individuals, including the six sentinel patients and 27 individuals who filled out questionnaires. What is noteworthy are the extremely brief latency periods for certain cancers in many of the workers: for leukemia, 2 years; for lymphoma, testicular cancer, cancers of bone and muscle and cancers of head and neck, as brief as 2, 5, 5, 6, 7, and 14 years, respectively; with shortest latency periods as brief as 2, 5, 1, 2, 3, and 2 years, respectively for these tumors.

DISCUSSION

Our findings suggest that these young workers were at increased risks for cancer from occupational exposures to RF/MW radiation from radar sources, either as radar operators or repair technicians. In four situations, there were individual patients. In two additional situations, there were clusters of individuals with different tumors. Exposures were sometimes intense and often prolonged. Work hours often exceeded regular 40-hour work schedules, including periods of exposure in enclosed environments, and settings where there was potential for exposure to ELF radiation. In the first two episodes, patients reported working closer to radar sources than their peers, a circumstance that suggests why, in these cases, there were no other reported individuals with cancer in their immediate units.

The findings suggest that groups of workers subject to whole-body exposures to RF/MW radiation have in-

creased risks for different tumors, and not only one target organ or tumor type. For workers with cancers of the testicles and the head and neck, the question arises whether their exposures were preferentially directed to these sites of the body. We also received reports from other individuals with various neuropsychological complaints. There was a striking degree of consistency in the preliminary information we received from these individuals with regard to their high levels of exposure, the absence of monitoring and safeguards, and diverse tumor types in their units. We are now organizing a worker-based group to define and trace the population at risk, reconstruct and estimate past exposures, and promote preventive measures.

Interactions with other exposures. None of the six sentinel patients smoked. The patient with squamous-cell carcinoma of the nasopharynx had been subjected to concurrent exposures to ionizing radiation and had a prior history of exposure to air pollutants. The patient with breast cancer had a prior history of whole-body exposure to diagnostic x-rays as a child. Both episodes raise the question of whether other exposures interact with exposures to RF/MW radiation, and whether exposures to RF/MW radiation can serve as a promoter.

Prior familial susceptibility. In all cases there was no evidence to indicate that prior familial susceptibility played a role in inducing the tumors in the index patients.

Surveillance and monitoring. In all cases, there was no evidence to indicate the use of environmental or medical measures for routine monitoring of exposures. Cytogenetic changes in the morphology of lymphocyte chromosomes^{11,12} and fluorescence in-situ hybridization (FISH or chromosome painting) of stable translocations,¹³⁻¹⁶ GPA glycophorin A (GPA) locus analyses of somatic cell mutations in peripheral red blood cells,¹⁷ and clastogenic factors in the serum¹⁸⁻²¹ have been suggested to serve as early markers of increased risk in population groups with potential for exposures to ionizing radiation. But whatever the value of these measures, they cannot substitute for the use of Faraday-type barriers for preventing exposure.²²

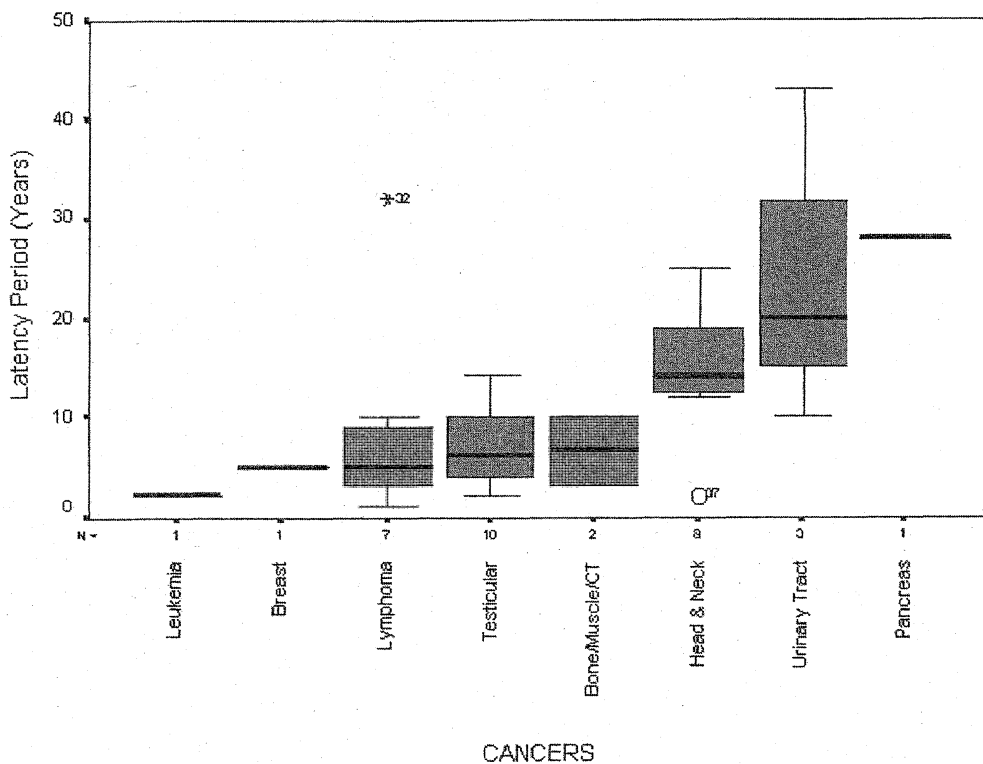


Figure 1—Latency periods of cancers in sentinel patients and self-reported individuals.

Risk assessment: high exposures and short latency periods. The latency periods between onset of exposure and onset of disease were sometimes short—2.5 years in the patient with seminoma of the testis, five years in the patient with breast cancer, and eight years in the patient with non-Hodgkin's lymphoma. Following reports of the two clusters in an Israeli newspaper, we received calls from over 100 individuals with similar occupational exposures to RF/MW radiation from radar. Ex-workers reported leukemia, testicular cancer, sarcoma of the foot, non-Hodgkin's lymphoma, and cancers of the thyroid, larynx, nasal gland, stomach, eye, and brain. Median latency periods in this larger group were also extremely brief—less than five years—especially for leukemia, lymphoma, and testicular cancer (Figure 1). Such short latencies recall earlier observations that latency periods for cancer can be extremely short,²³ the age of onset for human cancer from carcinogenic exposure falls with exposures of increased intensity,²⁴ latency time decreases with increasing dose of exposure,¹⁷ and large doses of a causative agent are needed to shorten the incubation period.²⁵

The finding that there was a plausible sequential distribution of latency periods for the different tumor types argues for a common exposure source for all of them. Data from the above-cited sources indicate that leukemia, lymphoma, testicular cancer, and brain cancer are tumor types known to follow short induction periods from environmental exposures. We suggest that this information provides additional support for a cause-effect relation-

ship between exposures to RF/MW radiation and the tumor types. If RF/MW exposures are promoters, short latency periods are entirely predictable.

We suggest that exploitation of the finding of very short latency periods is especially important in risk assessment and management when there are difficulties with access to data or estimates of person-years of risk.

Risk assessment: high exposures, linear models, and predicting risks from low doses. Table 4 is a summary based on Goldsmith's⁶ and Cherry's²⁶ reviews of the literature. These reviews conclude that tumor risks from RF/MW radiation exposures in occupational and community settings were evident from findings in many earlier studies, which their own investigators missed, for a variety of reasons: failure to look at exposure subgroups and excessive reliance on statistical probability testing (Figure 1). As Table 4 suggests, there has been an increase in background exposure of the general population to RF/MW radiation in the past two decades. For example, in 1979, the average exposure estimate for the general community in the United States was estimated to be $0.003 \mu\text{W}/\text{cm}^2$, with 1% of the population having exposures exceeding $2 \mu\text{W}/\text{cm}^2$. The question is whether subsequent increases in background exposure are obscuring our ability to detect increasing risks from exposures that are now regarded as low, but that in fact are much higher than those seen in previous decades. In the interim, we have to address the issue of what the risks from high concentrated exposures, such as those we have seen in our sentinel patients, actually are.

TABLE 4 RF/MW: Regulatory Standards, Exposure Levels, and Suggested Model for Exposure–Outcome Relationships

Standard or Exposure Levels	Effect	Exposure Level ($\mu\text{W}/\text{cm}^2$)
Worker standard	Accelerated cell death	> 10,000
	Accelerated cell damage	10,000
		5,000
Community "thermal standard"	Cell phone users get more headaches, memory loss, fatigue	1,000
		500
		100
	Miliary cancer	
	DNA damage exceeds repair	
	Amateur radio operator cancer	10
	Occupational cancer	
1% of U.S. population, 1979 U.S. average exposure, 1979 (0.003)	Dose–response for heart attack in electrical industry	
	Dose–response for cancer and reproductive effects (brain tumors,* leukemia, miscarriage)	
		2
	Residential cancer	< 1
	DNA damage balanced by repair	
	Sleep disturbance, chronic fatigue and children's learning at Schwarzenburg	
	Dose–response for neurologic effects	
	Children's learning and physical performance impaired with radar exposure in Latvia	
	Solar storm (stress, heart attack, reduced melatonin, migraine headache, apopleptic seizures, short-term memory loss, crime, SIDS)	
	Optimum (Schumann resonances)	
	Quiet sun (circadian rhythm, arrhythmia, stroke, suicide, sudden cardiac death, aperiodic brain states, SIDS)	

*Moscow Embassy studies.

We used the data on exposure and risks in the cluster summarized in Table 3 to examine the validity of Goldsmith's statement that risks for cancer increased following exposure to levels as low as 5–18 $\mu\text{W}/\text{cm}^2$ in U.S. diplomatic personnel and their children exposed to RF/MW radiation in the Moscow Embassy.⁶ We applied the principle that risks from high-level exposures in small populations predict risks from lower exposures²⁷ to calculate the exposure levels for relative risks of 1.0 and 2.0 from exposures to RF/MW radiation. This principle presupposes a linear dose–response relationship, and the absence of a threshold for risk from exposure to a carcinogen, and derives from epidemiologic data on dose–incidence relationships in humans and experimental dose–effect data on carcinogenesis in laboratory animals.²⁸

For a conservative estimate of increased risk in this group (RR = 50), and whole-body exposure estimate of 55 mW/cm^2 or 5,000 $\mu\text{W}/\text{cm}^2$, we obtain relative risks of 1.0 and 2.0 for all tumors combined from *occupational* exposures reaching 100 and 200 $\mu\text{W}/\text{cm}^2$, respectively. If our calculations are based on risks of RR = 100 or more in this group, and on an estimate of average whole-body exposure of 1 mW/cm^2 , or 1,000 $\mu\text{W}/\text{cm}^2$, we obtain levels of 10 $\mu\text{W}/\text{cm}^2$ and 20 $\mu\text{W}/\text{cm}^2$ for RRs of 1 and 2, respectively, for all tumors combined.

The first set of calculations suggests that risk for cancers in unprotected workers with frequent repeated and sustained exposures to RF/MW radiation over a period

of several years increases arithmetically with each additional 100 $\mu\text{W}/\text{cm}^2$ of exposure in the range of 100 to 200 $\mu\text{W}/\text{cm}^2$. The second set of calculations suggests that the risk increases arithmetically with each additional 10 $\mu\text{W}/\text{cm}^2$ of exposure in the range of 10 to 100 $\mu\text{W}/\text{cm}^2$. For special tumors, e.g., hematolymphatic growths, the threshold for no detectable increase in risk can be expected to be lower than 10 $\mu\text{W}/\text{cm}^2$ and the slope of the increase in risk in relation to increases in exposure can be expected to be higher.

On the basis of these inferences, we state that current recommended standards for workers (5,000 $\mu\text{W}/\text{cm}^2$ or 5 mW/cm^2) and the general community (500 $\mu\text{W}/\text{cm}^2$ or 0.5 mW/cm^2) are hazardous for both, and are accepting a level of risk that in fact may be very high.

Is it valid to compare the risks in our group of young adults with high-level work exposures with the risks of a population including children, presumably a more vulnerable group, with much lower levels of exposure? Is it valid to estimate general risks from estimates of exposure for isolated clusters that may be occurring by chance and therefore overstate risk? We suggest that the answer to both these questions is yes if we discover other clusters in small groups of workers, such as the one with the worker with breast cancer. Therefore, we would not be able to regard the clusters we report as isolated events, but as outcomes that are representative of the true risks from the estimated high-level exposures. It follows that calculations based on high risks from high-

level exposures provide estimates of increased risk from RF/MW radiation level at low-level exposures that are close to Goldsmith's estimates.

We suggest examination of this predictive model not only to see whether it serves as a valid predictor of risk, but, far more important, for elimination of risk through prevention of exposure. Results of studies in which large numbers of laboratory animals are exposed to low-, intermediate-, and high-level exposures to RF/MW radiation are not yet available to confirm the validity of these estimates.^{7,29} Therefore, we call for immediate steps to prevent prolonged or repeated occupational exposures in the range of 10–100 $\mu\text{W}/\text{cm}^2$ and lower, based on application of the precautionary principle—without waiting for the results of these studies. In June, Dr. G. Hyland of the University of Warwick informed us that limits for community exposure have been reduced to 2.4 $\mu\text{W}/\text{cm}^2$ in Belgium, 10 $\mu\text{W}/\text{cm}^2$ in Italy, and 4.5 (9.0) $\mu\text{W}/\text{cm}^2$ at 900 (1800) MHz in Switzerland.

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