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PROVINCE OF QUEBEC
DISTRICT OF MONTREAL
DOCKET No. R-3770-2011

## RÉGIE DE L'ÉNERGIE / ENERGY BOARD

AUTHORIZATION OF AN INVESTMENT BY HYDRO-QUEBEC DISTRIBUTION ADVANCED METERING PROJECT PHASE 1

HYDRO-QUEBEC As Electricity Distributor

Petitioner -and-

STRATEGIES ENERGETIQUES (S.E.) / ENERGY STRATEGIES (E.S.)

ASSOCIATION QUEBECOISE DE LUTTE CONTRE LA POLLUTION ATMOSPHERIQUE (AQLPA) / QUEBEC ASSOCIATION TO FIGHT AGAINST AIR POLLUTION

Interveners

## S.K. PARK, M. HA, H.J. IM

Ecological study on residences in the vicinity of AM radio broadcasting towers and cancer death: preliminary observations in Korea.
Int Arch Occup Environ Health. 2004 Aug:77(6):387-94
http://www.ncbi.nlm.nih.gov/pubmed/15338224
This study found higher mortality areas for all cancers and leukemia in some age groups in the area near the AM towers.

Referred to in David O. CARPENTER, Expert Report, Revised on May 14, 2012, C-SE-AQLPA-0072, SE-AQLPA-7, Doc. 1.1, parag. 38.

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Exhibit SE-AQLPA-7 - Document 11
S.K. PARK et als, Ecological study on residences in the vicinity of AM radio broadcasting towers and cancer death: preliminary observations in Korea, 2004.
Attachment to the Expert Report of David O. Carpenter
Filed by Stratégies Énergétiques (S.É.) / Energy Strategies (E.S.) and the AQLPA

## Sue Kyung Park • Mina Ha • Hyung-Jun Im

# Ecological study on residences in the vicinity of AM radio broadcasting towers and cancer death: preliminary observations in Korea 

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#### Abstract

Objectives: Public health concern about the health effects of radio-frequency electromagnetic fields (RF-EMFs) has increased with the increase in public exposure. This study was to evaluate some health effect of RF exposure by the AM radio broadcasting towers in Korea. Methods: We calculated cancer mortality rates using Korean death certificates over the period of 1994 1995 and population census data in ten RF-exposed areas, defined as regions that included AM radio broadcasting towers of over 100 kW , and in control areas, defined as regions without a radio broadcasting tower inside and at least 2 km away from the towers. Results: All cancers-mortality was significantly higher in the exposed areas [direct standardized mortality rate ratio $(\mathrm{MRR})=1.29, \quad 95 \% \mathrm{CI}=1.12-1.49]$. When grouped by each exposed area and by electrical power, MRRs for two sites of 100 kW , one site of 250 kW and one site of 500 kW , for all subjects, and for one site of 100 kW and two sites of 250 kW , for male subjects, showed statistically significant increases without increasing trends according to the groups of electric power. Leukemia mortality was higher in exposed areas ( $\mathrm{MRR}=1.70,95 \% \mathrm{CI}=0.84-3.45$ ), especially among young adults aged under 30 years ( $0-14$ years age group,


[^0]
#### Abstract

$\operatorname{MRR}=2.29,95 \% \mathrm{CI}=1.05-5.98$; 15-29 age group, $\operatorname{MRR}=2.44,95 \% \mathrm{CI}=1.07-5.24$ ). Conclusions: We observed higher mortality rates for all cancers and leukemia in some age groups in the area near the AM radio broadcasting towers. Although these findings do not prove a causal link between cancer and RF exposure from AM radio broadcasting towers, it does suggest that further analytical studies on this topic are needed in Korea.


Keywords Radio-frequency • Broadcasting
towers • Neoplasm • Mortality

## Introduction

Public health concern about the health effects of electromagnetic fields (EMFs) has increased as public exposure to EMFs has increased. Public exposure to diverse radio-frequency electromagnetic fields (RFEMFs) has tended to increase steadily in line with the continuous development of new technologies. RF-EMFs are generated by wireless communication systems, as bands of AM/FM radio-frequency: Very high frequency (VHF) and ultra-high frequency (UHF). RF is defined as the EMF of frequencies with the range of $300 \mathrm{~Hz}-$ $3,000 \mathrm{GHz}[1]$. RF-EMF resulting from radio and television broadcasting towers has a range of frequencies of between $1,000 \mathrm{kHz}$ and $1,000 \mathrm{MHz}$.

The thermal effects of high exposure to RF-EMF have been accepted, and a safety guideline for RF exposure has been established. However, the adverse health effects of RF exposure have been the subject of considerable controversy [1, 2]. Experimental investigation suggests that RF fields are not tumor initiators, and that if they are related to carcinogenicity, this would be by tumor promotion or by increased uptake of carcinogens in cells [3]. Few epidemiological studies are available on the use of mobile phones or on RF exposure and the development of cancer. The first types of
studies were ecological correlation studies that resulted from mortality and/or morbidity associated with proximity to radio and/or television transmitters. Some studies have suggested excess leukemia morbidity and/or mortality rates [4, 5]; however, others have not consistently found such findings $[6,7]$. These conflicting results might be caused by ecological fallacy, misclassification of exposure assessment and uncontrolled confounding factors. Others studies involve occupational exposure. A study of a population in Poland that was occupationally exposed to RF or microwaves, showed excess risks of all cancer, cancer of the alimentary tract, brain tumors, and cancers of the hematopoietic system and lymphatic organs [8]. In a cohort of Italian plasticware workers exposed to RF fields generated by dielectric heat sealers, mortality rate from cancers was slightly elevated, and increased risks of leukemia were detected [9]. In a casecontrol study, an association between occupational RF radiation exposure and uveal melanoma was reported [10]. However, some studies have shown no evidence of elevated cancer deaths or incidence in occupationally exposed workers [11, 12, 13].

During the recent decades, Korea has rapidly developed in the field of wireless communication systems, and public exposure to diverse RF-EMFs has increased. However, the potential adverse effects of RF-EMFs have not been extensively assessed. We performed this study to compare the mortality rates of a population residing within 2 km of a radio broadcasting tower (over 100 kW ) with those of a population residing at least 2 km away from such towers, using data from death certificates and population censuses in Korea.

## Materials and methods

Addresses on Korean death certificates are described by the governmental administrative unit, such as a small city (Si), a small administrative department in a large city $(\mathrm{Ku})$, and medium-sized rural area (Kun). The exposed areas were chosen by the selection of administrative units (Si, Kun, or Ku ) that included the Korean main AM radio broadcasting towers, whose electrical power output was 100 kW or more. Among a total of 107 Korean AM radio broadcasting towers, ten of 100 kW and more were selected. The levels of electrical power were 100 kW in four sites, 250 kW in two sites, 500 kW in three sites and $1,500 \mathrm{~kW}$ in one site. All these towers had begun transmission before 1979. The control areas selected were four administrative units that matched to each selected exposed area.

The control areas had similar numbers of people and were located in the same province as the matched exposed area, but they did not contain broadcasting towers and were at least 2 km distant from such towers. When appropriate control areas could not be chosen in the same province, they were selected from the nearest neighboring province.

All deaths due to cancer and death by cancer type were identified in Korean death certificates over the period of 1994-1995. A Korean population census has been performed on November $1^{\text {st }}$, every 5 years. The 1995 data were collected in accordance with the newly formed administration units (by the law of district rearrangement in 1995). On the other hand, the death certificate data were compiled by the old administration units. Therefore, we established the base population, using the 1990 population census data [14, 15], which were gathered before the district rearrangement.

The study population was selected as the residents in each exposed or control area. We assumed that the resident population in each area during 1994-1995 was equal to that at the time of the Korean nationwide population census of November $1^{\text {st }}, 1990$, and that all dead persons registered in the death certificate data for 1994-1995, were resident for at least 1 year. To control for possible bias related to the selection of each control area, we selected the four control areas per one exposed area, and each control area was chosen as the site having a similar population number and similar status of socioeconomic indices (e.g., the number of health personnel, regional hospital, school, the structure of industry and occupation) as each exposed area. The total numbers were $1,234,123$ and $6,881,783$ persons in the exposed area and control area, respectively. From January 1st, 1994 to December 31st, 1995, the number of people who died from various cancers (ICD-9 code 140208 and 230-238; ICD-10 code C00-C99 and D00-D09) was 97,927, and among these, 97,817 individuals were selected. The cases with wrong addresses were excluded. The number of deaths from cancer was 1,722 for the exposed area and 6,191 for the control area.

We calculated the age-adjusted cancer mortality rates of the two groups in a total of ten exposed areas and 40 control areas, using the direct standardization method used for the standard world population by the World Health Organization (WHO) [16]. For adjusting age, we divided all populations in each area into six age groups ( $0-14,15-29,30-44,45-59,60-74$, and 75 or more years), and calculated all cancer and specific cancer mortality rates with $95 \%$ confidence intervals [17, 18]. They were calculated based on 100,000 subjects annually, and the difference in the mortality rates between the exposed group and the control group was shown by the direct standardized mortality rate ratio (MRR) and its 95\% CI using Byar's approximation [17]. By each AM broadcasting site and each group of electrical power, we also calculated MRs in the exposed and control groups and MRRs to see whether the increasing trends were in accord with the electrical power or not.

In the case of four cancers (leukemia: ICD-10 code C90-C95, malignant lymphoma: ICD-10 code C81-C88, brain cancer: ICD-10 code C69-C72, and breast cancer: ICD-10 code C50) that were already suspected of having associations with RF exposure, we calculated the agespecific mortality rates in the exposed and control groups, the age-specific MRRs and their $95 \%$ CIs to
compare the two groups. All calculations were carried out by SAS software.

## Results

The mortality rates for all cancer were 113.07 per 100,000 persons in the exposed group and 87.32 per 100,000 in the control group. All cancer mortality in the exposed group was 1.29 -times higher than the control groups, and this was significant ( $95 \% \mathrm{CI}=1.12-1.49$ ). The mortality rates for all cancer, by gender, were significantly different in the exposed and control areas for male subjects (male, $\mathrm{MRR}=1.43,95 \% \mathrm{CI}=1.29-1.59$; female, $\mathrm{MRR}=1.14,95 \% \mathrm{CI}=0.92-1.42$ ). However, mortality rates for specific cancer type were not significantly different in the two groups (Tables 1 and 2). The association between mortality rates due to leukemia, malignant lymphoma, brain cancer and breast cancer, and EMF exposure has been suspected in previous other studies; however, these were also not significantly different in the two groups (Tables 1 and 2).

The mortality rates for all cancer in the exposed and control groups, and MRRs between exposed and control group, by electrical power, are shown in Tables 3, 4 and 5. For the total population, the MRRs in areas 1 and 3 $(100 \mathrm{~kW})$, area $6(250 \mathrm{~kW})$, and area $7(500 \mathrm{~kW})$ were statistically significantly increased. In the electrical power groups of 100 kW and 250 kW , MRRs showed statistically significant increases, although there was no increasing trend according to the electrical power. Among the male population, the MRRs in area 1 $(100 \mathrm{~kW})$, area $5(250 \mathrm{~kW})$, and area $7(500 \mathrm{~kW})$, showed statistically significant increases, as did those for
the female population in area $6(250 \mathrm{~kW})$. MRRs for the electrical power groups of 100 kW and 500 kW for male subjects showed significant increases.

The age-specific MRRs, and their 95\% CIs, for leukemia, malignant lymphoma, brain cancer and female breast cancer, are shown in Tables 6 and 7. The mortality rate of childhood leukemia in the exposed group was 1.70 -times higher than in the control group ( $95 \%$ $\mathrm{CI}=0.84-3.45$ ). In leukemia, among those under 45 years of age, mortality rates in the exposed group were significantly higher than in the control group (0-14 year age group, $\mathrm{MRR}=2.29,95 \% \mathrm{CI}=1.05-5.98 ; 15-29$ year age group, $\quad \mathrm{MRR}=2.44, \quad 95 \% \mathrm{CI}=1.07-5.24$ ). The MRR for those over 75 years of age was also found to be significant ( $\mathrm{MRR}=3.26,95 \% \mathrm{CI}=1.07-9.96$ ). In the cases of malignant lymphoma, brain cancer and female breast cancer, no significant differences were found between the exposed and the control groups.

## Discussion

Stomach cancer was the most common cause of cancer death among Koreans in 1995, and liver cancer (including that of intra-hepatic duct) was the second most common cause of cancer death. These were followed by lung cancer (including tracheal cancer) and colorectal cancer (including anal cancer) during the study period [19]. The chosen study areas showed the same order of death due to cancer.

In 1999, many broadcasting stations (107 AM radio, 200 FM radio and 1,187 television), wireless transmission facilities (cellular phones), car phones, and radar for civil and military purposes, were operational in Korea. Among

Table 1 Cancer mortality rate per 100,000 persons in the exposed and control groups, for all subjects

| Localization | Total |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | Exposed |  | Controls |  | MRR ${ }^{\text {b }}$ ( $95 \% \mathrm{CI}$ ) |
|  | No. of deaths | MR ${ }^{\text {a }}$ | No. of deaths | MR ${ }^{\text {a }}$ |  |
| All cancer | 1,722 | 113.07 (118.47-107.67) | 6,191 | 87.32 (85.14-89.51) | 1.29 (1.12-1.49) |
| Oral cavity and pharynx | 14 | 0.90 (0.42-1.39) | 53 | 0.75 (0.54-0.95) | 1.21 (0.41-3.57) |
| Esophagus | 49 | 3.05 (2.18-3.92) | 178 | 2.53 (2.16-2.91) | 1.20 (0.71-2.03) |
| Stomach | 403 | 25.72 (23.19-28.26) | 1559 | 21.83 (20.74-22.92) | 1.18 (0.96-1.44) |
| Colorectum including anus | 78 | 5.04 (3.90-6.17) | 273 | 3.80 (3.35-4.25) | 1.33 (0.83-2.11) |
| Liver including intrahepatic duct | 271 | 18.17 (15.99-20.36) | 1,255 | 17.98 (16.98-18.98) | 1.01 (0.80-1.27) |
| Pancreas | 74 | 4.38 (3.35-5.40) | 215 | 2.88 (2.49-3.27) | 1.52 (0.97-2.39) |
| Lung including trachea | 232 | 14.59 (12.70-16.49) | 964 | 13.52 (12.66-14.38) | 1.08 (0.84-1.38) |
| Central nervous system including brain | 30 | 2.10 (1.34-2.87) | 100 | 1.39 (1.11-1.66) | 1.52 (0.61-3.75) |
| Thyroid | 7 | 0.46 (0.10-0.82) | 25 | 0.34 (0.20-0.47) | 1.35 (0.22-8.19) |
| Breast | 22 | 1.61 (0.93-2.28) | 84 | 1.17 (0.92-1.42) | 1.38 (0.63-3.02) |
| Leukemia and multiple myeloma | 55 | 4.02 (2.94-5.11) | 169 | 2.36 (2.00-2.72) | 1.70 (0.84-3.45) |
| Lymphatic organs | 31 | 2.11 (1.36-2.86) | 96 | 1.32 (1.05-1.59) | 1.60 (0.72-3.56) |
| Bone and connective tissue | 8 | 0.51 (0.14-0.88) | 35 | 0.49 (0.32-0.65) | 1.05 (0.21-5.22) |
| Urinary bladder | 16 | 0.95 (0.48-1.42) | 60 | 0.84 (0.63-1.05) | 1.13 (0.48-2.65) |
| Prostate |  | - |  | - | - |
| Uterine cervix |  | - |  | - | - |
| Skin | 8 | 0.52 (0.15-0.88) | 21 | 0.30 (0.17-0.43) | 1.72 (0.36-8.21) |

[^1]Table 2 Cancer mortality rate per 100,000 persons in the exposed and control groups, by gender

| Localization | Male |  |  |  |  | Female |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Exposed |  | Control |  | $\begin{aligned} & \text { MRR }^{\mathrm{b}} \\ & (95 \% \mathrm{CI}) \end{aligned}$ | Exposed |  | Control |  | $\begin{aligned} & \text { MRR }^{\mathrm{b}} \\ & (95 \% \mathrm{CI}) \end{aligned}$ |
|  | No. of deaths | $M^{\text {a }}$ | No. of deaths | $M R^{\text {a }}$ |  | No. of deaths | $M^{\text {a }}$ | No. of deaths | $M R^{a}$ |  |
| All cancer | 1,115 | $\begin{aligned} & 161.50 \\ & (151.96-171.05) \end{aligned}$ | 4,054 | 112.59 (109.10-116.07) | 1.43 (1.29-1.59) | 607 | 73.78 (67.74-79.83) | 2,249 | 64.83 (62.12-67.54) | 1.14 (0.92-1.41) |
| Oral cavity and pharynx | 11 | 1.59 (0.62-2.56) | 42 | 1.16 (0.81-1.51) | $\begin{aligned} & 1.37 \\ & (0.42-4.49) \end{aligned}$ | 3 | 0.35 (0.00-0.76) | 11 | 0.31 (0.12-0.51) | 1.11 (0.08-14.87) |
| Esophagus | 43 | 6.15 (4.30-8.00) | 160 | 4.55 (3.84-5.26) | 1.35 (0.77-2.37) | 6 | 0.61 (0.09-1.13) | 18 | 0.50 (0.27-0.73) | 1.23 (0.25-5.92) |
| Stomach | 235 | 34.24 (29.83-38.65) | 998 | 28.01 (26.27-29.76) | 1.22 (0.94-1.58) | 168 | 19.16 (16.19-22.12) | 561 | 15.67 (15.36-16.98) | 1.22 (0.88-1.70) |
| Colorectum including anus | 41 | 6.05 (4.18-7.91) | 142 | 3.94 (3.28-4.58) | 1.54 (0.80-2.94) | 37 | 4.31 (2.87-5.74) | 131 | 3.71 (3.97-4.35) | 1.16 (0.60-2.25) |
| Liver including intrahepatic duct | 197 | 28.62 (24.60-32.64) | 934 | 25.80 (24.13-27.46) | 1.11 (0.85-1.45) | 74 | 9.05 (6.94-11.16) | 321 | 9.38 (8.34-10.42) | 0.96 (0.61-1.52) |
| Pancreas | 41 | 5.59 (3.86-7.32) | 126 | 3.36 (2.77-3.95) | 1.66 (0.93-2.96) | 33 | 3.26 (2.09-4.44) | 89 | 2.36 (1.85-2.86) | 1.38 (0.68-2.80) |
| Lung including trachea | 169 | 24.58 (20.85-28.31) | 730 | 20.46 (18.97-21.95) | 1.20 (0.90-1.61) | 62 | 6.89 (5.14-8.63) | 234 | 6.55 (5.70-7.40) | 1.05 (0.64-1.72) |
| Central nervous system including brain | 17 | 2.54 (1.34-3.76) | 51 | 1.31 (0.94-1.67) | 1.95 (0.59-6.46) | 13 | 1.77 (0.76-2.78) | 49 | 1.47 (1.05-1.90) | 1.20 (0.31-4.61) |
| Thyroid | 2 | 0.24 (0.00-0.63) | 13 | 0.34 (0.15-0.52) | 0.71 (0.04-13.35) | 5 | 0.68 (0.06-1.29) | 12 | 0.33 (0.14-0.52) | 2.05 (0.25-17.00) |
| Breast | 1 | 0.08 (0.00-0.30) | 3 | 0.07 (0.00-0.16) | 1.09 (0.03-34.68) | 21 | 3.10 (1.78-4.42) | 81 | 2.46 (1.92-3.01) | 1.26 (0.57-2.77) |
| Leukemia and multiple myeloma | 33 | 4.87 (3.19-6.55) | 101 | 2.58 (2.07-3.09) | 1.89 (0.75-4.75) | 22 | 3.26 (1.86-4.66) | 68 | 2.10 (1.59-2.60) | 1.55 (0.52-4.68) |
| Lymphatic organs | 19 | 2.63 (1.42-3.83) | 65 | 1.72 (1.30-2.15) | 1.52 (0.56-4.14) | 12 | 1.68 (0.73-2.63) | 31 | 0.93 (0.60-1.27) | 1.80 (0.48-6.71) |
| Bone and connective tissue | 6 | 0.75 (0.12-1.38) | 22 | 0.58 (0.33-0.83) | 1.29 (0.22-7.50) | 2 | 0.33 (0.00-0.79) | 13 | 0.41 (0.19-0.63) | 0.80 (0.06-11.14) |
| Urinary bladder | 13 | 1.82 (0.80-2.84) | 47 | 1.33 (0.95-1.72) | 1.37 (0.52-3.60) | 3 | 0.40 (0.00-0.83) | 13 | 0.36 (0.17-0.55) | 1.14 (0.24-2.89) |
| Prostate | 8 | 1.04 (0.29-1.78) | 20 | 0.58 (0.32-0.84) | 1.78 (0.55-5.81) |  | - |  | - | - |
| Uterine cervix |  | - |  | - | - | 26 | 3.49 (2.13-4.85) | 89 | 2.61 (2.06-3.16) | 1.34 (0.60-2.97) |
| Skin | 2 | 0.31 (0.00-0.74) | 12 | 0.34 (0.15-0.54) | 0.90 (0.08-10.31) | 6 | 0.71 (0.12-1.29) | 9 | 0.26 (0.09-0.43) | 2.76 (0.31-24.63) |

[^2]Table 3 MRR of all cancers, by each area and by the level of electrical power, for all subjects

| Area | Electrical power (kW) | Exposed |  |  |  | Matched control |  |  |  | MRR ${ }^{\text {c }}$ ( $95 \% \mathrm{Cl}$ ) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | No. | No. of deaths | $\begin{aligned} & \mathrm{CMR}^{\mathrm{a}} \\ & (95 \% \mathrm{CI}) \end{aligned}$ | $\begin{aligned} & \text { MR }^{\mathrm{b}} \\ & (95 \% \mathrm{CI}) \end{aligned}$ | No. | No. of deaths | $\begin{aligned} & \text { CMR } \\ & (95 \% \mathrm{CI}) \end{aligned}$ | $\begin{aligned} & \mathrm{MR}^{\mathrm{b}} \\ & (95 \% \mathrm{CI}) \end{aligned}$ |  |
| 1 | 100 | 151,380 | 231 | 152.27 (132.62-171.91) | 150.43 (130.96-169.91) | 944,244 | 909 | 96.21 (89.96-102.47) | 104.27 (97.46-111.08) | 1.44 (1.10-1.89) |
| 2 | 100 | 84,847 | 130 | 152.63 (126.36-178.90) | 111.33 (91.65-131.01) | 268,763 | 401 | 149.20 (134.61-163.80) | 77.35 (69.25-85.47) | 1.44 (0.97-2.13) |
| 3 | 100 | 56,116 | 173 | 307.40 (261.60-353.20) | 236.34 (200.11-272.57) | 462,122 | 844 | 182.53 (170.22-194.83) | 173.68 (161.91-185.45) | 1.36 (1.00-1.84) |
| 4 | 100 | 120,669 | 282 | 233.70 (206.45-260.94) | 184.04 (162.29-205.79) | 454,319 | 818 | 180.05 (167.72-192.38) | 203.55 (189.50-217.60) | 0.90 (0.70-1.17) |
| 5 | 250 | 122,586 | 181 | 109.66 (93.69-125.62) | 78.45 (66.82-90.08) | 355,171 | 408 | 114.87 (103.73-126.02) | 64.21 (57.60-70.82) | 1.22 (0.87-1.71) |
| 6 | 250 | 100,085 | 230 | 229.31 (199.67-258.94) | 276.04 (240.05-312.03) | 479,816 | 576 | 118.80 (109.05-128.54) | 158.25 (145.11-171.40) | 1.74 (1.33-2.28) |
| 7 | 500 | 148,434 | 111 | 74.44 (60.57-88.32) | 85.91 (69.51-102.32) | 2,697,922 | 672 | 24.89 (23.01-26.77) | 36.97 (34.09-39.84) | 2.32 (1.58-3.42) |
| 8 | 500 | 187,349 | 176 | 93.68 (79.82-107.53) | 77.12 (65.59-88.64) | 370,420 | 596 | 160.76 (147.86-37.79) | 118.25 (108.62-127.88) | 0.65 (0.48-0.88) |
| 9 | 500 | 88,262 | 97 | 109.33 (87.53-131.14) | 59.39 (46.94-71.84) | 356,712 | 507 | 142.13 (129.77-154.50) | 90.11 (81.98-98.25) | 0.66 (0.43-1.01) |
|  | 1,500 | 131,921 | 115 | 86.79 (70.90-102.69) | 60.00 (48.80-76.20) | 492,294 | 636 | 129.19 (119.16-139.23) | 82.29 (75.71-88.87) | 0.73 (0.50-1.07) |
| 100 kW | group | 413,012 | 222 | 197.21 (183.68-210.74) | 163.56 (152.22-174.89) | 2,129,448 | 3,005 | 141.09 (136.05-146.14) | 130.94 (126.24-135.64) | 1.25 (1.08-1.45) |
| 250 kW | group | 265,145 | 411 | 154.82 (139.86-169.79) | 129.81 (117.15-142.48) | 834,987 | 996 | 119.22 (111.82-126.63) | 96.93 (90.84-103.03) | 1.34 (1.08-1.65) |
| 500 kW | group | 424,045 | 383 | 90.20 (81.17-99.24) | 74.17 (66.62-81.71) | 3,425,054 | 1,829 | 53.38 (50.94-55.83) | 61.94 (59.08-64.80) | 1.20 (0.98-1.47) |
| $1,500 \mathrm{k}$ | W group | 131,921 | 115 | 86.79 (70.90-102.69) | 60.00 (48.80-71.20) | 492,294 | 636 | 129.19 (119.16-139.23) | 82.29 (75.71-88.87) | 0.73 (0.43-1.24) |
| All |  | 1,234,123 | 1,722 | 139.53 (132.95-146.12) | 113.07 (118.47-107.67) | 6,881,783 | 6,191 | 89.96 (87.72-92.20) | 87.32 (85.14-89.51) | 1.29 (1.12-1.49) |

${ }^{\text {a }}$ Crude mortality rate per 100,000 persons annually
${ }^{\mathrm{b}}$ Age-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by the WHO
${ }^{\circ}$ Calculated by dividing MR of exposed group (observed) by MR of control group (expected). The $95 \%$ CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])
Table 4 MRR of all cancers, by each area and by the level of electrical power, for male subjects

| Area | Exposed |  |  |  | Matched control |  |  |  | $\begin{aligned} & \text { MRR }^{\mathrm{c}} \\ & (95 \% \mathrm{CI}) \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | No. | No. of deaths | $\mathrm{CMR}^{\text {a }}$ (95\% CI) | $\mathrm{MR}^{\mathrm{b}}$ (95\% CI) | No. | No. of deaths | $\begin{aligned} & \text { CMR } \\ & (95 \% \mathrm{CI}) \end{aligned}$ | $\mathrm{MR}^{\mathrm{b}}$ (95\% CI) |  |
| 100 | 75,562 | 138 | 182.63 (152.19-213.08) | 222.40 (184.70-260.10) | 471,939 | 524 | 110.93 (101.43-120.42) | 146.00 (133.22-158.79) | 1.52 (1.07-2.16) |
| 100 | 41,098 | 92 | 223.86 (178.16-269.55) | 184.11 (145.88-222.33) | 132,454 | 279 | 210.26 (185.59-234.93) | 121.37 (106.59-136.14) | 1.52 (0.98-2.36) |
| 100 | 28,973 | 119 | 410.73 (337.09-484.37) | 324.97 (260.46-389.48) | 250,607 | 578 | 230.64 (211.86-249.42) | 243.74 (223.75-263.72) | 1.33 (0.89-1.99) |
| 100 | 59,790 | 189 | 316.11 (271.11-361.10) | 289.17 (247.58-330.76) | 232,890 | 547 | 234.66 (215.01-254.31) | 336.16 (307.00-365.32) | 0.86 (0.63-1.17) |
| 250 | 82,733 | 116 | 140.21(114.71-165.71) | 120.00 (98.04-141.95) | 177,515 | 276 | 155.20 (136.89-173.51) | 101.31 (89.05-113.57) | 1.53 (1.04-2.27) |
| 250 | 51,262 | 143 | 278.96 (233.30-324.62) | 400.57 (333.49-467.64) | 247,112 | 381 | 153.98 (138.52-169.44) | 261.11 (233.74-288.48) | 1.18 (0.85-1.64) |
| 500 | 93,170 | 69 | 74.06 (56.5902-91.53) | 84.05 (63.50-104.60) | 1,800,137 | 777 | 24.39 (22.11-26.67) | 33.93 (30.69-37.16) | 2.48 (1.55-3.97) |
| 500 | 94,731 | 103 | 108.20 (87.27-129.14) | 100.47 (80.98-129.96) | 189,623 | 333 | 188.27 (168.76-243.90) | 157.10 (120.72-173.47) | 0.64 (0.43-0.95) |
| 500 | 43,891 | 64 | 145.82 (110.12-181.52) | 96.69 (72.38-121.00) | 178,532 | 349 | 195.20 (174.73-215.68) | 146.54 (130.92-162.16) | 0.66 (0.40-1.09) |
| 10 1,500 | 66,822 | 83 | 123.46 (96.84-150.09) | 98.92 (77.40-120.45) | 268,487 | 439 | 163.32 (148.05-178.60) | 109.65 (99.18-120.11) | 0.90 (0.58-1.40) |
| 100 kW group | 205,423 | 538 | 261.90 (239.80-284.00) | 249.23 (227.87-270.58) | 1,087,890 | 927 | 177.09 (169.19-184.99) | 192.49 (183.85-201.14) | 1.29 (1.08-1.55) |
| 250 kW group | 133,995 | 259 | 193.29 (169.77-216.81) | 193.11 (169.50-216.72) | 424,627 | 656 | 154.49 (142.68-166.30) | 150.94 (139.34-162.54) | 1.28 (0.99-1.65) |
| 500 kW group | 231,792 | 236 | 101.60 (88.63-114.57) | 93.46 (81.40-105.52) | 2,168,292 | 1,145 | 52.78 (49.73-55.84) | 65.44 (61.60-69.27) | 1.43 (1.11-1.84) |
| $1,500 \mathrm{~kW}$ group | 66,822 | 83 | 123.46 (96.84-150.09) | 98.92 (77.39-120.45) | 268,487 | 439 | 163.32 (148.05-178.60) | 109.65 (99.18-120.11) | 0.90 (0.58-1.40) |
| All | 638,032 | 1,115 | 174.76 (164.51-185.01) | 161.50 (151.96-171.05) | 3,949,296 | 4,054 | 102.65 (99.49-105.81) | 112.59 (109.10-116.07) | 1.43 (1.29-1.59) |

[^3]Table 5 MRR of all cancers, by each area and by the level of electrical power, for female subjects

| Electric power (kW) | Exposed |  |  |  | Matched control |  |  |  | $M_{\text {MRR }}{ }^{\text {c }}$ (95\% CI) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | No. | No. of deaths | $\mathrm{CMR}^{\text {a }}$ ( $95 \% \mathrm{CI}$ ) | $\mathrm{MR}^{\mathrm{b}}$ (95\% CI) | No. | No. of deaths | CMR ${ }^{\text {a }}$ (95\% CI) | $\mathrm{MR}^{\mathrm{a}}$ (95\% CI) |  |
| 100 | 75,818 | 93 | 122.00 (97.15-146.85) | 105.88 (83.96-127.79) | 472,305 | 204 | 80.46 (72.37-88.54) | 76.03 (68.32-83.74) | 1.39 (0.90-2.16) |
| 100 | 43,749 | 38 | 85.72 (58.29-113.14) | 58.21 (38.52-77.90) | 136,309 | 123 | 87.67 (71.96-103.38) | 41.93 (33.49-50.38) | 1.39 (0.62-3.12) |
| 100 | 27,143 | 54 | 197.10 (144.34-249.87) | 155.12 (112.50-197.73) | 211,515 | 307 | 145.14 (128.92-161.37) | 123.89 (109.83-137.95) | 1.25 (0.73-2.16) |
| 100 | 60,879 | 93 | 152.76 (121.74-183.79) | 111.17 (87.71-134.63) | 221,429 | 272 | 122.61 (108.04-137.19) | 118.59 (104.20-132.97) | 0.94 (0.57-1.55) |
| 250 | 82,327 | 65 | 78.95 (59.77-98.14) | 46.61 (34.75-58.46) | 177,656 | 120 | 68.95 (56.75-81.16) | 34.31 (27.45-41.17) | 1.36 (0.72-2.57) |
| 250 | 48,823 | 87 | 177.17 (139.87-214.48) | 185.28 (145.85-224.72) | 232,704 | 217 | 93.25 (80.85-105.65) | 101.33 (87.65-115.01) | 1.89 (1.16-2.88) |
| 500 | 55,264 | 42 | 75.09 (52.26-97.93) | 96.64 (66.31-126.97) | 897,785 | 279 | 31.08 (27.43-34.72) | 54.91 (47.99-67.82) | 1.76 (0.93-3.34) |
| 500 | 92,618 | 73 | 78.82 (60.75-96.89) | 60.44 (46.19-79.69) | 180,797 | 247 | 136.34 (119.33-48.09) | 90.96 (73.30-102.63) | 0.66 (0.41-1.08) |
| 500 | 44,371 | 33 | 73.25 (48.07-98.42) | 33.53 (21.10-45.96) | 178,180 | 159 | 88.96 (75.11-102.80) | 48.90 (40.67-57.14) | 0.69 0.32-1.47 |
| 10 1,500 | 65,099 | 32 | 49.16 (32.13-66.1834) | 28.90 (18.48-49.33) | 223,807 | 380 | 91.15 (78.65-103.65) | 56.09 (47.99-64.19) | 0.52 (0.25-1.08) |
| 100 kW group | 207,589 |  | 133.20 (117.51-148.89) | 100.80 (88.61-112.98) | 1,041,558 | 1,078 | 103.50 ( 97.32-109.67) | 84.93 (79.78-90.08) | 1.19 (0.91-1.55) |
| 250 kW group | 131,150 |  | 115.52 (97.13-133.91) | 82.42 (68.95-95.89) | 410,360 | 340 | 82.73 (73.94-91.53) | 57.54 (51.21-63.86) | 1.43 (0.98-2.08) |
| 500 kW group | 192,253 |  | 76.46 (64.11-88.82) | 56.83 (47.37-66.29) | 1,256,762 | 684 | 54.43 (58.50-50.35) | 56.84 (52.55-61.13) | 1.00 (0.70-1.42) |
| $1,500 \mathrm{~kW}$ group | 65,099 | 116 | 49.16 (32.13-66.18) | 28.90 (18.48-39.33) | 223,807 | 204 | 91.15 (78.65-103.65) | 56.10 (47.99-64.19) | 0.52 (0.14-1.89) |
| All | 596,091 |  | 101.83 (93.73-109.93) | 73.78 (67.74-79.83) | 2,932,487 | 2,249 | 76.69 (73.52-79.86) | 64.83 (62.12-67.54) | 1.14 (0.92-1.41) |

[^4]Table 6 Age-specific MR and MRR $(95 \%$ CI) of leukemia, including multiple myeloma and malignant lymphoma in the exposed and control groups

| Age (years) | No. of population |  | Leukemia |  |  |  |  | Malignant lymphoma |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Exposed | Control | Exposed |  | Control |  | $M^{\prime} \mathrm{R}^{\mathrm{b}}$ (95\% CI) | Exposed |  | Control |  | MRR ${ }^{\text {b }}$ (95\% CI) |
|  |  |  | No. of deaths | $\mathrm{MR}^{\text {a }}$ | No. of deaths | MR ${ }^{\text {a }}$ |  | No. of deaths | $\mathrm{MR}^{\text {a }}$ | No. of deaths | $\mathrm{MR}^{\text {a }}$ |  |
| Total | 1,234,123 | 6,881,783 | 55 | 4.02 | 169 | 2.36 | 1.70 (0.84-3.45) | 31 | 2.11 | 96 | 1.32 | 1.60 (0.72-3.56) |
| 0-14 | 309,648 | 1,830,824 | 11 | 3.31 | 27 | 1.44 | 2.29 (1.05-5.98) | 1 | 0.28 | 2 | 0.12 | 2.46 (0.07-82.66) |
| 15-29 | 375,218 | 2,038,615 | 11 | 3.60 | 30 | 1.48 | 2.44 (1.07-5.24) | 2 | 0.53 | 7 | 0.35 | 1.51 (0.15-15.18) |
| 30-44 | 242,685 | 1,589,992 | 9 | 3.63 | 26 | 1.68 | 2.16 (0.95-4.04) | 5 | 1.94 | 14 | 1.00 | 1.94 (0.37-10.20) |
| 45-59 | 178,624 | 870,196 > | 5 | 3.01 | 31 | 3.52 | 0.73 (0.48-2.89) | 8 | 4.33 | 22 | 2.46 | 1.76 (0.43-7.15) |
| 60-74 | 101,605 | 442,853 | 10 | 9.45 | 48 | 10.81 | 0.87 (0.57-2.78) | 13 | 11.72 | 38 | 8.33 | 1.41 (0.47-4.14) |
| 75 or over | 26,343 | 109,303 | 6 | 22.78 | 7 | 7.26 | 3.08 (0.95-6.59) | 2 | 6.27 | 13 | 11.36 | 0.55 (0.05-5.67) |

a Age-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by WHO
${ }^{\mathrm{b}}$ Calculated by dividing MR of exposed group (observed) by MR of control group (expected). The $95 \%$ CI was estimated from a logarithmic scale (Breslow and Day [17])

Table 7 Age-specific mortality rate and MRR ( $95 \%$ CI) of brain tumor and female breast cancer in the exposed and control groups

| Age (years) | No. of population |  | Brain cancer |  |  |  |  | Female breast cancer |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Exposed | Controls | Exposed |  | Control |  | $\begin{aligned} & \text { MRRR }^{\mathrm{b}} \\ & (95 \% \mathrm{CI}) \end{aligned}$ | Exposed |  | Control |  | $\begin{aligned} & \text { MRR }^{\mathrm{b}} \\ & (95 \% \mathrm{CI}) \end{aligned}$ |
|  |  |  | No. of deaths | MR ${ }^{\text {a }}$ | No. of deaths | MR ${ }^{\text {a }}$ |  | No. of deaths | MR ${ }^{\text {a }}$ | No. of deaths | $M^{\text {a }}$ |  |
| Total | 1,234,123 | 6,881,783 | 30 | 2.10 | 100 | 1.39 | 1.52 (0.61-3.75) | 21 | 3.10 | 81 | 2.46 | 1.26 (0.57-2.77) |
| 0-14 | 309,648 | 1,83,0824 | 2 | 1.12 | 10 | 0.53 | 2.12 (0.44-12.06) | 0 | 0.00 | 0 | 0.00 | - |
| 15-29 | 375,218 | 2,038,615 | 5 | 1.34 | 11 | 0.54 | 2.47 (0.41-14.01) | 1 | 0.60 | 1 | 0.11 | 5.43 (0.18-161.83) |
| 30-44 | 242,685 | 1,589,992 | 3 | 1.38 | 12 | 0.82 | 1.68 (0.22-12.95) | 7 | 6.41 | 23 | 3.67 | 1.74 (0.43-7.19) |
| 45-59 | 178,624 | 870,196 | 8 | 4.11 | 18 | 1.97 | 2.08 (0.54-7.99) | 9 | 10.00 | 31 | 7.53 | 1.33 (0.39-4.54) |
| 60-74 | 101,605 | 442,853 | 9 | 8.74 | 38 | 8.38 | 1.04 (0.33-3.28) | 3 | 5.66 | 19 | 9.05 | 0.62 (0.10-4.00) |
| 75 or more | 26,343 | 109,303 | 3 | 10.29 | 11 | 10.72 | 0.96 (0.13-6.77) | 1 | 5.89 | 7 | 9.62 | 0.61 (0.03-12.26) |

${ }^{\text {a }}$ Age-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by WHO
${ }^{\mathrm{b}}$ Calculated by dividing MR of exposed group (observed) by MR of control group (expected). The $95 \%$ CI was estimated from a logarithmic scale (Breslow and Day [17])
the main AM radio broadcasting tower sites the present study included ten with more than 100 kW of electrical power and which had begun transmission at least 15 years before 1979, from the point of cancer death. In this study, leukemia mortality in the exposed group for those aged less than 30 years was significantly higher than in the control group. Some previous studies reported an excess of childhood leukemia in association with proximity to AM/FM radio and television facilities [4, 5], others reported negative association [6, 7, 20]. In the case of leukemia in this paper, however, there was no doseresponse or increasing/decreasing trends according to the level of electrical power. Previous studies performed in Great Britain showed an excess cancer incidence or increasing trend of incidences according to the proximity of the towers [5, 6].

Our exposure assessment did not quantify actual exposure status, because individual exposure levels were not measured. Despite this, our finding of the risk to young adults needs to be thoroughly investigated so that we can definitively answer the question of whether this leukemia risk is a result of exposure to RF or whether it is due to other causes, such as exposure from work.

In this study, stomach cancer, the primary cause of Korean cancer death before 2001, was associated with higher mortality in the exposed group, although the MRR did not show a statistically significant increase. In addition, two previous studies reported the risk of gastric cancer in association with EMF exposure [8, 21]. However, these were results of occupational exposure and not of environment exposure. In our study we are unable to prove that RF exposure increases the risk of gastric cancer in Koreans. However, further meaningful research on the relation between gastric cancer and RF exposure is needed in Korea, where the mortality and morbidity rates for gastric cancer in Korea are very high compared with other countries.

Our study has the following limitations. First, the address on the mortality records may not reflect the real address. We obtained the address information from the death certificate, in which the recorded address was the place of death. This might not be the actual house where
the dead person had resided during life. In the Korean culture, most people tend to return to their hometown when they die. However, we do not have the information about how exactly the recorded address on the death certificate and the actual address are matched. This factor might be one of the misclassification biases. Second, the exposed areas were defined as locations within 2 km of AM radio broadcasting towers of 100 kW or more. This location was taken to be the location of the regional government center, and, therefore, the defined exposed area was a little wider than that defined by a 2-km radius. Furthermore, the towers' electrical power was not the same. Some of them were 100 kW , and others 250 kW or 500 kW . But we defined the exposed area as the same 2 km radius from the tower regardless of the electrical power. These might be other misclassification factors. Third, the study was limited in terms of the amount of information about other environmental hazards and our inability to control confounding factors, including the socioeconomic status (SES) of the dead, which was reported as an important factor for leukemia mortality at a young age, since SES is usually associated with survival [22]. Other RF sources (mobile phones, VHF sources, etc.) were not considered. Fourth, because cancer deaths are rare events, the higher death numbers or longer follow-up periods must be considered to increase statistical power. This study was limited in terms of its ability to identify a small risk of RF exposure, because the total population size of each exposed area did not exceed 80,000 people. Finally, since the proportion of physician-diagnosed cause of death in Korean death certificates was $60.0 \%$ in 1995 [19], there might be a misclassification of disease. However, there was no definitive evidence of differential misclassification between the exposed group and the control group.

Overall, the main result of this study was the observed higher mortality rate for all cancers and leukemia in the young in the RF-exposed area. Although these findings could not prove a causal link between cancer mortality and exposure to RF fields, the results suggest that further analytical studies on this topic are needed in Korea.

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[^1]:    ${ }^{\text {a }}$ Age-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by the WHO
    ${ }^{\mathrm{b}}$ Calculated by dividing MR of exposed group (observed) by MR of control group (expected). The $95 \%$ CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])

[^2]:    ${ }^{2}$ Age-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by the WHO
    ${ }^{\mathrm{b}}$ Calculated by dividing MR of exposed group (observed) by MR of control group (expected). The $95 \%$ CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])

[^3]:    ${ }^{2}$ Crude mortality rate per 100,000 persons annually
    ${ }^{\text {b Age-adjusted mortality rate per } 100,000 \text { persons annually, standardized directly by the world standard population proposed by the WHO }}$
    ${ }^{\circ}$ Calculated by dividing MR of exposed group (observed) by MR of control group (expected). The $95 \%$ CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])

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