Int. J. Cancer: **124**, 945–951 (2009)

Causes of death among Belgian professional military radar operators: A 37-year retrospective cohort study

Etienne Degrave[1]*, Ben Meeusen[1], André-Robert Grivegnée[2], Mathieu Boniol[3] and Philippe Autier[3]

[1]*Unit of Epidemiology and Biostatistics, Military Hospital Brussels, Brussels, Belgium*
[2]*Unit of Epidemiology and Prevention, Jules Bordet Institute, Brussels, Belgium*
[3]*Epidemiology and Biostatistics Group, International Agency for Research on Cancer, Lyon, France*

Concerns have been raised about the safety of the electromagnetic (microwave) emissions of radars, as well as about the ionizing radiation that is emitted on short distances (<2 m) by devices in the radars producing the microwaves. We retrospectively compared the cause specific mortality of 4,417 Belgian professional male military personnel who served in anti-aircraft radar units in Germany between 1963 and 1994 to the cause specific mortality of 2,932 Belgian military personnel who served at the same time in the same place in battalions not equipped with radars. Mean follow-up was 26 years in the 2 groups. Age-adjusted rate ratio (RR) and 95% confidence intervals were derived from a Poisson regression model. Four hundred twenty-four deaths in the battalions groups and 271 deaths in the control battalions occurred (RR = 1.04 (0.96–1.14)). For specific causes of deaths, RRs were 1.22 (1.03–1.47) for neoplasms and 3.51 (1.19–10.3) for symptoms, signs and ill defined conditions. RRs for other causes of death were not significantly different from 1.00. Among deaths from neoplasms, RR for hemolymphatic cancer was 7.22 (1.09–47.9). RRs for other causes of cancer deaths were not significantly different from 1.00. The results for specific tumor types were all based on very small numbers. The RR for cancer increased with decreasing age and suggested that the RR for cancer increased with the duration of stay in radar battalions. In conclusion, exposure of professional military personnel to anti-aircraft radars that existed in Western Europe from the 1960s until the 1990s may have resulted in an increase in the incidence of hemolymphatic cancers. It remains to be established whether this increase is due to microwaves generated by radars or ionizing radiation produced by electronic devices producing the microwaves.

Key words: cancer; radar; Poisson regression; military personnel

Radars have been used by many military forces since the 1950s, for steering aircrafts, boats and vehicles and also for guiding anti-aircraft missiles. The health hazards that could be associated with exposure to electromagnetic fields remain a contentious subject in many countries where worries have emerged on health hazards risked by military personnel who served in units that implied regular exposure to radars.[1] Concerns have been raised about the safety of the electromagnetic (microwave) emissions of radars, as well as about the ionizing radiation emitted on short distances (<2 m) by devices producing the microwaves.

In Belgium, military personnel who served in units operating the anti-aircraft defense systems "Nike" and "Hawk" were fully dedicated to the functioning of these defense systems and were thus in regular contact with radars. The Nike and Hawk systems have been widely used since 1950 in countries belonging to the North Atlantic Treaty Organization (NATO). The Hawk anti-aircraft defense unit was created in the Belgian army in 1963 and was dismantled in 1994. The Hawk system used middle range radars emitting electromagnetic waves between 1 and 10 GHz frequency. Two kinds of radars were used: acquisition radars (wide range radar for detection of aircraft) and illumination radars (narrow beam radar for guiding missiles). Both radar types used continuous waves or pulsed mode emission. The average radiated power was about 1.5 kW. The peak power emitted by the pulses was about 500 kW.

In a previous study, we compared the all-cause mortality of military professionals or conscripts who served between 1963 and 1994 in Hawk anti-aircraft units of the Belgian army to the mortality observed in units of Belgian military professionals or conscripts located in the same area (in Germany) but who were never exposed to radars.[2]

This first study showed no increase in all-cause mortality in the military personnel that served in radar units. Since that publication, we have been able to examine likely specific causes of death among these military personnel, to extend by 1 year the period of follow-up and to retrieve data that were still missing for some personnel. In this study, we compared the cause specific mortality of the professional military personnel who served in radar units to those who did not serve in such units. We restricted this study to professional military personnel because the duration of military service of Belgian conscripts was about 1 year, and their allocated tasks made them less susceptible to significant radar radiation exposure.

Material and methods

The study was designed as a retrospective cohort study, comparing the disease-specific mortality of Belgian professional male military personnel who served in 2 radar battalions in Germany and were ever exposed to Hawk radar systems from 1963 until 1994 to the disease-specific mortality of Belgian professional military personnel who served in 3 battalions located in the same place in Germany during the same period but not equipped with radars. The study was approved by the Bioethical Commission of the Belgian Defense in March 2002.

Professional military personnel exposed to radars

The exposed group was constituted of all professional military personnel who served in the 2 "battalions Hawk 43A and 62A" from 1963 until 1994. During the entire period, the 2 battalions were located in Germany in the Eastern part of the Land of North Rhine-Westphalia in Germany. Professional military personnel operated the complex radar devices and were thus in contact with them. In 1994, these 2 radar battalions were dismantled.

Professional military personnel in units not equipped with radars

The control group was constituted of all professional military personnel who served in 1 armored and 2 artillery battalions located in the same area in Germany during the same period from 1963 until 1994. Fifty military personnel of the armored and artillery battalions also served in Hawk battalions and were classified in the exposed group.

*Correspondence to: Department of Well-Being, Belgian Ministry of Defence, Bruynstraat, Brussels 1120, Belgium. Fax: +32-0-2-264-4048. E-mail: etienne.degrave@mil.be
Received 15 April 2008; Accepted after revision 4 August 2008
DOI 10.1002/ijc.23988
Published online 9 September 2008 in Wiley InterScience (www.interscience.wiley.com).

Publication of the International Union Against Cancer

Data collection

For the period 1963–1977, no electronic records existed, and there was no centralized listing of military personnel. We thus had to use the administrative archives of the battalions for reconstructing a complete list of all military personnel who served in each battalion. These administrative archives consisted of "daily orders" (DO) and "Reports from the Chief of Unit" (RCU), which were often handwritten. The DO and RCU were related to the daily life of battalions, and all new arrivals of military personnel, reassignments, nominations, training and leaves were recorded. Each person cited in the DO or RCU was entered in the database, with date of DO or RCU and his military identification number allocated by the Belgian army. Distinction between conscripts and professional military personnel was possible because their unique identification numbers had a different format. For the period 1978–1994, we could utilize computerized records. We, however, double-checked the completeness of computerized records using DOs and RCUs. Number of years served in the battalions was computed from DOs and RCUs.

Formal identification

DOs and RCUs only provided the last name, the first name (or initial) and the military identification number. To get a complete identification, lists derived from DOs and RCUs were matched with lists of the Department of Human Resources of the Belgian army (this department did not know in which battalions the military personnel served). Because of misspellings of names, difficulties in reading the handwritten DOs and RCUs, and because of reallocation of some military ID numbers to other military personnel, the names cited in the DOs and RCUs could not always be matched with certainty to the Department of the Human Resources lists. Only unequivocal matches were kept for subsequent retrieval of vital status. After this formal identification, the National Number used by the Belgian State administrations could be used. In the radar group, 76.1% of the names could be correctly identified and 71.6% in he control group. The identified persons constituted the cohort.

Vital status

The Department of Human Resources of the Belgian Army regularly receives from the Belgian National Register updates on active and retired military personnel including the vital status: alive or dead and the date of death. The matching key is the National Number. Because the National Number has only been used since January 1968, we could only trace the vital status from January 1968 until December 2004, resulting in a 37-year follow-up period.

Causes of deaths

The first source of information on cause of death was the official Belgian death registry that collects anonymous data. Using the date of birth and date of death as matching variables, we linked our database to the Belgian death registry. The link pointed mostly to 1 death certificate. If the matching was equivocal, the cause of death was not used. We always took the "underlying cause of death." For military personnel dead before 1979, the registry only recorded the month and year of birth, and thus for 35 dead military personnel for whom we did not have the exact birthdates, the matching was equivocal and the cause of death was not used. The registry was complete until 1997. Between 1998 and 2004, the registry was complete for the Northern Dutch speaking part of Belgium but not for the Southern French speaking part.

In parallel, for all professional military personnel who died between the first day served in radar or in control battalions and December 31, 2004, we tried to identify the first degree family members. A questionnaire was sent to them in order to know the likely cause of death. The letter stated that the motive for obtaining this information was a study on causes of death of Belgian military personnel who served in several battalions, without mentioning any detail about radars.

Figure 1 – Example of HAWK radar: the PAR (Pulse Acquisition Radar). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

When there was a discrepancy between the cause of death received from the family and the Belgian death registry, we always selected the cause reported in the registry. We coded the causes of deaths using the ICD-9 classification, unless they were already coded according to ICD-9 or ICD-10 classification.

When the cause of death from the Belgian death registry or from families was a cancer, we asked the Belgian cancer registry if they had a record of cancer for dead military personnel. For the period of follow-up of this study, the Belgian cancer registry was notoriously incomplete, but the information on cancer cases reported to the registry was reliable. Thus, the Belgian cancer registry was helpful for confirmation of a cancer diagnosis, but absence of information on a cancer diagnosed in a particular individual did not invalidate the likelihood of the cancer.

Radars and electromagnetic fields

Each radar battalion was operating 4 anti-aircraft sites each equipped with 2 acquisition radars (Fig 1) (PAR—Pulse Acquisition Radar/CWAR—Continuous Wave acquisition Radar) and 3 illumination radars (2 × HIPIR—High Power Illumination Radar and ROR—Range Only Radar). An additional "support site" was used for logistic and maintenance purposes. Electromagnetic fields have been retrospectively modeled for each site taking into account the radar characteristics, the 3D configuration of each site, including reflection and diffraction on ground and buildings, and

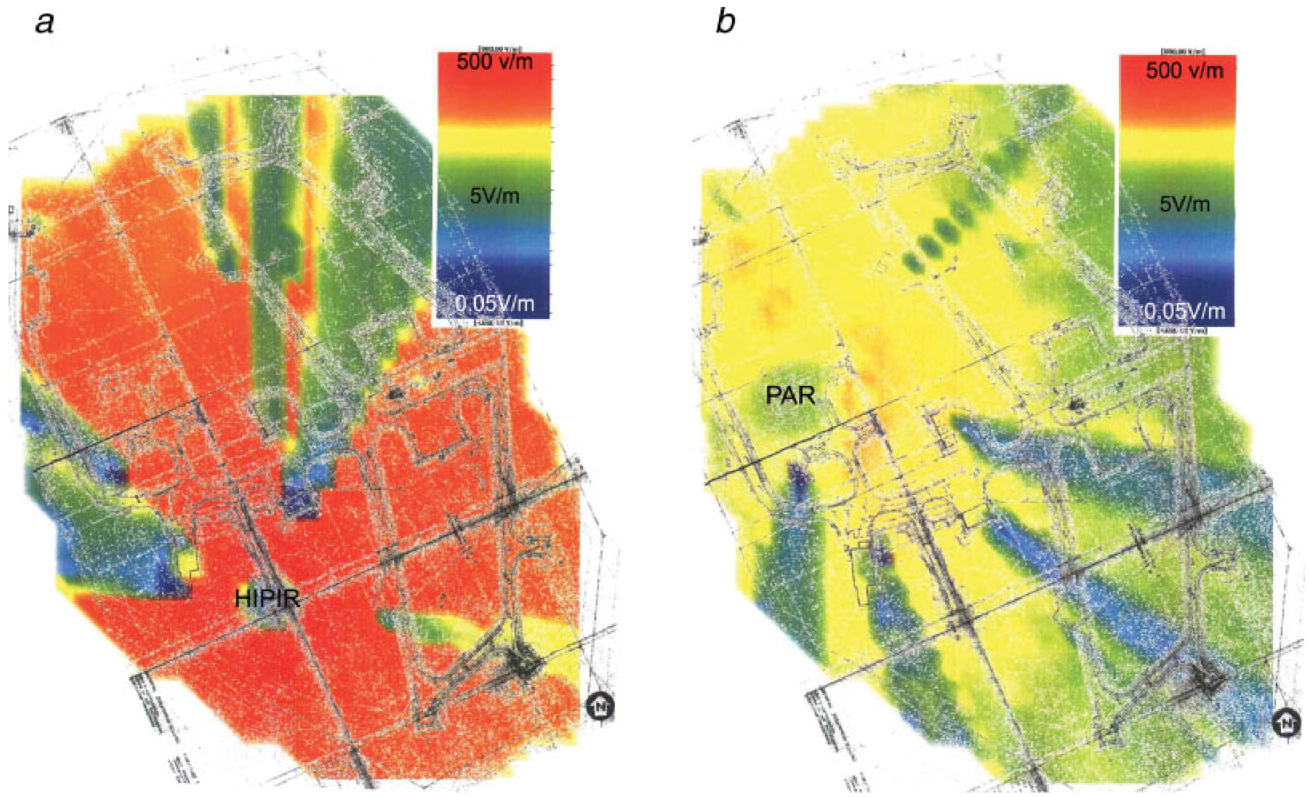

FIGURE 2 – Modeling of the Electric Field caused by operating radars on a radar site (Tietelsen site) A theoretical scenario is modeled for 2 radars: radar pointing toward each point of the site. At each coordination point a volume representing a human body (1.8 m tall) is exposed to the beam of the radar. (*a*) HIPIR: High Power Illumination Radar and (*b*) PAR: Pulse Acquisition Radar. The shadow effect of the buildings can easily be observed. The size of the Tietelsen site is about 400 × 350 m. Electrical Fields are expressed in V/m on a log scale.

absorption by walls (Fig 2).[3] The modeling showed that all the typical job locations were exposed to fields of 10–50 V/m (volt per meter) for acquisition radars and 100–500 V/m for illumination radars. The latter were highly directional and activated in case of plane detection and targeting the plane starting just above the horizon. On each site, there were also potential hot spots of 300 V/m (PAR, CWAR) and 1300 V/m (HIPIR, ROR).

On the support site, exposure of personnel was mostly due to maintenance and testing of radars. These were usually tested outside, in front of the maintenance building, sometimes during the whole week. In this case, the modeling showed the existence of electrical fields of 10–50 V/m on the majority of the support site.

All the personnel living on the radar base had technical jobs in contact with the radars. These jobs included radar and missile operators, radar and missile engineers, transmission specialists and missile launchers. On the support sides 2 categories of functions were more exposed: radar engineers and transmission technicians. People working in the vicinity of the maintenance building were also more exposed. This included car technicians.

Occupational standards in the late1960s established by NATO defined a maximal exposure of 112 V/m at 1 GHz and 196 V/m at 10 GHz (average doses over 6 minutes of exposure).[4] For the ICNIRP, the maximal exposure was 100 V/m at 1 GHz and 137 V/m at 10 GHz (average doses over 6 min of exposure).[5] Given these facts, it is well possible that some military personnel who served in the radar battalions may have been exposed to quite high microwave fields, largely exceeding recommended maximal exposure values.

We were interested in constructing an exposure index for the whole population. Unfortunately, the tasks performed by the radar workers were not archived. We succeeded in retrieving the tasks of most living military personnel by sending questionnaires and asking relatives. Questionnaires could not be utilized for deceased subjects. Constructing an index exposure was thus not feasible without introducing bias. For the hemolymphatic cancer, we could identify some of the technical tasks performed by examining individual administrative records.

Radars and ionizing radiation

The electron tubes (Klystron, Stabilotron, Thyratron) modulating or amplifying the radiofrequency emission also produce some parasitic X-rays. Because this ionizing radiation is considered as low, the use of individual dosimeters was not prescribed by the radar constructor or by the NATO. The microwave emitting devices were placed inside a cabinet closed with a door lowering the level of X-ray emission. Worst case estimation (1 daily hour of exposure at 5 cm from the emitting tube, door of the cabinet open) led by an independent German investigation[6] indicated a yearly dose of 15 MilliSievert which is below the annual permissible occupational level. However, these figures are estimations and we lack dosimetric data for the period under investigation.

Statistical methods

Ten-year age categories were defined and the number of person-year spent by each individual in the cohort as well as death numbers were distributed in these categories. Then annual age-specific death rates were calculated for each category. For comparing all cause and cause-specific death rates between the radar and the control subjects, we used a Poisson regression. The Poisson model was fitted with cause specific deaths between 1968 and 2004 as count variable and log person-years of follow-up as offset. These models were adjusted for age at entry entered in the model

TABLE I – CHARACTERISTICS OF BELGIAN PROFESSIONAL MILITARY PERSONNEL

	Radar battalions (n = 4,417)	Control battalions (n = 2,932)
Mean year of birth	1953.1	1952.6
Year of entry in battalions [No. and (%)]		
1963–1970	1,351 (30.6)	817 (27.9)
1971–1980	1,245 (28.2)	1,132 (38.6)
1981–1994	1,821 (41.2)	983 (33.5)
Mean age at entry in battalions		
Entry in 1963–1970	27.6	28.7
Entry in 1971–1980	21.7	22.2
Entry in 1981–1994	21.8	22.4
Mean number of years in battalions		
All (range in years)	6.1 (1–32)	4.3 (1–29)
Entry in 1963–1970	8.1	5.1
Entry in 1971–1980	5.3	3.9
Entry in 1981–1994	5.3	4.2
Follow-up		
Mean number of years	27.3	27.2
Range (years)	1–37	1–37

TABLE II – NUMBER OF DEATHS AND THE PERCENTAGES ON MISSING DATA IN AVAILABLE SOURCES OF CAUSE OF DEATH

Year of death	No. of deaths		% Missing data in death certificates		% Missing data in questionnaires		% Missing data in both	
	Radar	Control	Radar	Control	Radar	Control	Radar	Control
<1980	26	22	77	82	42	41	31	23
1980–89	98	67	25	12	17	37	4	3
1990–99	164	110	18	17	26	22	5	7
2000–04	136	72	35	50	27	26	15	18
Total	424	271	29	30	25	28	9	10

as age categories (18–29; 30–39; 40–49; 50–59). When an age category did contain zero death in both groups, age groups were aggregated to the lower age category. To account for extra-Poisson variation, we also included in the model a scale parameter based on the deviance estimated in the model.[7] We also used the Poisson model to analyze the influence of the number of years of exposure to Hawk radars. Ten-year age categories and number of years served in radar battalion categorized in tertiles (0–2 years, 3–7 years and 8+ years of serving) were introduced as independent variables. For interaction between exposure group and age, we introduced age group as a quantitative variable to investigate a possible trend.

Results

Between 1963 and 1994, we registered 5,817 different names of professional soldiers in the archives of the 2 radar battalions and 4,116 in the control battalions. Complete identification (names, birthdates and national number) was possible for 4,417 (75.9%) subjects in the radar battalions and 2,932 (71.2%) military personnel in the control battalions. These 7,349 persons were included in the study. Table I displays the main characteristics of identified military personnel, showing a longer stay for soldiers in the radar battalions than in the control battalions. The mean duration of follow-up among military personnel was equivalent in both groups, and totaled 120,461 person-years in the radar battalions and 79,725 person-years in the control battalions. The average year of birth was 1953 in both groups.

Between 1968 and 2004, 424 deaths in the battalions groups and 271 deaths in the control battalions occurred (Rate ratio = 1.04; 95% CI: 0.96–1.14). Mean age at death was 53 in both groups. Details on all-cause mortality were published elsewhere[2] and showed no increase in mortality with duration of service or with involvement in radar battalions before 1979, when radars underwent important technical modifications.

Table II shows, for each decade of mortality, the source of information that was available for both groups. The death certificates allowed us to identify the cause of death for 71% of persons in the radar group and 70% in the control group. The response rate for the questionnaire sent to the family was similar in both groups: 75% and 72% for the radar and the control group, respectively. Combining the 2 sources allowed us to identify the cause of death for 90.6% (radar group) and 89.7% (control group) of the deceased persons.

The rate ratios of the mortality rates between the radar and the control population were not significantly different from 1.00 for most causes of deaths, including death from a disease of the circulatory system or from injuries or other external causes (Table III). Rate ratio was significantly increased in the radar group for cancer (Rate ratio = 1.23) and the category regrouping the symptoms, signs and ill-defined conditions (Rate ratio = 3.51).

The difference in cancer-related deaths was in mainly due to hemolymphatic cancers (11 *vs.* 1 deaths; Rate Ratio = 7.22), to eye and brain tumors (8 *vs.* 2 deaths; Rate Ratio = 2.71) and to other and unspecified cancers (11 *vs.* 3 deaths; Rate Ratio = 2.43) (Table IV). Among these cancers a statistically significant increase was found for hemolymphatic cancers only. No significant differences were noticeable for the more numerous cancers of the digestive, the respiratory or the genitourinary systems.

For hemolymphatic cancer deaths, the number of years served in the radar units ranged from 2 to 14 and the number of years from the beginning of exposure to death ranged from 3 to 39. For tumors of the brain and of the nervous system, most deaths occurred twenty years or more after the beginning of service in the radar battalions. The complementary information gathered from the family or from the Belgian cancer registry allowed the identification of the type of brain tumors the 5 military personnel died from: glioblastoma (2), astrocytoma (1), oligodendroglioma (1), meningioma (1). Twelve of the 19 military personnel who died from hemolymphatic cancer or from brain tumors were radar technicians (including operators, engineers, transmission specialist or missile launchers), and 3 were mechanic technicians working in 2 garages located about 50 and 100 m away from the maintenance buildings. The latter military personnel were more exposed to radar fields when these were tested outdoors near the support site facilities (see methods for

TABLE III – MAIN CAUSES OF DEATHS AMONG BELGIAN MILITARY PERSONNEL BY ICD-9 CHAPTERS

Causes of death (ICD-9 chapters)	No. deaths (Radar battalions)	No. deaths (Control battalions)	Rate ratio	95% CI
Infectious and parasitic diseases (0–139)	4	3	0.88	0.18–4.26
Neoplasm (140–239)	133	72	1.23	1.03–1.47
Endocrine, metabolic and immunity disorders (240–279)	1	3	0.22	0.04–1.27
Blood and blood forming organs (280–289)	1	0	–	–
Mental disorders (290–319)	4	0	–	–
Nervous system and sense organs (320–389)	11	7	1.07	0.26–4.31
Circulatory system (390–459)	87	61	0.96	0.66–1.41
Respiratory system (460–519)	16	18	0.59	0.25–1.40
Digestive system (520–579)	8	10	0.54	0.25–1.14
Genitourinary system (580–629)	2	2	0.65	0.14–2.95
Skin and subcutaneous tissue (680–709)	0	1		–
Symptoms, signs, ill-defined conditions (780–799)	21	4	3.51	1.19–10.33
Injuries and external causes (800–999-E)	96	62	1.02	0.68–1.54
No data on cause of death	40	28	0.96	0.64–1.43
All causes of death	424	271	1.04	0.96–1.14

TABLE IV – DEATHS FROM TUMORAL DISEASE AMONG BELGIAN MILITARY PERSONNEL BY ICD-9 CATEGORIES

Tumor site (ICD-9 chapter)	No. deaths (Radar battalions)	No. deaths (Control battalions)	Rate ratio	95% CI
Lip, mouth and pharynx (140–149)	5	2	1.66	0.23–12.19
Digestive organs and peritoneum (150–159)	35	22	1.07	0.69–1.64
Respiratory and intrathoracic organs (160–169)	45	28	1.07	0.66–1.71
Bone, connective tissue, skin and breast (170–178)	2	1	1.32	0.12–14.24
Genitourinary organs (179–189)	16	13	0.81	0.37–1.78
Lymphatic and hematopoietic tissue (200–208)	11	1	7.22	1.09–47.91
Eye, brain and nervous system (190–192)	8	2	2.71	0.42–17.49
Other and unspecified sites (193–199)	11	3	2.43	0.64–9.13
All cancers (140–199)	133	72	1.23	1.03–1.47

TABLE V – RATE RATIO OF DYING FROM CANCER BETWEEN RADAR AND CONTROL BATTALIONS ACCORDING TO AGE AND NUMBERS OF YEARS SERVED IN THE RADAR BATTALIONS

	Person-years radar group (No. deaths from tumoral disease)	Person-years control group (No. deaths from tumoral disease)	Rate ratio	95% CI
Model with risk of dying from cancer according to age group[1]				
Age				
<30	31,630 (6)	20,462 (1)	1.98	1.33–2.94
30–40	38,984 (5)	25,196 (2)	1.72	1.18–2.52
40–50	26,351 (19)	18,428 (10)	1.50	1.02–2.21
50–60	14,159 (34)	9,788 (19)	1.31	0.87–1.98
60–70	7,471 (43)	4,518 (22)	1.14	0.72–1.81
>70	1,869 (26)	1,333 (18)	1.00	0.59–1.67
Total	120,464 (133)	79,725 (72)		
Model with duration of service in radar battalions[2]				
Control battalions			1.00	(Reference)
<3 years			1.10	0.67-1.80
3–8 years			1.21	0.80-1.84
8 years and more			1.33	0.89-1.97
Test for trend			$p = 0.1305$	

[1]Rate ratio of dying from tumoral disease when having served in radar battalions versus control battalions derived from a Poisson model with an interaction term between service in radar or control battalion and age.–[2]Adjusted for age.

details on exposure pattern). The specific function of the other 4 military personnel could not be retrieved.

At the end of the 70s, technical improvements were brought to the Hawk systems shielding of the microwave generators that were responsible for the emission of ionizing radiation on short distances. We performed a separate analysis for military personnel serving in the batallions during that first period. There were 117 cancer deaths in the radar group and 69 in the control group (Rate Ratio 1.15 CI: 95% 0.85–1.55).

The Poisson model with cancer death as dependent variable (Table IV) showed a rate ratio for cancer death of 1.23 (95%CI: 1.03–1.47) for military personnel who served in radar battalions after adjustment for number of years of follow-up in each 10-year age category. A significant negative interaction ($p = 0.004$) was found between having served in radar battalions and years of follow-up by age categories, suggesting that the cancer death rate ratio increased with decreasing age (Table V). Always taking the control battalion as reference, and after adjustment for years of follow-up by age categories, another Poisson model suggested that the risk of dying from a cancer increased with duration of service in these battalions, but the test for trend was, however, not statistically significant (Table V).

Discussion

This study suggests that Belgian military personnel who served between 1963 and 1994 in units equipped with anti-aircraft radars had a higher risk of dying from cancer, especially of hemolymphatic cancers.

The study has several strengths and limitations. The main strength is the constitution of a control group that included military personnel very closely resembling the radar battalions that served in battalions during the same period of time in the same location in Germany.

Cohort effects are unlikely to explain the findings because of similarity of year of birth in both groups. Although no data were available on some confounding factors such as smoking, alcohol drinking and dietary habits, the daily life and lifestyles of Belgian military personnel who served in Germany at that time did not differ much between battalions. Social contact happened essentially inside the military sphere. The 2 cohorts were located in the same German federal state. We can reasonably accept that the usual confounding factors were comparable in both groups. Moreover smoking and alcohol consumption are not risk factors for hemolymphatic or brain cancer[8,9] and can therefore not be considered as potential confounding factors.

The control battalions contained a relatively small number of military personnel, and death from some specific cancers could have been lower than expected just because of statistical hazard. In this respect, the higher risks found for hemolymphatic cancers, tumors of the brain and of the nervous system, and cancers of unspecified sites could be overestimated because of the small number of such cancers in the control battalions. But use of Poisson regression estimation is adequate when numbers of events are small, and provides conservative estimates of confidence intervals.

In addition, we were conservative in the assessment of causes of deaths. Nine deaths in the radar battalions reported by families as being due to cancer (1 was a multiple myeloma), with a diagnosis of cancer sometimes confirmed by the Belgian cancer registry, were not reported as due to cancer by death certificates. Since the rule we adopted was to give priority to official causes of deaths, these deaths were not counted as "cancer deaths."

One might suppose that the data collected from the family could be biased because of possible financial claim. The introductory letter to the family was very neutral. The response rates in the radar and in the control group were very similar 74.8 and 71.6%, respectively, showing that both groups paid the same attention to the study. Missing data on cause of death was similar in both groups. These elements do not support the presence of differential bias. Death certificates are not as precise and valid as pathology reports, but were handled the same way in both groups. The proportion of deaths due to symptoms, signs and ill-defined conditions was comparable to official Belgian mortality statistics.[10] For the neurological cancers, the information always came from the Belgian death registry. For all the hematolymphatic cancers a death certificate was available except for 2 cases: for 1 case, in the radar group the source of information was the family, but the diagnosis was confirmed by the medical record. For the second case, in the control group, only the information from the family was available.

The group of professional military personnel included in this study was part of a larger longitudinal study that also included 36,425 conscripts (23,244 in the radar battalions and 13,181 in the control battalions). Conscripts usually served during 1 year. All-cause mortality of conscripts for the period 1968–2003 was lower in radar than in control battalions.[2] We did not analyze specific causes of deaths among conscripts because of the short duration of exposure period, and also because causes of deaths could be found for 80% of deaths in the radar battalions against 62% in the control battalions. No questionnaire was sent to the family of deceased conscripts. This difference in the gap in the identification of causes of death was probably due to the larger proportion of French-speaking military personnel in control battalions. As we mentioned in the Method section, complete official statistics on causes of death were available until 1997. From 1997 to 2004, official statistics could be used for the Dutch speaking part of Belgium but only partially for the French speaking part. We also examined whether radar and control military personnel could have been in contact with different chemical substances. Most substances used in the 2 types of battalions were exactly the same for maintenance of vehicles and custom materials, and for general cleaning purposes. The only difference was the use, by radar battalions, of refrigeration liquids for the cooling of radars. These products are not known classified as carcinogenic agents by the International Agency for Research on Cancer.[11]

We also considered possible exposure to the ionizing radiation emitted by the electron tubes producing the microwaves. Investigation using data from German[6] and Dutch[12] military sources concluded that the risk associated with exposure to ionizing radiation in radar installations was limited. We, however, noticed that 4 of the eleven persons deceased from hematological cancers served as radar or missile maintenance engineers and were more in contact with the electron tubes than most other subjects. They also worked on Hawk radars before the technical improvements brought at the end of the 1970s.

We performed an analysis of mortality taking the last year of available Belgian mortality statistics[10] and found rate ratio for cancer mortality of 0.76 in the radar group and of 0.62 in the control group. The lower mortality rates in military personnel than the general population is due to the "healthy worker effect," *i.e*., on average military professionals have a better health status than the general population of the same sex and age. This "healthy worker effect" was also observed for major causes of death. In this respect, the control group of military personnel was more relevant than the general population for comparing the frequency of causes of death.

Few studies have been conducted on exposure to military radar beams. In the USA, Groves *et al.*[13] followed during 40 years 40,581 veterans of the Korean War who were potentially exposed to high intensity radar beams. Compared with cancer death rates in the USA, this study found no increase in cancer deaths among exposed military personnel, for all cancer or for specific cancers. The only statistically significant finding was a relative risk of 1.48 (95% CI: 1.01–2.17) for leukemia among the most exposed *versus* the least exposed military personnel. In Poland, Szmigielski[14] conducted a retrospective cohort study among 128,000 military personnel who served in the Polish army between 1971 and 1985. Three percent of these military personnel were exposed to microwave radiation. The study found an increase in the risk of hemolymphatic cancers of 6.31 (95% CI: 3.12–4.32) but had several methodological limitations.

In conclusion, our study suggests that exposure of military personnel to anti-aircraft radars that existed in Western Europe from the 1960s until the 1990s may have resulted in an increase in the incidence of hemolymphatic cancers. It remains to establish whether this increase is due to microwaves generated by radars or by the ionizing radiation emitted by electronic devices producing the microwaves.

Acknowledgements

The authors thank Mrs. L. Bellamammer (Direction générale Statistique et Information économique), Dr. A. Kongs (Vlaams agentschap Zorg en Gezondheid), Dr. L. Van Eycken (Belgian Cancer Registry) and Mr. Henkibrant (Direction générale de la Santé) for their essential contributions. The authors also thank Mr. S. Pellizzaro, Mr. A. Rasemont and Dr. C.H. Wynants and for their thorough collaboration.

References

1. Breckenkamp J, Berg G, Blettner M. Biological effects on human health due to radiofrequency/microwave exposure: a synopsis of cohort studies. Radiat Environ Biophys 2003;42:141–54.
2. Degrave E, Autier P, Grivegnée AR, Zizi M. All-cause mortality among Belgian military radar operators: a 40-year controlled longitudinal study. Eur J Epidemiol 2005;20:677–81.
3. Stockbroeckx B, Colette TH, Degrave E. Electromagnetic exposure assessment on nine military radar sites. Belgian Defense Report. MIC6, Louvain-la-Neuve 2006.
4. STANAG 2345. NATO standardization agreement. Evaluation and control of personnel exposure to radio frequency fields (3 kHz to 300 GHz), 3rd edn. The Hague: NATO Publication, 2005.
5. ICNIRP (International Commission on Non-Ionizing Radiation Protection). Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Phys 1998;74:494–522.
6. Sommer TH. Die Bundeswehr und ihr Umgang mit Gefährdungen und Gefahrstoffen -Uranmunition, Radar, Asbest -, Bericht des Arbeitsstabes Dr. Sommer, 21 June 2001.
7. Gardner W, Mulvey EP, Shaw EC. Regression analyses of counts and rates: poisson, overdispersed poisson, and negative binomial models. Psychol Bull 1995;118:392–404.
8. Boffetta P, Hashibe M. Alcohol and cancer. Lancet Oncol 2006;7:149–56.
9. International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to human, Vol. 83: Tobacco smoke and involuntary smoking. Lyon: IARC, 2004.
10. Belgian mortality statistics. Available at:http://www.statbel.fgov.be/figures/download_fr.asp. Accessed July 3, 2008.
11. International Agency for Research on Cancer. List of all agents, mixtures and exposures evaluated. IARC monographs on the evaluation of carcinogenic risks to human. Lyon, France: International Agency for Research on Cancer, 2008. Available at:http://monographs.iarc.fr. Accessed August 4, 2008.
12. De Jong P, Busscher FA, Van Dijk W. Onderzoek naar de mogelijke blootstelling aan ioniserende straling bij de HAWK. Report K5002/01.IM505. The Hague: Nuclear Research & Consultancy Group, 2001.
13. Groves FD, Page WF, Gridley G, Lisimaque L, Stewart PA, Tarone RE, Gail MH, Boice JD, Jr, Beebe GW. Cancer in Korean war navy technicians: mortality survey after 40 years. Am J Epidemiol 2002;155:810–8.
14. Szmigielski S. Cancer morbidity in subjects occupationally exposed to high frequency (radiofrequency and microwave) electromagnetic radiation. Sci Total Environ 1996;180:9–17.