Epidemiological Surveillance at Électricité de France and Gaz de France: Health Assessment of Nuclear Power Plant Employees between 1993 and 1998

A. Chevalier¹, H. Gros¹, E. Carrié¹, G.Lahon¹

¹SGMC, EDF –GDF, 22-28 Rue Joubert 75009 Paris France
E-mail : anne.chevalier@edfgdf.fr

Abstract. Because the 17,500 employees working in nuclear power plants at Electricité de France, the national power company, may be exposed to a wide variety of industrial hazards, the health insurance department of the company has set up an epidemiologic surveillance programme for them. This descriptive, cross-sectional, and exhaustive study examined sick-leaves, mortality and cancer incidence to assess the health of the employees working from 1993 through 1998. The analysis comparing the employees in nuclear power plants, considered "exposed", to the rest of the personnel of Electricité de France-Gaz de France, the "non-exposed" (125,000 persons) showed that globally, the employees in the nuclear sector appeared to have fewer health problems than the other company employees. This was true regardless of age and especially for men, operating employees, and supervisory employees. Nonetheless three points must be noted: non-work accidents generated a non-significant excess of absenteeism and mortality among these employees, especially among management and supervisory personnel; suicides affected supervisors in particular; and an excess of primary malignant brain tumors affected both mortality (RR=1.96, NS) and incidence, especially among operating employees (RR = 2.87, 95% CI =[1.00-8.43]). No excess of malignant blood disease was observed.

I. Introduction

The carcinogenic effects of low doses of ionizing radiations are still not clear. To assess the effects of low doses of ionizing radiation directly is the aim of the International Agency for Research on Cancer (IARC) that has undertaken a cohort study bringing together nuclear industry employees "working directly with ionizing radiation" in fifteen nations [1]. Numerous descriptive studies have also examined cancers in cohorts of nuclear industry employees [2,3]. In France, a recent study examined the mortality of CEA workers [4].

Parallel to this aetiological aim, there is a need for descriptive epidemiological studies in order to assess the health status of nuclear workers (and not only cancer risks), to stress their specific health problems (if they have any), to prevent them if possible from having these health problems in respect to work legislation, to raise aetiological hypotheses. It therefore appeared constructive to begin epidemiological surveillance of the health status of Electricité de France employees currently working in its nuclear power plants. Electricité de France-Gaz de France (EDF-GDF) is the national French company that produces, transports and distributes energy. Its employees have a special health insurance programme that made it possible in 1978 to set up an epidemiological database and a cancer registry [5-7]. This programme greatly facilitated our work here.

This study targets employees in nuclear power plants who, in addition to their potential exposure to ionizing radiation, may also be exposed to other occupational hazards. They also differ from other EDF-GDF employees in some aspects of their recruitment and in their type of activity. This surveillance was carried out at the same time among the rest of the company's employees, thereby making possible a comparative study of these two groups of workers.

2. Population and methods

2.1. Population

The target population, all EDF personnel who worked for any period of time between 01
January 1993 and 31 December 1998 in a nuclear power plant, was considered to be “exposed”, regardless of whether they were directly exposed to ionizing radiation or carried a dosimeter. We chose a 6 year period so that we could analyse rare health phenomena such as death or cancer occurrence. This group was compared to the “non-exposed” population which included all other employees at EDF and GDF, that is, all those working outside the nuclear sector during the same period (employees involved in the production and transportation of gas, the distribution of gas or electric energy, other electricity production services, research, and customer and administrative services,...)

2.2 Methods

We considered several health phenomena occurring during the study period as descriptive of the employees' health status: medical absences or sick-leaves, with each separate episode verified by a medical certificate, overall and by-cause mortality, and cancer incidence.

We used the information recorded in the epidemiological database of the company's medical department (Service Général de Médecine de Contrôle, or SGMC), a specific branch of the national health service and insurance programme specifically for the electric and gas industries [5]. For each sick-leave verified by a doctor's certificate, the annual files of absences for medical reasons include the date it started, its duration, and its cause. One of the medical advisors' duties is to verify the validity of these sick-leaves, at a so-called "control" visit during which the physician confirms the diagnosis of the condition underlying the absence. The annual death files provided the cause of each recorded death. Finally, the cancer registry identified all the cases of cancer diagnosed since 1978 in EDF-GDF workers employed at the time of diagnosis; it also includes benign bladder and brain tumors [6,7]. The cancer cases are coded according to the International Classification of Diseases – Oncology [8 ]. The causes of absences and of death are coded according to an abridged version (170 items) of the International Classification of Diseases (9th Revision). We used the major sections of this classification and, for the cancers, the most common sites. In the case of injuries, we considered separately work-related accidents and "non-work" accidents, which include household, traffic, sports and other leisure accidents.

The duration of work in nuclear power plants was not taken into account in this study, nor were ionizing radiation measurements or data about exposure to other carcinogenic hazards including tobacco and alcohol. Finally, three individual factors were considered in this analysis: age, sex and work grade. The grade is a social-occupational classification specific to EDF-GDF, with three categories: operating employees, supervisory employees and managers.

2.3. Analysis

We began by describing the characteristics of the "exposed" population and comparing them to those of the "non-exposed" population. We looked specifically at sex, age and grade because they are associated with health status.

Because it is a frequent event, sick leave was studied on an annual basis. We considered three different years over the study period -- 1993, 1995 and 1997 -- to verify the stability of this health phenomenon. The sick-leave indices considered were absence rate (number of days of absence per 100 working days), percentage of employees with at least one day of sick-leave during the year, the mean number of sick-leaves and the mean duration of each absence (in days) for employees with any sick-leave[9,10]. Mortality, because much rarer, was examined over a 5-year period (1993-1997), and cancer incidence over the 6-year period from 1993 through 1998 (in the course of the study, the registry was completed up to 1998).

To determine rates, we used personnel file data ascertained each December to calculate the number of people in each population, expressed as person-years. The analysis was performed by calculating the relative risks of absence (absent at least once during the year), of death (overall and by cause), and of
cancers by site, for nuclear plant workers compared with other company employees. Relative risks were assessed with their 95% confidence intervals. Age, sex, and work grade were taken into account both by stratification of the relative risks for each of these characteristics and by adjustment according to Mantel and Haenszel's method.

3. Results

3.1. Description of the population

Between 1993 and 1998, an average of approximately 17,500 employees each year (105,293 person-years for the entire observation period) worked in EDF nuclear power plants; there were approximately 125,000 other company employees per year (748,851 person-years). Over the study period, the total number of EDF-GDF workers fell at the same time as the number of personnel assigned to the nuclear industry increased; this sector developed substantially. On average, each year over the study period, 3.75% of nuclear sector employees worked in a nuclear power plant for the first time while 2.77% left this sector. More than 85% of the employees in nuclear plants in December 1992 were still there in December 1998. The distribution by age, sex and work grade of workers in nuclear power production was different than that for the rest of EDF-GDF: the former were younger and had a lower percentage of both women (11.4% versus 21.2) and operating employees (16.8% versus 32.2). The ageing of both populations between 1993 and 1998 reflects the overall reduction in hiring by EDF-GDF during this period.

3.3. Study of absences

The comparative analysis of the principal absence measures showed that globally the nuclear plant employees were absent less often than the other EDF-GDF workers. The absence rate for nuclear workers was lower in each of the three years we studied (resp. 2.1%, 2.2% and 2% for 1993, 1995 and 1997 versus 3%, 3% and 2.8%). They were absent in lower numbers, less often, and for shorter periods. These results were stable over time.

We also analysed absences more precisely in each of the three years (1993, 1995 and 1997) to examine the causes (diagnoses) for the absences: we found that the absences for the two populations could be distinguished not only by their overall rates but also by their causes. Because there were no differences from year to year, we present here only the analysis for 1995 (Table I). Fewer nuclear plant employees missed work because of respiratory, osteoarticular, gastrointestinal, or cardiovascular diseases, cancer, psychiatric illness or work accidents. They were, however, absent in equal or greater numbers (depending on the year) for non-work accidents.

The relative risks of absence were calculated by sex, age and grade. For the most frequent causes (respiratory, osteoarticular, gastrointestinal, and psychiatric diseases and work accidents), the men working in nuclear plants had a significantly lower risk of absence from work than the men in the rest of the company. Women nuclear plant employees, however, were absent at a rate similar to that of the other women at EDF-GDF for these same causes. The relative risks of absence due to respiratory, osteoarticular, gastrointestinal and psychiatric diseases were significantly less than 1 in both age classes (younger than 40 years and 40 years or older). The relative risks adjusted for age, calculated with the Mantel and Haenszel method, are very similar to the crude relative risks. Finally, we observed substantial variations by grade. For the most frequent causes of absence, listed above, the nuclear sector operating employees had a lower risk of absence than their colleagues in other sectors. On the other hand, the causes of absences for nuclear sector managers cannot be distinguished from those of other managers, with one exception: absences for non-work accidents were significantly higher for the former than the latter. The supervisory employees also had a higher risk of absence for non-work accidents, but their profile for the most frequent diseases was the same as that of the operating employees.
3.4. Mortality study

Because of the relatively low number of women at EDF-GDF as a whole and especially in the nuclear sector and also because of their low mortality, separate mortality analyses were not conducted for men and women. The all-cause mortality rate for the nuclear plant workers was lower than that for the other EDF-GDF employees, as the crude relative risk of death shows: 0.72 [0.59 - 0.88].

By analysing the relative risks of death, both crude and stratified for age and grade, we can compare the causes of death for both populations (Table II). We note first that the nuclear workers had a significantly lower mortality from cancer, with a crude relative risk of 0.49 [0.33-0.71]. This trend continued for lung cancers (RR=0.48 NS) and other upper respiratory and digestive tract cancers (URDT) (RR=0.54 NS). For deaths from lung cancer, the overall lower mortality observed in the nuclear sector was seen in those 40 years or older (RR=0.36 [0.13-0.98]), but mortality was higher for those younger than 40 (RR=5.77 [1.16-28.6]). This result is based on the observation of three cases in the nuclear sector and three in the rest of the company.

Moreover, we also observed an excess of deaths from primary central nervous system (CNS) cancer in nuclear plant employees: their relative risk of death from a primary malignant brain tumor was 1.96, not statistically significant. This trend can be seen regardless of age (RR adjusted for age=2.19 NS) or work grade (RR adjusted for grade=2.27 NS).

Finally, we observed an increased (but not significantly so) risk of death from suicide, non-work accidents and work accidents among the nuclear sector workers. For suicides, this trend is especially notable among supervisory employees.

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### Table I. Stratification of the relative risk of absences according to age, sex and work grade (Year 1995)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Male</th>
<th>Female</th>
<th>Operating employees</th>
<th>Supervisory employees</th>
<th>Managers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory disease</td>
<td>0.80</td>
<td>0.75</td>
<td>0.86</td>
<td>0.80</td>
<td>0.98</td>
</tr>
<tr>
<td>Osteoarticular</td>
<td>0.72</td>
<td>0.66</td>
<td>0.85</td>
<td>0.70</td>
<td>0.67</td>
</tr>
<tr>
<td>Gastrointestinal</td>
<td>0.73</td>
<td>0.69</td>
<td>0.80</td>
<td>0.74</td>
<td>0.70</td>
</tr>
<tr>
<td>Psychiatric disorders</td>
<td>0.71</td>
<td>0.75</td>
<td>0.75</td>
<td>0.81</td>
<td>0.83</td>
</tr>
<tr>
<td>Cancers</td>
<td>0.78</td>
<td>1.20</td>
<td>0.75</td>
<td>0.85</td>
<td>0.81</td>
</tr>
<tr>
<td>Non-work accidents</td>
<td>1.07</td>
<td>1.00</td>
<td>1.10</td>
<td>0.99</td>
<td>0.96</td>
</tr>
<tr>
<td>Work accidents</td>
<td>0.79</td>
<td>0.70</td>
<td>0.90</td>
<td>0.76</td>
<td>0.73</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>0.88</td>
<td>0.97</td>
<td>1.01</td>
<td>0.89</td>
<td>0.79</td>
</tr>
</tbody>
</table>
3.5. Study of cancer incidence

### TABLE III. Relative risks of cancer by age, sex and work grade, for the most frequent sites

<table>
<thead>
<tr>
<th>SITE</th>
<th>Age &lt; 40</th>
<th>Age ≥ 40</th>
<th>Men</th>
<th>Women</th>
<th>Operating employees</th>
<th>Supervisory employees</th>
<th>Managers</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sites</td>
<td>0.79</td>
<td>0.66</td>
<td>0.62</td>
<td>0.63</td>
<td>0.48</td>
<td>0.72</td>
<td>1.05</td>
</tr>
<tr>
<td>URDT</td>
<td>0.83</td>
<td>0.54</td>
<td>0.47</td>
<td>0.64</td>
<td>0.42</td>
<td>0.66</td>
<td>1.25</td>
</tr>
<tr>
<td>Colon, Rectum</td>
<td>1.44</td>
<td>0.72</td>
<td>0.64</td>
<td>0.64</td>
<td>0.66</td>
<td>0.61</td>
<td>0.94</td>
</tr>
<tr>
<td>Malignant melanoma</td>
<td>2.89</td>
<td>0.55</td>
<td>0.88</td>
<td>1.26</td>
<td>0.80</td>
<td>0.80</td>
<td>2.50</td>
</tr>
<tr>
<td>CNS</td>
<td>1.38</td>
<td>0.90</td>
<td>1.35</td>
<td>1.34</td>
<td>0.90</td>
<td>0.97</td>
<td>2.38</td>
</tr>
<tr>
<td>CNS tumors, malignant and benign</td>
<td>1.36</td>
<td>0.85</td>
<td>1.19</td>
<td>0.47</td>
<td>0.20</td>
<td>0.79</td>
<td>0.98</td>
</tr>
<tr>
<td>Malignant blood disease</td>
<td>0.61</td>
<td>0.81</td>
<td>0.69</td>
<td>0.51</td>
<td>0.58</td>
<td>0.58</td>
<td>1.31</td>
</tr>
</tbody>
</table>

The incidence of all cancers was lower among nuclear plant workers than among the other EDF-GDF employees (RR=0.60, [0.50-0.71]). This result was not affected by the difference in the age and sex distributions in the two populations (Tables III). This trend was not found among nuclear plant managerial staff who, overall, were diagnosed with cancers of all types as often as the other company managers. The nuclear plant managers had a relative risk of cancer of 1.05 [0.70 – 1.55]

For some cancer sites, the incidence rate was lower among nuclear sector workers; depending on the site, this difference was significant or on the borderline of significance. This was the case for colorectal (RR=0.48, [0.26-0.88]), URDT (RR=0.47, [0.26-0.87]), lung (0.65, [0.38-1.11]) and prostate (RR=0.30,[0.07-1.24]) cancers. While the nuclear sector employees had a lower incidence of overall...
cancer than other EDF-GDF employees, their risks for primary CNS cancer (RR=1.05 NS), cancer of the pancreas (RR=1.08 NS) and bone tumors (RR=1.19 NS) were similar to those of their non-nuclear counterparts. We were able to look at these results in more detail and to bring out some trends by stratifying the relative risks for age, sex and grade (Table III).

Lung cancer, although globally lower in the nuclear sector, was higher among the workers in this sector younger than 40 years, compared with the same age group in the rest of the company (RR=1.44 NS, number of cases 3 and 12, respectively). Similarly, there was a relative risk greater than 1 for malignant melanoma among young nuclear sector workers (RR=2.89 NS, number of cases: 4 and 8, respectively) as well as in their managers (RR=2.50 NS, number of cases: 2 and 6, respectively).

The incidence of primary malignant CNS tumors was significantly higher among operating employees in the nuclear sector (RR=2.87 [1.00-8.43], number of cases: 4 and 19, respectively). When benign and malignant brain tumors are considered together, the results are similar, but attenuated (Tables III).

4. Discussion

4.1. Study limitations

The objective of this cross-sectional study was to describe various health problems within the population of nuclear sector employees of EDF-GDF, a group likely to be exposed to many hazards, and to compare them with the other employees of this national power company. This study is the first step in establishing an on-going epidemiological surveillance programme of these employees’ health status.

These results should be interpreted prudently for two principal reasons. First, the size of the two populations we are comparing here is too small to show a risk of rare diseases such as cancer. Second, all members of the study population do not necessarily work with ionizing radiation: this population also includes administrative personnel, service employees, and others with non-exposed jobs. Moreover, in this preliminary study, we did not use data about occupational exposures to ionizing radiation or to other hazards (electromagnetic fields, chlorinated solvents, mineral fibers, polyurethane resins, benzene, dichloromethane, etc.). These data are maintained elsewhere in the company and may be used later, in particular in the on-going French contribution to the IARC study. A final limitation of this study is that we did not take into account the duration of work in the nuclear power plants. Despite these limitations, our study has provided an image of the health status of EDF's nuclear sector employees.

4.2. Discussion of the results

We assessed the health status of nuclear sector employees based upon their sick-leaves, mortality, and cancer incidence. We chose these three approaches because they reflect different aspects of health. Sick-leave in general involves common mild diseases, almost the opposite of causes of death. The existence of a cancer registry in the company enabled us to focus on cancers, which are the centre of the debate about occupational risks in the nuclear industry.

Absences from work are not a common measure of health status. One of the particularities of the specific health insurance programme for EDF-GDF employees is the medical verification of sick-days: the information recorded for this purpose makes it possible to study the diagnoses for sick-leaves. The analysis showed that for each of the three years studied (1993, 1995 and 1997) fewer employees in the nuclear sector took time off for illness and they were absent less often and for shorter periods than the other EDF-GDF employees. The results were stable over time: the principal causes of absence are underrepresented in this group, except for non-work accidents. These results are consistent regardless of age, for men, operating employees, and supervisors, but not for managerial personnel. The latter were absent as often as their colleagues in other sectors, overall and for most of the specific diseases studied.

Analysis of the deaths among active workers clearly showed that the mortality rate was lower among nuclear sector employees and that this was not explained by the different age and grade distributions in
the two populations. The age- and grade-standardized mortality ratios were, respectively, 83.5% [68.7-99.8] and 79.7% [65.5-95.2]. Looking at the causes of death, we observed that the nuclear workers had a lower mortality rate for cancer as a whole and, in particular, for URDT and lung cancers. On the other hand, their mortality rate for brain tumors was higher, with a relative risk of 1.96, on the borderline of statistical significance. Finally, we saw a trend towards excess mortality from non-work accidents and from suicide.

The results for cancer incidence rates point in the same direction as the mortality results: the overall incidence of cancer is lower in nuclear sector employees. In particular, their incidence of URDT and lung cancers was at least on the borderline of statistical significance (depending on the particular comparison). The incidence of colorectal cancers and prostate cancers was also lower among nuclear plant employees. On the other hand, cancer in this population tended to be found in excess at three sites: primary CNS cancers, bone tumors, and cancer of the pancreas. Analysis of the SIRs confirms these trends. The excess of brain tumors was significant among operating employees, with a relative risk of 2.87 [1.00-8.43]. Some factors are thought to be involved in the development of both malignant and benign brain tumors [11]. We therefore thought it important to take benign CNS tumors into account in our analysis. The results were similar but attenuated: operating employees still experienced a higher incidence of brain tumors, but this excess was no longer significant. No excess risk was found of any malignant blood disease or thyroid cancer.

Overall, then, the employees in the nuclear power plants seemed to have fewer health problems than the other EDF-GDF employees, even though they tended to be absent more often because of non-work accidents, to die more often by suicide, and finally, for operating employees, to develop primary brain tumors more often.

The excess of absences due to non-work accidents, confirmed by the trend to excess mortality, is probably explained by the rural residence of the great majority of nuclear plant workers: they therefore make more automobile trips and thereby increase their risk of traffic accidents (they are currently required to live within 80 kilometers of the plant).

The trend to a higher suicide rate especially affects supervisory employees. Paradoxically, these employees are less often absent due to psychiatric disorders than their colleagues in the other sectors of the company. A 1993 study at EDF-GDF showed an increased risk of depression in supervisory employees overall [12], and it should be noted that a recent study in the United States reported an excess risk of suicide among employees exposed to electromagnetic fields [13].

We observed a lower incidence of and mortality from overall cancer in the nuclear sector. Similar results have previously been reported in several studies in the US and in the United Kingdom [2-3] as in France [4]: they are most often attributed to the "Healthy Worker Effect". One especially interesting aspect of our study is that it compares two populations of workers at the same company, with the same health care plan and social status; the "Healthy Worker Effect" should thus play an attenuated role, if any, in the interpretation of our results. Nonetheless, it is clear that the nuclear sector, with its "high-tech" allure and its career possibilities, attracted the most dynamic and healthiest employees in the 1980s. This may explain our results and the fact that adjustment for work grade, which is distributed differently in the two populations, did not modify them.

The analysis of cancer showed that nuclear sector employees had incidence and mortality rates for URDT and lung cancers lower than the other employees; again, depending on the specific comparison this difference was at least on the borderline of statistical significance. The principal risk factors for these two cancers, well known today, are alcohol and tobacco. We therefore tried to determine whether drinking and smoking varied in the two populations. We analysed two sources of data for this: information from the 1995 report on the GAZEL [14] cohort, which is made up of volunteers among the older employees at EDF-GDF, and the A.I.R.E.L survey on smoking [15]. In the GAZEL sample, the proportion of heavy and intermediate drinkers was significantly lower in the nuclear sector than in the rest of the company, while smoking did not differ in the two populations. The A.I.R.E.L study, carried out by volunteers among the EDF-GDF occupational physicians, also found no difference in smoking behavior. Accordingly, the lower incidence of URDT cancers in nuclear plant employees may be explained in part by their lower level of alcohol consumption. The results concerning lung cancer are more difficult to interpret.
While the overall cancer rate was low in the nuclear sector, the incidence of malignant brain tumors was equal in the two populations, and there was even an excess among the nuclear sector operating employees. Mortality for brain cancer followed a similar trend.

Between 1993 and 1998, nine cases of primary malignant brain tumors were diagnosed in nuclear plant employees, including seven gliomas, one malignant meningioma, and one choroid tumor. Sixty-one cases were identified among the non-nuclear employees. Over the past 15 years many studies have sought to determine whether brain tumors are associated with a variety of occupational exposures, since many are currently suspected of causing them [16-21]. In considering the findings in our study, we looked particularly at the studies that have explored the effects of electromagnetic fields and ionizing radiation on cerebral carcinogenesis.

Some studies have found an excess risk of brain cancer in workers exposed to electromagnetic fields [22-31] while others have found no such association [32-38]. One study in the US [24] found a dose-effect relation, with the risk of death from brain cancer multiplied by 1.94 per microtesla-year. Because the workers exposed to electromagnetic fields were also exposed to a multitude of other potentially dangerous hazards, the authors drew very prudent conclusions.

As it is generally agreed that high doses of ionizing radiation can induce brain tumors, several epidemiological studies have examined the possible role of low doses of ionizing radiation in the development of these tumors [25,35-38]. These studies have led to extremely varied results and are at this point very inconclusive. The studies showing an excess risk of death from brain tumors in workers exposed to ionizing radiation, such as Alexander's meta-analysis, which reports a significant excess risk of 15% [35], are always limited in their conclusions by the concomitant presence in this type of workplace of many other potentially hazards. Thus no study has yet been able to conclude that occupational exposure to low doses of ionizing radiation has a causative role in the development of these tumors.

5. Conclusion

Overall, the employees in EDF nuclear power plants appeared to have fewer health problems than the other EDF-GDF employees. They nonetheless tended to miss work in greater numbers because of non-work accidents, to die by their own hand more often, and finally, to develop brain tumors more often (the operating employees in particular).

The risk factors for brain tumors are not well known, although electromagnetic fields and ionizing radiation, both present in their workplace environment, are suspected today. Brain tumors appear to be increasing in incidence, but their etiology raises many questions. Scientists must today take over the study of this issue, and the cancer registry at EDF-GDF should be able help them do so.

This first effort at surveillance was made possible by the facilities for epidemiological research within the company. This experiment will be continued, restricted to the cohort set up for the IARC study. It will take into account the duration of employment in nuclear plants, the level of radiation exposures and specific occupational exposures.

REFERENCES


