
Assessment of the health consequences of the Chernobyl accident in France

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Abstract: During the last years, several reports in the media and the publication of a map of environmental radioactive contamination spots linked to the Chernobyl fallout in France rose the concern of a potential public health effect in French populations. Several thyroid cancer patients are convinced that their disease is related to the radioactive fallout of 1986. Thyroid cancer is a rare disease : in 2000, it represents approximately 1.5 % of new incident cancers in France. This incidence has been multiplied by 5.2 in men and 2.7 in women during the last 20 years. French health authorities asked IRSN to test the feasibility of an epidemiological study able to demonstrate a link between Chernobyl and thyroid cancer increase in France. The most exposed and most sensible population was considered: people living in eastern France and aged less than 15 years on April 26, 1986. Calculation of the “spontaneous” rates, existing before 1986 was based on very few register data which covered only part of the chosen regions. The thyroid doses were calculated for different age groups, using all available environmental data. Associate risks postulating a linear dose-effect relation at very low doses, indicated a potential excess of cases ranging from 11.2 to 55.2 compared with the 1,342 spontaneous cases (0.8 to 4.1%) expected during the observation period, 1991-2015. These risk calculations indicate that the Chernobyl fallout cannot explain the increase of thyroid cancers in France and an epidemiological study will be unable to demonstrate this level of excess, if it exists.

1. INTRODUCTION

The main health consequence linked to the Chernobyl radioactive fallout and observed up to now is the high increase in thyroid cancers in young children and adolescents in the highly contaminated areas of Belarus, Ukraine and Russia [1-6]. The widespread radioactive contamination of these territories, with the presence of short-lived isotopes of iodine, in the first hours and days, may explain a large part of this increase. Several hundreds of children were exposed to thyroid doses in the order of 1 and 10 Sv in the regions close to Chernobyl, mainly in Belarus.

In France, more than 10 years after Chernobyl, some doubts exist in the population about the potential health effect that may be linked to the radioactive “clouds” of April and beginning of May 1986. Indeed in some regions, mainly in the eastern and southern part of France, strong raining made it possible to isolate some “hotspots” and to measure ^{137}Cs deposits on the soil [7]. At the request of French health authorities, IRSN has estimated doses to the thyroid gland for the most exposed populations and studied if, based on these doses, an epidemiological study ought to be launched to verify if any excess of cancer could be linked to the radioactive fallout in France.

2. METHODOLOGY

The thyroid cancer incidence rate in the French general population has been increasing for more than 20 years. Estimations for the overall population, from 1975 to 1995 increased from 0.6 to 3.1 per 100,000 for men and from 2.1 to 5.7 per 100,000 for women [8; 9].

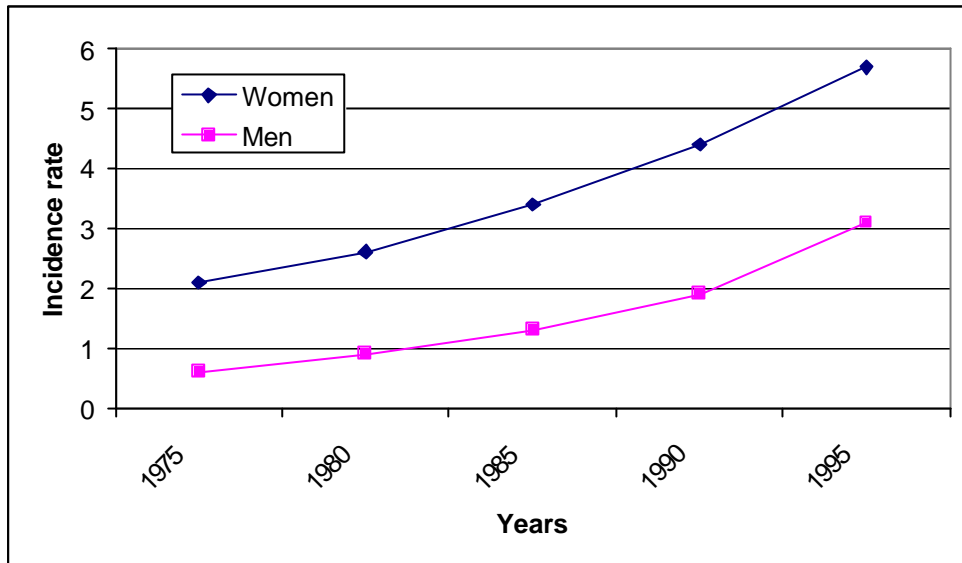


Figure 1: Age-standardized thyroid cancer incidence rate per 100 000 and per year, in France (standardized on European population).

This increase is often perceived by the public and the physicians as a consequence of the Chernobyl accident, even though the rate began to increase well before 1986.

Available data on cancer incidence in France come from several regional cancer registers, but there is no national cancer register. Thus, we can't be able to describe evolution of regional variation of thyroid cancer on a small scale. Estimation of the incidence of thyroid cancer in France before 1986 has been based on very few registers' data, existing since 1976 (see figure 2 for their type and localisation).

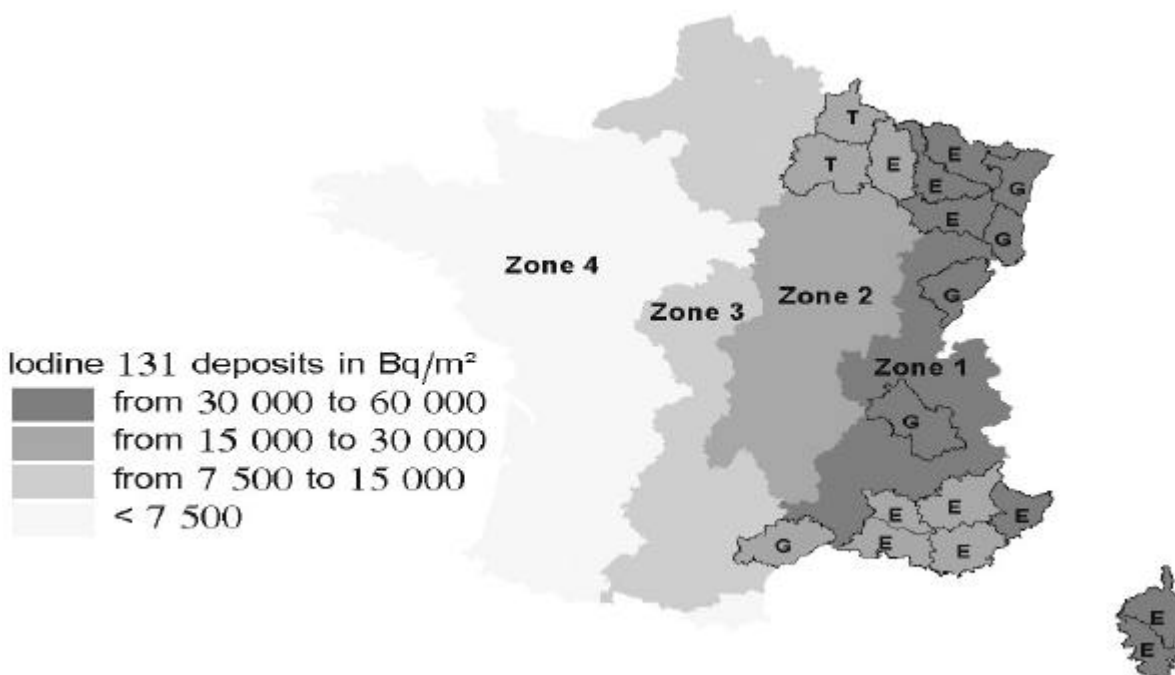


Fig. 2: Average deposits of ¹³¹I in France after the Chernobyl accident (in Bq/m²) - Estimates for May 1986 (IPSN source [10]).

Departments of eastern France, with a cancer register, considered for the study:
G general population cancer register
T specialized thyroid cancer register
E childhood cancer register

2.1 Exposed population

The risk of thyroid cancer potentially associated with the Chernobyl fallout in France was estimated for people who were younger than 15 years at the time of accident, considering them as the most sensible population group regarding the effects of ionizing radiation on the thyroid gland [4; 11-15]. The people concerned was residents of eastern France, the area most exposed to the Chernobyl fallout [11] (Fig. 2), that is, approximately 2,295,000 individuals (data from the 1990 census). Calculations were carried out for two periods 1991-2000 (observable risk period) and 1991-2015 (projected risk period). The public is asking questions about the first period. The second period gives the opportunity to examine the feasibility of retrospective and prospective epidemiological studies on a longer period and consequently of a higher statistical power.

2.2 Thyroid doses

Thyroid doses associated with ingestion of contaminated products were estimated by "ASTRAL" software [16]. Mean levels of radioactive deposits on agricultural areas were calculated from ^{131}I measurements in samples of cow milk and leafy vegetables in France during the first two months after the accident [10]. Specific activities of foodstuffs and doses associated with the following categories of food were estimated: milk, other dairy products, leafy vegetables, seed-containing vegetables (that is, botanically fruit), root vegetables and beef [11]. Soil ingestion was also considered. Diet according to age, the proportion of fresh food eaten, food origin, storage time and "use-by" dates, and the effects of processing food, as well as the transfer coefficient of ^{131}I in breast milk were considered. ASTRAL was also used to calculate thyroid doses due to inhalation from the ^{131}I concentrations measured in the air as the radioactive cloud passed over France. Thyroid doses were estimated for five age groups (3 months, 1 year, 5 years, 10 years, adult). Doses for each (Table 1) were estimated by linear interpolation from the doses by age.

2.3 Calculation of the number of thyroid cancers expected in the population studied

The number of thyroid cancers expected spontaneously, in the absence of exposure to Chernobyl fallout, was estimated for the two study periods for the following age groups in 1986: 0-4 years, 5-9 years, and 10-14 years. The estimates were calculated for each year of the period based on incidence data by 5-year age group, by sex from the French general cancer registers located in the area under study (see figure 2). Data from these registers were available only since 1988: we used the mean incidence for the period 1988-1996 which was the starting period of risk. Only papillary and follicular thyroid cancers were considered because they were the main types for which an epidemic was observed in Belarus, Ukraine and Russia after the Chernobyl accident [2; 3]. The 95% confidence interval associated with the number of expected thyroid cancers was estimated on the assumption of a Poisson distribution.

No published risk coefficient is totally appropriate to the type of exposure (^{131}I) and to the low dose levels that occurred in France after the Chernobyl accident. Several studies in recent years have estimated the risk of thyroid cancer after exposure to ^{131}I at ages younger than 15 years: most of these involve medical exposures (for diagnosis or treatment). None of them reported a dose-effect relationship [17; 18]. To estimate the potential risk of thyroid cancer, inferences were based on various

models and risk coefficients available for external irradiation occurring before the age of 15 years (Table 2). Two types of risk models were used: models of *excess relative risk* (ERR) and of *excess absolute risk* (EAR). Risk calculations were made assuming a latency period of 5 years.

2.3.1 Pooled analysis by Ron et al.

The results from the pooled analysis by Ron et al. give maximum information about the increase of thyroid risk after external irradiation of the gland during young ages (Table 2) [14]. We used only the ERR (excess relative risk model) in our assessment.

The carcinogenic effects of external irradiation of the thyroid are probably different from those due to internal irradiation by ^{131}I , the dose rate being lower in the latter situation. "Relative effectiveness coefficient" (REC) are proposed [13; 19; 20] in order to express the ratio between the risk of thyroid cancer due to internal ^{131}I and that due to external high dose-rate irradiation. We used various REC values for the risk assessment in our study, as proposed by the NCRP (Table 4).

The pooled study by Ron et al. showed that the ERR increased significantly as age at exposure diminished: for the groups aged 5-9 years and 10-14 years at exposure, the risk coefficients were respectively half and one fifth of the risk coefficient for the group aged 0-4 years at exposure. In the absence of ERRs published by age group (at exposure), we approximated them, by considering that the ERR for those younger than 15 years was the sum of the ERR for each age group considered (0-4, 5-9, 10-14), weighted according to the proportion of cases observed in each group in the study by Ron et al. [21].

2.3.2 The Marshall Islands studies

In that case, exposure is qualitatively similar to that following Chernobyl, but the mean doses in the Marshall Islands were very elevated and the follow-up concerns only a small population with very few cases of thyroid cancer (6 in all) [13]. The estimate of the spontaneous incidence of thyroid cancer in this population is therefore unstable, and we concluded that this coefficient could not be used for this risk assessment.

2.3.3 Study of thyroid cancer around Chernobyl

A geographic correlation study using thyroid cancer data aggregated by village in the countries most affected by the Chernobyl accident provided two risk coefficients (Table 1) [5]. This study considers a population of children aged from 0 to 14 years when they were exposed to the Chernobyl fallout. The incidence data, however, cover only a short period (1991-1995). We used only the EAR in the present study. EAR reflects present published knowledge about the Chernobyl accident effects on thyroid cancer but its use in projections over 25 years must be considered very cautiously.

Table 1: Risk coefficients available for assessing the risk of radiation-induced thyroid cancer*

Source	Types of irradiation	Mean thyroid doses (Gy)	EAR.10 ⁻⁴ PY.Gy ^{-1**} (95% confidence interval)	ERR.Gy ⁻¹ (95% confidence interval)
Marshall Islands [13]	¹³¹ I, ¹³² I, ¹³³ I external gamma irradiation	12.4	<u>1.1 (0.4-2.3)</u>	0.3 (0.1-0.7)
Chernobyl [5]	¹³¹ I, ¹³² I, external gamma irradiation	0.03 - 1.8 according to region	<u>2.1 (1.0-4.5)</u>	23.0 (8.6-82)
Pooled analysis [14]	external X or gamma irradiations (medical, Hiroshima, Nagasaki)	0.09 - 1.36 according to study	4.4 (1.9-10.1)	<u>7.7 (2.1-28.7)</u>

* The underlined coefficients are those used for the calculation of risks presented in this study.

** P-Y: person-years.

3. RESULTS

The thyroid doses in France were approximately 100 times less than the mean thyroid doses received by the children in Belarus. Major part of the estimated thyroid doses from the Chernobyl fallout came from the ingestion of food contaminated by ¹³¹I. The thyroid dose due to external irradiation was only 0.1 milliSievert (mSv) for the first year and was therefore neglected in the present risk calculations. Ingestion of the cesium and ruthenium present in the radioactive cloud also contributed only marginally to the thyroid dose.

Table 2 : Thyroid doses by age group due to average ¹³¹I deposits in France (1986) (zone I)†

Age group	Estimated dose (mSv)
0-6 months	1.9 (1.3-2.5)
7 months - 4 years	7.9 (5.3-10.4)
5-9 years	4.5 (3.1-5.9)
10-14 years	2.2 (1.4-2.9)

† Doses in brackets correspond to the lower and upper values of the range of average deposits as calculated by

The expected spontaneous number of thyroid cancers, calculated for the 2,295,000 individuals in zone 1 during the period 1991-2000 was estimated to be 212 cases \pm 29. The potential excess of thyroid cancers ranged from 0.6 % to 10.5 %, depending on the assumptions and risk models used. An absence of excess could not be excluded, considering that some studies conducted on individuals exposed to low diagnostic radioactive iodine were unable to demonstrate any increase of thyroid cancer. For the period 1991-2015, the expected spontaneous number of cases increases with aging of the cohort: 1342 \pm 73 cases are estimated. The potential excess attributable to the Chernobyl accident would range between 0.8% and 4.1% (details of risk calculations in table 3).

Table 3. Estimates of expected spontaneous and potential in excess thyroid cancers for the periods 1991-2000 and 1991-2015 for people living in zone 1 and younger than 15 years on 1986 (n = 2 295 000)

Number of expected cases		Number of excess cases (percentage of excess cases)					
		Ron et al.				Jacob et al.	Marshall Islands
		REC [†] = 1 ^A	REC [†] = 1 ^B	REC [†] = 0.66 ^B	REC [†] = 0.33 ^B	--- ^c	--- ^c
Period 1991-2000	212 [183–241]*	5.8 (2.7)**	3.9 (1.8)	2.5 (1.2)	1.3 (0.6)	22.3 (10.5)	11.7 (5.5)
	--	1.9 - 15.3 [‡]	1.3 - 10.2	0.9 - 6.7	0.4 - 3.4	7.2 - 63.3	2.9 - 32.4
Period 1991-2015	1,342 [1,269–1,415]*	42.1 (3.1)	33.9 (2.5)	22.4 (1.7)	11.2 (0.8)	55.2 (4.1)	28.9 (2.1)
	--	14.2 - 111.7	11.5 - 89.8	7.6 - 59.3	3.8 - 29.6	17.8 - 156.7	7.1 - 80.1

^A model of constant excess relative risk for those 0-14 years.

^B model of excess relative risk according to age group [21].

^C model of constant absolute excess risk.

* 95% confidence interval.

** percentage of excess cases = number of excess cases /number of expected cases.

†REC = relative effectiveness coefficient.

‡ uncertainty about the total number of excess thyroid cancers.

4. DISCUSSION

Regardless of the risk model and the period of calculation, the number of excess cases attributable to the Chernobyl fallout in France, under a no threshold linear dose-effect relation hypothesis, was less than the statistical uncertainty associated with the number of expected cases.

Whereas the relationship between thyroid cancer and exposure to ionizing radiation is accepted, many uncertainties remain about the risk quantification and the risk model type. Many epidemiological studies have been conducted during the last century. None of them can give direct risk estimation at low doses. Inferences have to be done to extrapolate high doses to low doses and to transpose between populations.

Because of differences between the cohorts included in the pooled study of Ron, notably concerning the types and intensity of screening methods, and because of the strong influence of the latter on the EAR (excess absolute risk), we considered it inappropriate to use the EAR from this study to make risk projections for the French population. On the other hand, to the extent that the screening was independent of exposure levels, the ERR should have been modified only slightly, if at all, and was used for our calculations. Nonetheless, an assessment of the risk of thyroid cancer during the first ten years after the Chernobyl accident in the population of children most highly exposed in Belarus and Russia showed that the ERR calculated by Ron et al. predicted fewer cases than the number actually observed [5]. We therefore deemed it necessary to use other risk models. The study by Jacobs et al. was a geographical study based on aggregates rather than individual epidemiological data: the dose estimates were mean doses for villages. Moreover, the histological diagnoses could not be verified for some cases of thyroid cancer, and potential confounding factors such as iodine deficiency were not taken into account. Nonetheless, the consequences of these limitations are probably less important when the risks observed are very high, as they were for the regions most heavily affected by the Chernobyl disaster: the spontaneous incidence of childhood thyroid cancer was multiplied 10 to 100-fold in these areas. Jacob et al. mentioned that the variations in the mean doses by village were greater than the inter-individual variations; the mean dose by village is therefore a useful indicator. The risk coefficients found by Jacob et al. must nonetheless be interpreted prudently and be confirmed by analytic studies currently underway. Differential screening can be a major bias, since after the accident the priority for implementation of detection campaigns depended on the level of contamination in these regions; this implementation was progressive and difficult to quantify. This situation may have led to an overestimation of the true ERR. Jacob et al. tried to quantify this effect in their analysis; in particular, they used the data from the Belarus cancer registry to compare the incidence of thyroid cancer before and after the accident in regions with very low exposures.

In France, only few registries can provide spontaneous thyroid cancer incidence data. Registry based incidence data show an increasing trend (around 15 % in 5 years) from the end of the seventies onward in France. This trend is possibly due to better screening and ascertainment of this disease. The increasing trend among females appears to be more marked than among males, especially since 1994.

A misunderstanding of the degree of the exposure associated with communication problems in France in 1986 and the observed increasing trend of thyroid cancer make the public and many physicians establish of a direct link between this disease and the Chernobyl fallout. However, the increasing rate started well before 1986. Regardless of the risk model and the period of calculation, the number of excess cases attributable to the Chernobyl fallout in France under a non-threshold linear dose-effect relation hypothesis was less than the statistical uncertainty about the number of expected cases. On the basis of such results, it was recommended that the surveillance of thyroid cancers in France be reinforced. This would provide an epidemiological "zero point" that could be the start for a health surveillance program should a nuclear accident occur. Surveillance should also involve a better description of indicators more or less in relation to the incidence change: size of tumors, anatomopathology type, medical practices. It should provide a tool to facilitate future epidemiological studies able to account for all the risk factors: environmental, hormonal and behavioral diet, of the thyroid cancer.

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