Nord-Cotentin radioecological study – sensitivity and uncertainty analysis

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Abstract: A radioecological study has been performed by the Nord Cotentin Radioecology Group to assess the radiation-induced leukaemia risk in the Beaumont-Hague canton of the Nord-Cotentin region. Results were published in July 1999. One important figure was the number of leukaemia cases in excess for young people aged 0 to 24, living in the Beaumont-Hague canton and exposed to radioactive discharges from nuclear facilities located in the Nord-Cotentin region, that was estimated at some 0,002 for the years 1978 to 1996. This number is low in comparison with the incidence of leukaemia recorded by recent epidemiological studies for the same period (4 cases observed versus 2 expected). Nevertheless, this result caused debate, particularly because the uncertainty associated with it had not been estimated. This led to launch a study to estimate the uncertainty of the number of excess cases of leukaemia. In this paper the methodological approach retained for the sensitivity and uncertainty analysis is presented and the results are discussed.

1. INTRODUCTION

On 24 August 1997 the French Ministry for Health and the Ministry for Regional Development and Environment commissioned a first study from the Nord Cotentin Radioecology Group (GRNC) to assess the risk of radiation-induced leukaemia in the Beaumont-Hague canton of the Nord-Cotentin region. The GRNC submitted its findings in July 1999. The expected number of excess leukaemia cases for people aged 0 to 24 in the canton of Beaumont-Hague exposed to the radioactive discharges from the nuclear facilities located in Nord-Cotentin was estimated at roughly 0.002 cases for the period 1978-1996 [1]. This result corresponds to the best estimation possible in the present state of knowledge. However, in this first study, there was no quantification of the uncertainty associated with the estimated risk.
On 24 June 2000, the Ministry for Health and the Ministry for Regional Development and Environment sent a mission statement to the GRNC commissioning it to conduct a sensitivity and uncertainty analysis on the main parameters of the estimation of leukaemia cases attributable to the Nord-Cotentin nuclear facilities.

This second study was conducted in four stages: definition of the scope of the study and identification of the predominant parameters, determination of the distributions and variation ranges of the predominant parameters, sensitivity analysis, and finally uncertainty analysis for which two different methods were taken.

Broadly speaking, there are several sources of uncertainty in the risk assessment:

- specific parameters of the nuclear facility and the area in question, i.e. the canton of Beaumont-Hague. This basically means radioactive discharges from the Cogema reprocessing plant at La Hague[1], the atmospheric transfer coefficients (ATC), and the lifestyles of canton residents – particularly their dietary habits and time budget. The values of these parameters are taken from measurements or surveys, or are extrapolated;
- parameters that are an integral part of the models, such as marine and terrestrial transfer coefficients. The values of these parameters are often generic, although some can be adapted to the study area;
- models themselves, which represent complex transfer phenomena with varying degrees of precision.

[1] The impact of the other nuclear facilities in Nord-Cotentin is negligible.

In this study, in compliance with the GRNC mission statement, the sources of uncertainty considered are those related to the parameters. The models themselves have not been re-examined.

Once the uncertainties are quantified, one must examine how they combine to produce uncertainty in the risk assessment. The working group first adopted the probability method, i.e. the Monte-Carlo simulation. This is a classic method in which the uncertain parameters are modelled by random variables. The risk probability distribution is obtained using models of transfer, impact and risk that link the risk to the uncertain parameters. During the discussion of the results of this method, a second approach was applied, the possibilistic method that is less demanding in terms of available information [2].

2. METHODOLOGY FOR THE UNCERTAINTY ANALYSIS

2.1. Selection of parameters

The risk calculation involves several thousand parameters that are used to model atmospheric dispersion, marine dispersion and transfers of the radionuclides released in marine and terrestrial compartments, and to deduce from that first the dose to the population in question and then the associated leukaemia risk (cf. Figure 1).

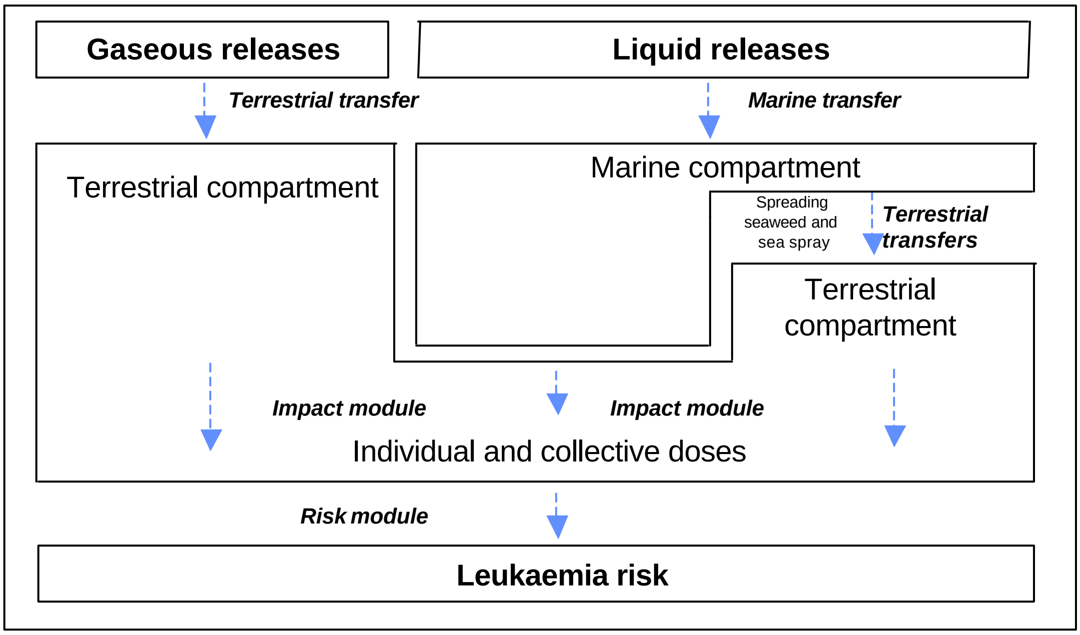

Figure 1: General description of the calculation procedure

It is impossible to estimate the uncertainty of each parameter involved in the risk calculation. The selection of the parameters to which uncertainty will be attributed has been carried out in two steps: limitation of the scope of the study and identification of the predominant parameters. For the remaining parameters, the values attributed in the GRNC first study were retained.

The uncertainty calculation was performed for the collective *ex utero* risk of leukaemia associated with routine discharges from the nuclear facilities located in the Nord-Cotentin region (0.0009 cases of leukaemia for the period considered), denoted more simply as "risk" in the rest of this paper.
No uncertainty was assigned to dose or risk coefficients, for which there is an international consensus not challenged by the GRNC.

The predominant parameters were identified by examining each step of calculation. Selection criteria were devised to ensure that these parameters represented at least 95% of the risk. The criteria were as follows:

- a radionuclide in an exposure pathway was selected if it alone contributed to more than 0.5% of the risk,
- a transfer or lifestyle parameter in an exposure pathway was selected if its contribution to the risk was greater than 0.15%.

This selection approach led to the choice of 214 predominant parameters to be varied for the purposes of the uncertainty analysis.

2.2. Distributions of the predominant parameters

For constructing the probability distribution of the values that can be attributed to each parameter, there are three scenarios:

- specific data on the nuclear facility and the study area are available from the results of previous specific studies conducted on site. In these cases the distributions of possible parameter values are specific to the site in question;
- no data are available from specific studies conducted on site, but bibliographical references provide indications on "generic" values or values close to the conditions existing on the site in question;
- no data are available, whether from specific studies conducted on site or from general bibliographical research. Then parameter distributions are constructed from hypotheses based on analogies or expert opinion.

Local data were taken in preference to national or international data, average levels of radioactivity in the environment rather than extreme values and average lifestyles rather than particular behaviours. These choices reflect the fact that the calculation concerns a large cohort of individuals in a wide age interval, resident in the Beaumont-Hague canton as a whole rather than a specific place, and who could have been exposed to the radioactive discharges from the La Hague facility over a long period (since 1966).

To determine the joint distribution of the entire set of parameters, dependencies between parameters were also studied qualitatively. Dependencies, expressed in the form of correlation coefficients, are often difficult to quantify even when they are easy to identify. This task is important, because the fact that some parameters are correlated (i.e. do not vary independently of each other) has a major influence on the probability distribution of the estimated risk, especially the probability of the extreme values. The working group chose to assume independence for most parameters (either because this seemed logical to them, or by default) and to model the obvious dependencies by a correlation coefficient close to 1 or -1 between the parameters concerned.

2.3. Monoparametric sensitivity analysis

An analysis of single parameter sensitivity was then conducted. This consisted of calculating the risk variation for each parameter whose variation range was known, the values of the other parameters being set at the values the GRNC proposed in its first study. The purpose of the sensitivity analysis was to identify, among the predominant parameters, those whose variation led to a strong variation in the risk. These parameters, being considered the most sensitive, were then used for the uncertainty analysis. With this single-parameter approach, two calculations were made for each predominant parameter: one for its minimum value and one for its maximum value. The sensitivity indicator used to interpret the sensitivity calculations was the risk variation divided by the risk calculated by the GRNC in its first study[2]. The calculations showed that this indicator, expressed as a percentage, was virtually nil for a third of the parameters, equal to 1% for one parameter in five, and over 1% for half the parameters. For some parameters, the sensitivity indicator had a very high value: this was the case for the ATC (75%), ^{137}Cs activity in fish (79%), and ^{60}Co activity and ^{244}Cm activity in sediments (156% and 173% respectively).

Using these results with no interpretation would have eliminated many parameters from the uncertainty analysis (at least that half of the parameters whose indicators were equal to 0% or 1%). However, in view of the single-parameter sensitivity analysis method itself and the structure of the GRNC risk calculation model, it did not seem prudent to reduce so drastically the number of parameters taken into consideration for the uncertainty study. Indeed a parameter may seem to be of low or nil sensitivity in a single-parameter sensitivity analysis while appearing sensitive in a multi-parameter study if it interacts with other uncertain parameters. One example of this is the relationship between quantities of foodstuffs consumed and radionuclide activities in the environment. Because of these difficulties, it was decided not to reduce the number of parameters taken into account for the uncertainty analysis on the basis of the single parameter sensitivity analysis.

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[2] This risk value as referred to hereafter as the "reference value" or "reference risk".

2.4. Uncertainty analysis by the probabilistic method

The probabilistic method involves a Monte Carlo simulation that consists of making a random sample of *n* values for each of the parameters so as to calculate *n* values for the risk, and from that deduce its probability distribution. This means performing the calculation n times. The distribution obtained can be described by fractiles, i.e. the risk values associated with a given level of probability. The quality of the fractiles is measured by confidence intervals whose width depends on the number of calculations performed and is not affected by the number of uncertain parameters. The 5% and 95% fractiles can be accurately estimated from a sample of 1000.

2.5. Uncertainty analysis by the possibilistic method

The probabilistic method is widely used to analyse uncertainty [3] [4]. However, to implement it properly one must know not only the distributions of each parameter and the dependencies between the parameters, but also the joint probability law of the full set of parameters. This information is rarely available. In practice, numerous hypotheses have to be made [5] and these strongly affect the results [6]. For these reasons, it appeared appropriate to develop a complementary method, the possibilistic method [7], that would require fewer hypotheses.

Possibilistic analysis calls for breakdown of the risk into basic components, each representing the risk associated with an age group, exposure pathway or, where appropriate, type of food. The uncertainty inherent in each of these components is evaluated by the probabilistic method. Based on its probability distribution, each risk component is then also assigned a "possibility distribution"[3]. The final possibility distribution of risk is obtained by "summing" the basic possibility distributions. The upper and lower bounds for this final result are the sums of the corresponding basic component bounds.

3. RESULTS

3.1. Probabilistic method

In Figure 2, the risk is expressed as a percentage of the reference risk (the risk estimated by the GRNC at 0.0009 cases). The risk probabilistic distribution is very narrow (factor 2 to 3 between the 95% fractile and the 5% fractile). Moreover, the reference risk is located in the low values of this distribution (2% fractile). These results are due to the use of the Monte Carlo method and to the hypotheses adopted (large number of parameters, assumed independence of most parameters, distribution of parameters generally asymmetric with a mean higher than the mode).

[3] To determine a possibility distribution for a variable, each numerical value is assigned a possibility coefficient ranging from 0 to 1.For each basic component of risk, values higher or lower than the extremes obtained by Monte Carlo simulation are considered impossible (possibility = 0), median values obtained by Monte Carlo simulation are deemed fully possible (possibility=1) and intermediate values are assigned possibility coefficients proportional to their fractiles.

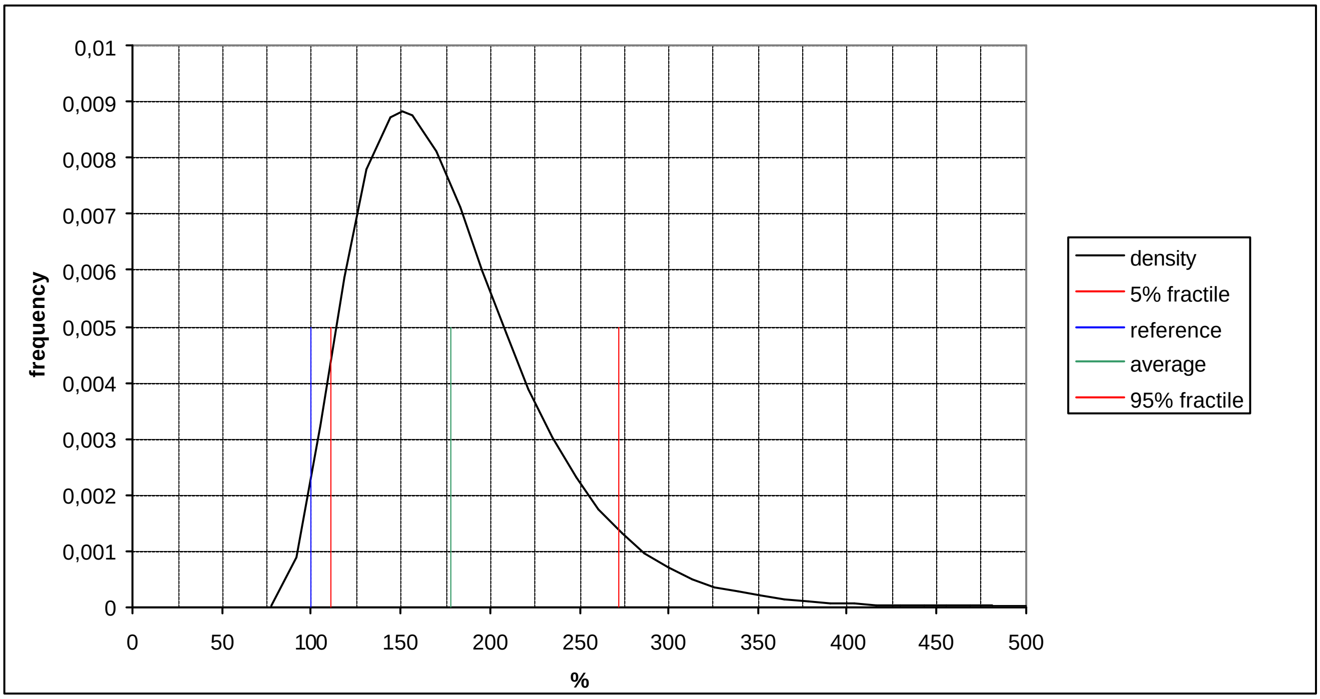

Figure 2: Risk distribution obtained by the probabilistic method

3.2. Possibilistic method

The risk possibility distribution obtained by the possibilistic method is shown in Figure 3. In this graph, as before, the risk is compared with the reference risk estimated by the GRNC at 0.0009 cases. The uncertainty calculations using the possibilistic method produce a wider risk distribution than with the probabilistic method: risk values greater than a possibility of 5% are between 0.4 and 5 times the reference value. This wider distribution is due to the fact that hypotheses concerning parameters' dependence or independence are not required. The reference risk value corresponds to a possibility of 60%, so it is slightly off-centre towards the low values. That is because the approach uses risk component distributions that are the result of running a Monte Carlo simulation both on environmental radioactivity and on lifestyles parameters for which the distributions are asymmetric.

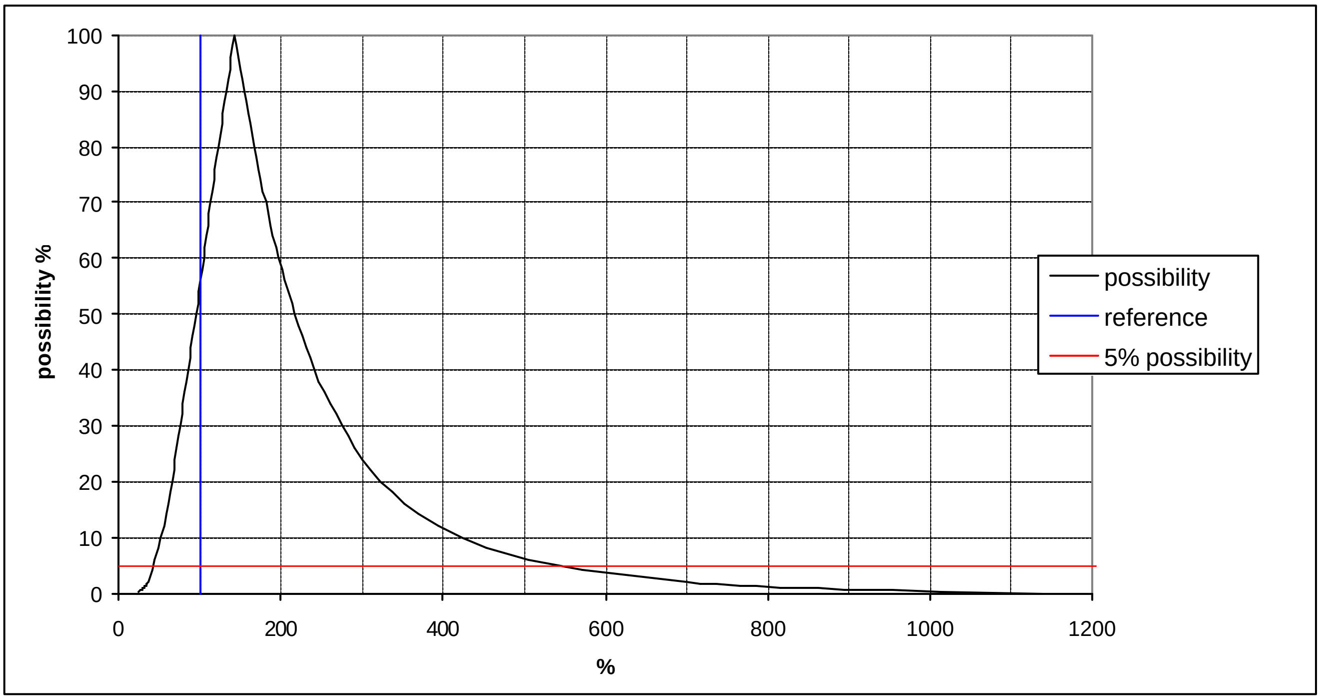

Figure 3: Risk distribution obtained by the possibilistic method

4. CONCLUSION

The monoparametric sensitivity analysis showed that the risk is virtually insensitive to at least half of the parameters taken into account.

Uncertainty analysis used two complementary methods – probabilistic and possibilistic – to determine variation ranges for the risk. Probabilistic analysis resulted in a range of values from 1.1 to 2.7 times the reference risk (or 0.001 to 0.0024 cases of leukaemia); and the possibilistic approach yielded a range from 0.4 to 5 times the reference risk (or 0.0004 to 0.0045 leukaemia cases). All of these estimates were well below the number of cases of leukaemia actually observed in the same population over the same period (i.e. 4 cases as opposed to the 2 expected) and far less than the risk of radiation-induced leukaemias from all (natural, medical and industrial) sources of exposure combined (0.84 cases).

It should be recalled at this stage that the uncertainty study performed has some limitations. Since it covers the risk of leukaemia resulting from *ex utero* exposure to routine discharges, which has been estimated in the initial GRNC evaluation at 0.0009 cases (reference risk), it does not include risks associated with either incidents and accidents (fewer than 0.0012 cases) or with *in utero* exposure (0.0003 cases). There is, however, another noteworthy limitation: uncertainties relating to dose and risk coefficients could not be considered here, because scientifically accredited data on the subject are missing. Note that the Nord Cotentin Radioecology Group, in liaison with COMARE experts, will be keeping abreast of the hearings held by the UK Ministry of the Environment to assess the quality of models used in calculating risks from dose data. The results of this work when published should permit access to variation ranges associated with such models.

An uncertainty study conducted on the scale described here for radiological impact evaluation is exemplary in more ways than one: diversity of the models used, parameters processed by the hundreds, choice of different methods to quantify uncertainty. Efforts devoted to refining variation ranges and parameter distributions have enhanced existing know-how by providing a database for future sensitivity and uncertainty studies. Finally, in subsequent research, application of possibility theory to this type of evaluation merits further reflection.

5. REFERENCES

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The Nord-Cotentin Radioecology Group (GRNC)

The Nord-Cotentin Radioecology Group (GRNC) is a multidisciplinary group of experts from diverse organizations (governmental institutions, universities, nuclear operators , NGOs, foreign scientists). It was set up by French ministries in 1997 when a scientific controversy irrupted about the high incidence of leukaemia in the Nord-Cotentin region and its hypothetized link with radioactive discharges from the reprocessing plant in La Hague. GRNC experts and their president Annie Sugier, Director of Protection at IRSN, defined the Group operating principles as follows : a critical approach the most complete possible, transparency and open communication, diversity in view points made explicit (reaching a consensus was not a necessary goal). GRNC has been concerned twice by the risk of leukaemia. In a first mission from 1997 to 1999, the Group developed a thorough study of that risk in relation to radiations and to radioactive discharges in particular. In the second mission from 2000 to 2002, uncertainty of the radiation induced leukaemia risk was estimated, an analysis of the risk in relation to chemical discharges was performed and approaches of GNRC in France and COMARE in UK were compared. Orientations and choices were the Group privilege. IRSN contributed to GRNC work in two ways: group membership - some IRSN experts were members - and technical assistance – several teams at IRSN were involved in data collection, modelling and calculations and preparation of scientific reports.