NORD-COTENTIN RADIOECOLOGY GROUP

Estimation of exposure levels to ionizing radiation and associated risks of leukemia for populations in the Nord-Cotentin

SUMMARY REPORT

FOREWORD

The Nord-Cotentin Radioecology Group[1] addressed its conclusions to the Minister of Internal Development and Environment and to the Secretary of State for Health, on July 7, 1999 after two years of work.

The documents produced by the Group may be consulted on Internet[2] at the same time.

The final summary report and the detailed final reports (Volume 1 - Inventory of radioactive releases from nuclear facilities; Volume 2 - Critical review of measurements in the environment; Volume 3 - Transfer models for radionuclides through the environment and Volume 4 - Estimate of doses and associated leukemia risks) were distributed in October 1999.

All the members of the Group except CRII-RAD[3] experts approved the contents of these reports.

Reservations about the evaluation of the results expressed by some members of the Group were included in the discussion of these results. Furthermore, more general comments made by Group experts were included both in the conclusions and in the General Appendices.

Only the summary of the document is available in English. This includes a small number of modifications by which it differs from the original French document.

[1] Membership: see General Appendices (Appendix 2)

[2] www.ipsn.fr/nord-cotentin – See the other websites mentionned in Appendix 5

[3] The reasons for wich CRII-RAD has distanced itself from the conclusions of the Nord-Cotentin Radioecology Group are stated in a provisional document that was addressed to the President on 5 July 1999 and are given in detail in Summary 99-26 available at the CRII-RAD website (www.criirad.com).

PREFACE

The existence of a trend towards an excess number of leukemia between 1978 and 1992 in young people (0 to 24 year old) in the Beaumont-Hague Canton (4 cases observed compared with 1.4 cases expected), the relation suggested in 1997 particularly with the consumption of local seafood and time spent on beaches, led public authorities to ask for two types of investigations to be carried out:

- firstly, a more detailed epidemiological study which demonstrated that further studies are necessary (reinforcement of epidemiological surveillance, assessment of the consequences of industrial exposure, taking into account other effects of ionizing radiation), even if there is not really an excess in the number of leukemia in the region for a longer period from 1978 to 1997. This study which is still going on at the present time, was entrusted to Professor Spira, director of research at INSERM[4] . The first result was the publication in 1998 of the "Ionizing radiation and health: measurement of exposures and surveillance of health effects"[5]

- secondly, a more detailed radioecological analysis which produces a direct and best estimate of the radiological exposure of the population and uses this estimate to predict effects on health. In the context described above, the objective was to evaluate the theoretical number of cases of leukemia that can be assigned to nuclear facilities and to other exposure sources (medical and natural) for a given population and geographic area. This work was carried out by the «Nord-Cotentin Radioecology Group» presided over by Mrs. Sugier, director of Protection at IPSN[6], including experts from a wide range of origins (inspectors, governemental experts, operators, experts from non governemental laboratories, foreign experts).

The Nord-Cotentin Radioecology Group's summary report and detailed reports are applicable to this second part of the request by public authorities and present work done by the Group, assisted by the IPSN.

The conclusions reached by the Group reflect agreement between experts about a methodology based on the model of radionuclide transfers through the environment to man, and the low calculated risk of radiation-induced leukemia in young people from 0 to 24 year old that can be assigned to Nord-Cotentin nuclear facilities based on this methodology: *of the order of 0.002 cases for the population considered during the 1978 - 1996 period, which is much less than the four cases observed during this period.*

This result is an average estimate (corresponding to the best estimate) that can be made based on current scientific knowledge. Uncertainties exist, and the Group has done its best to reduce them, particularly by making use of a very extensive database. The sensitivity of the results was tested by varying important parameters related to the dose-relevant habits of cohorts (time spent on beaches, consumption of seafood, etc.). The results obtained give no reason to modify the conclusion that the nuclear facilities do not appear to have any significant influence on radiation-induced cases of leukemia in young individuals in the area considered.

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[4] INSERM: National Institute of Health and Medical Research

[5] La Documentation Française

[6] IPSN: Institute of Protection and Nuclear Safety

However, a global uncertainty analysis was not carried out. This type of analysis would require a great deal of work, and was not done in similar studies carried out in other countries. Consequently, some members of the Group believe that it is not possible to reach any conclusion at this stage, whereas other members of the Group believe that these uncertainties would not modify the orders of magnitude obtained or the content of the conclusions.

Based on this methodology, both natural and artificial radiological exposures of the population considered could explain 0.83 cases of leukemia during this period.

This result confirms the importance of carrying out a study of local conditions of exposure to radiation from natural and medical sources, as was done for nuclear facilities.

This report also contains calculation data that can be used in a regulatory approach to assess the exposure of groups of population. The objective is to estimate the exposure of groups that are likely to be the most highly exposed to discharges from COGEMA La Hague reprocessing plants. The purpose of these elements is to provide background information about decisions to be made about revisions to regulatory texts governing the operation of these plants.

All the work done (epidemiological and radioecological) cannot explain the relatively high observed number of leukemia, but does not disprove the basic working assumption that there is no threshold in the dose/effect relation, in other words low doses are related to a low risk rather than a zero risk. However as a result of this work, it is recommended that priority should be given to carrying out a more detailed study of exposures due to medical and natural sources in the Nord-Cotentin, and that in any case, exposures of the public to all sources should be reduced as low as reasonably achievable (as required by the regulations). Other extensions to the study would include further consideration about whether a global uncertainty analysis should be carried out.

EXECUTIVE SUMMARY OF THE NORD-COTENTIN RADIOECOLOGY GROUP

1. OBJECTIVES

The Group had two separate tasks:

- Task 1: *to provide information to complement the epidemiological studies carried out or being carried out in the Nord-Cotentin, by estimating the exposure from the various sources of ionizing radiation (nuclear industry, medical examinations, natural radiation) and hence the risk of leukemia to young people (0 to 24 year old) living in the Beaumont-Hague Canton during the period (1978 – 1996).*

  The period considered (1978-1996) is the same period covered by the study done by J.F. Viel (1978 - 1992) and Doctor Guizard (1993 - 1996). It should be noted that the calculation of risk is restricted to one end point (i.e. leukemia), a restricted population (i.e. young individuals), and a given period (i.e. 1978-1996). Consequently, this calculation should not be considered as an estimate of the overall health impact of the nuclear facilities in the Nord-Cotentin. Furthermore, the Group's task did not include the study of other potential causes of leukemia.

- Task 2: *to provide background information for the decisions to be made regarding the revisions of the regulatory texts governing the operation of COGEMA La Hague reprocessing plants by determining the exposures of the population groups likely to be the most exposed.*

  This "regulatory" approach satisfies an objective of protecting the entire population, by ensuring that those groups that are likely to be the most highly exposed actually receive doses that are low compared with limits for individuals who may be exposed to several sources of exposure (medical and natural exposures are not considered in this context).

In both cases, exposure levels should be defined realistically wherever possible, even though there are difficulties with this in a retrospective study. This approach is different from the conservative estimates made in the past.

The nature of the Nord-Cotentin Radioecology Group and its work was exceptional and highly original, first in its composition (inspectors, governemental experts, operators, experts from non governemental laboratories and foreign experts) and also in carrying out the most exhaustive systematic critical analysis possible.

A total of 50 experts were involved in this study over a period of two years within the Plenary Group and four specialized Groups dealing respectively with releases, measurements in the environment, models and calculations of doses and risks.

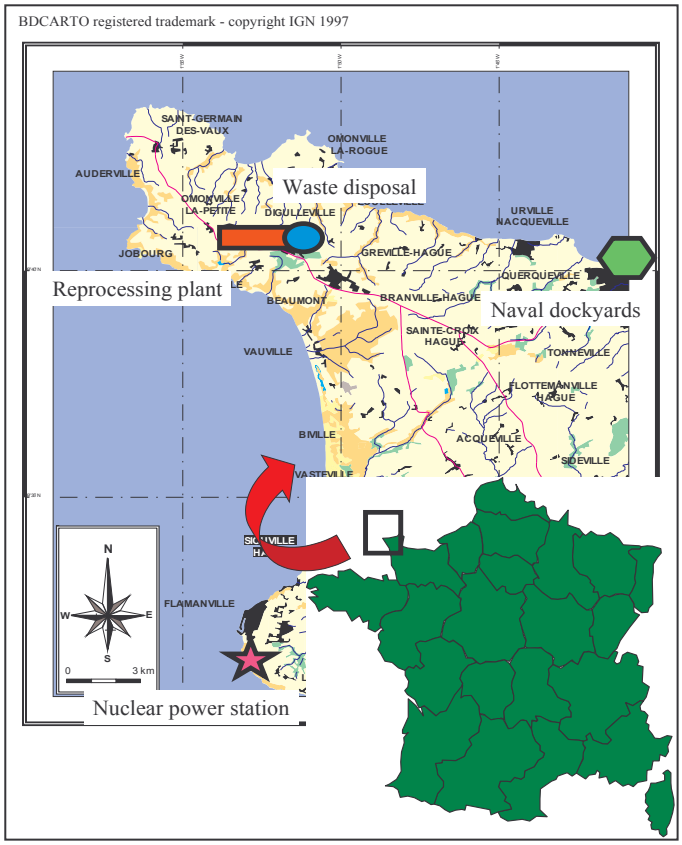
It should be noted that this study involved a multidisciplinary approach but the significant unbalance in the means of the various players should not be concealed.
This work is complementary to that of Professor Spira concerning epidemiological studies of Nord-Cotentin populations. This latter work have led to the publication of a report, and are continuing along the lines defined in that report[7].

[7] Ionizing radiation and health: measurements of exposure to radioactivity and surveillance of effects on health (1998) – French Documentation – Alfred Spira and Odile Boutou

2. METHOD

- Sources of exposure:

The emphasis was placed on the nuclear facilities (COGEMA La Hague reprocessing plants, ANDRA's shallow-land radioactive waste disposal center at La Hague, EDF's nuclear power station in Flamanville, and the French Navy Arsenal in Cherbourg). Particular attention was paid to COGEMA La Hague reprocessing plants due to the high level of its releases compared with those from other nuclear facilities [8].



The region concerned by the radioecological study

Other often quite substantial sources of exposure to ionizing radiation are medical (diagnostic) and natural (cosmic and terrestrial radiation, intake of natural radionuclides including radon), and fallout from atmospheric testing of nuclear weapons and the Chernobyl accident. These sources were not studied to anywhere near the same degree of detail. They do however provide some perspective to the exposures from the nuclear facilities.

- Radioactive releases:

The Group started from the radionuclide releases (liquid and gaseous) supplied by the operators. These were checked and other radionuclides that were not individually identified in measurements were added. The releases of some radionuclides for periods during which

[8] No specific studies were carried out on the Casquets trench in which radioactive waste was immersed in the 1950s and 1960s. This trench is a potential source-term, although no effect has been detected on the marine environment since monitoring measurements were first made (middle of the 1960s). This question is raised particularly in the release published by the "Les Mères en Colère" (Angry Mothers Association) (See General Appendices , Appendix 4).

they were not measured were also reconstructed. Almost 40 radionuclides were added. These additions did not significantly increase the total released activity, but they provided a more complete picture of releases. This work was done mainly for the releases from COGEMA La Hague plant.

For releases from the Arsenal, the Ministry of Defense provided the Group with information that was previously not available in the public domain.

- Measurements:

The most exhaustive possible inventory of the type of radioactivity sampling and measurements in the environment carried out by all of the various groups involved (inspectors, governemental experts, operators, experts from non governemental laboratories) has led to about 500,000 items of data up to 1997. The presentation of these data was standardized and results were evaluated in a consistent fashion. Appropriate data sets were then selected in order to test the models used for calculating radionuclide tranfers through the environment. In view of the volume of available data, only results subsequent to 1977 were processed.

A CD ROM containing the results of this large-scale review was made available to experts and the general public.

- Models:

Comparisons were made between the models frequently used for calculating radionuclide transfers through the environment. The models and parameters best suited to local characteristics were chosen and, wherever possible, their results were compared with measurements in the environment. Correction factors were introduced when necessary in order to make models more representative of the data.

This exercise increased the confidence in the modeling of releases of radionuclides into the marine environment, since the model was modified using the long series of measurements that were available for some radionuclides. However, the smaller number of measurements above the detection limits, or the relative magnitude of the background noise, made it impossible to carry out an equally extensive comparison between the models and measurements for the terrestrial environment.

In case where long series of measurements exceeding detection limits were available (as is the case for the marine environment), it was possible to quantify the variability of radionuclide activities in the marine environment.

- Populations:

For task 1, the Group reconstructed the population of young individuals (0 - 24 year old) living in the Beaumont-Hague Canton during the 1978-1996 period. This ''cohort'' contains 6 656 young individuals assumed to be living in the Canton up to 24 year old or 1996 (whichever is the earlier), which is of the order of 70,000 individual.years[9] between 1978 and 1996.

For task 2, exposure situations exploring geographic areas and dietary habits for which population groups are likely to be the most significantly exposed, were identified and studied.

[9] This is a total time during which each individual between 0 and 24 year old is present in the Beaumont-Hague canton within the 1978 - 1996 period, for the entire cohort considered.

- Doses:

Intakes of activities incorporated into the body and external exposure were calculated based on the activities in the environment and dose-relevant habits obtained from local investigations (geographic location of the groups considered, their use of the environment and consumption of foodstuffs).

Specific factors were used to convert these activities into doses. These were obtained from recommendations of International Organizations, and the Group did not undertake any critical analysis of them.
The dose-relevant habits of individuals within the cohort (task 1) correspond to average situations. The dose-relevant habits of population groups likely to be the most highly exposed (task 2) are related to worse situations resulting from specific behaviors or locations in which they would be more exposed to the releases. An attempt was made to be realistic in the choice of dose-relevant habits.

For task 1, the calculated doses are doses to the red bone marrow (target organ for the leukemia risk). All exposure pathways considered for each age group were considered both for routine releases and for releases due to accidents and incidents. Doses are calculated starting from the earliest releases from the nuclear facilities (1966, starting date for releases from COGEMA La Hague reprocessing plants). Doses for other sources of exposure to ionizing radiation were calculated from 1954 (medical, natural, fallout from atmospheric testing of nuclear weapons and the Chernobyl accident). Doses to the fetal red bone marrow during pregnancy (*in utero* exposure) were considered solely for routine releases from the nuclear facilities (sensitivity analysis).

For task 2, the calculated doses are doses to the whole body (also called "effective doses") which are considered as being an indicator of health detriment particularly the risk of cancer to tissues and organs known to be sensitive to radiation. Effective doses are calculated only for routine releases from the nuclear facilities.

- The risk:

For task 1, it was necessary to calculate the risk of leukemia induced by exposure to ionizing radiation (radiation-induced risk). The estimate of this risk is based on a dose/effect relation without any threshold, in other words "a low dose" introduces a "low risk" and not a zero risk. The models used are internationally recognized.

The Group accepted this assumption without carrying out a critical analysis, although the range of doses for which it is used here (of the order of 0.1 to 0.001 mSv for nuclear facilities) is very far from the range in which this relation has actually been demonstrated[10] .
The radiation-induced risk of leukemia was estimated over the period for which epidemiological data are available (1978-1996).

[10] Application of the risk without the threshold model to environmental exposure cases is debatable. The data used to calibrate this model are taken from the epidemiological study of Hiroshima and Nagasaki survivors. Firstly, in this case, the dose was contracted within a small fraction of a second ("high dose rate"), and secondly, a statistically significant increase in the various observed radiation-induced cancers was only observed above a dose range of 50 to 200 millisieverts (mSv). No radiation-induced risk was demonstrated at doses below these ranges. However, the models used to estimate the risk due to in utero exposures are derived from epidemiological studies that demonstrated a radiation-induced risk of leukemia associated with fetal doses starting from 10 mSv.

3. RESULTS

- Task 1:

Estimates of cases of leukemia that could theoretically be assigned to the various sources of exposure to ionizing radiation in young individuals from 0 to 24 year old for the Beaumont-Hague Canton over the 1978-1996 period, are broken down as follows:

Nuclear facilities	0.0014	(routine releases = 0.0009*, accidental releases = 0.0005)
Natural sources	0.62	
Medical sources	0.20	
Others	0.01	(fallout from nuclear tests, Chernobyl accident)
Giving a total (rounded)	0.83 cases	over a 19-year period.

*The contribution of *in utero* exposure calculated only for routine releases from nuclear facilities is equal to 0.0003 cases, and is additional to this risk.

On the basis of the risk models used, the number of cases of leukemia that can be assigned to exposure to releases from the nuclear facilities for the "reconstructed cohort" of 6656 young individuals living in the Beaumont-Hague Canton is estimated at 0.0014 cases for the period from 1978 to 1996. The number of cases that can theoretically be assigned to the nuclear facilities thus represents about 0.2% of cases that can be assigned to all sources of exposure to ionizing radiation. Based on this estimate, the probability of occurrence of a radiation-induced case due to the nuclear facilities is of the order of 1 per thousand (apart from *in utero* exposure).

On the basis of the risk models used, the number of cases of leukemia that can be assigned to all exposure sources is 0.83, much of which is due to exposure to natural and medical sources (99%). It should be noted that the national population in general is exposed to these same sources.

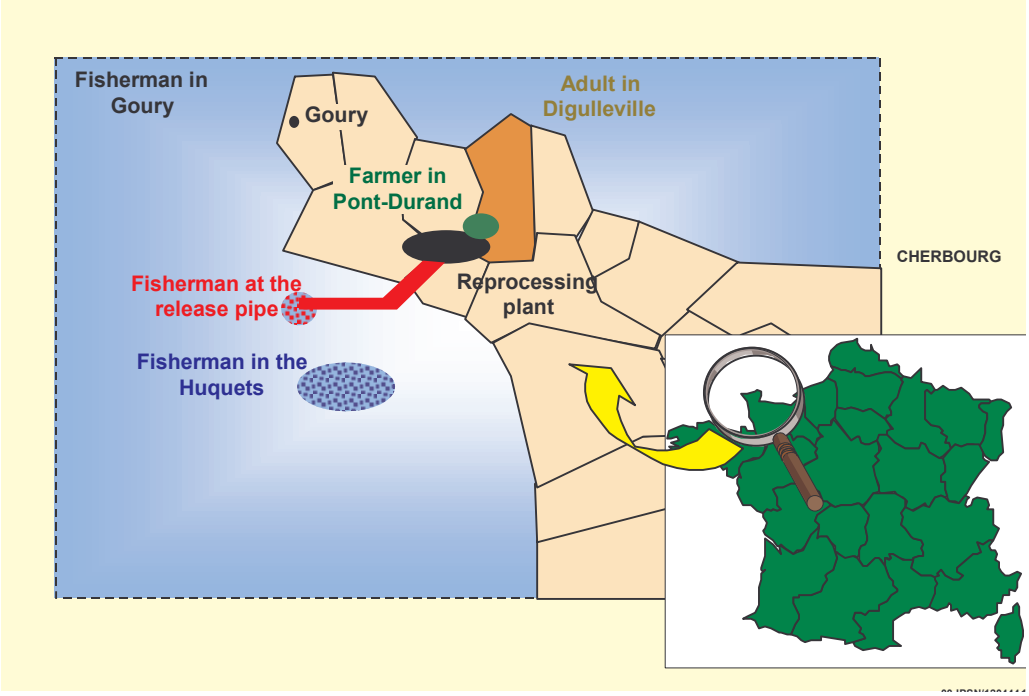
- Task 2:

The Nord-Cotentin Radioecology Group also studied about fifteen particular scenarios in which dose relevant habits were varied. The particular scenarios that give the highest effective doses (outside the near field) are compared with the critical groups used by COGEMA in its impact studies.

The years presented are those years that led to the highest impacts from the marine and terrestrial pathways (outside the near field):

	Individual dose (mSv/year)	
	1985	1996
COGEMA "critical groups"		
Fishermen of Goury	0.041	0.005
Inhabitants of Digulleville	0.014	0.006
Particular scenarios of the Radioecology Group		
Fishermen of Huquets	0.226	0.026
Farmers of Pont-Durand	0.053	0.059

The following figure illustrate the geographical localization of these specific groups of population.



The corresponding impact should be compared with the limit for the public of 1 mSv/year (in fact with a fraction of this to take into account the possible contributions from other industrial sources) and, for information, with the natural radioactivity of 2.4 mSv/year.

Furthermore, the results of task 2 should be compared with effective dose levels (up to a few hundred microsieverts) received by even smaller particular subgroups in some situations (scenarios).

4. DISCUSSION

- Task 1:

Epidemiological studies have shown that the total number of leukemia expected in the Beaumont-Hague Canton from 1978 to 1996 would be of the order of 2 if the occurrence rate of this disease was the same as the value observed nationally. Four cases were observed. However, this difference is not statistically significant[11] .

The reconstruction of exposures from the nuclear facilities by the Nord-Cotentin Radioecology Group, gave a calculated number of 0.0014 cases of radiation-induced leukemia during the 1978-1996 period. This number is low compared with the incidence of leukemia observed by recent epidemiological studies.

[11] See statistical distributions for observable cases and radiation-induced cases in the attached documents (figure 1 and figure 2).

However, this result is the best estimate and it should be emphasized that at this stage the margins of uncertainty have not been quantified. In view of this, some members of the Group did not feel that at this stage they could conclude that it is unlikely that the releases from nuclear facilities contribute to the incidence of leukemia observed in the Canton of Beaumont-Hague.

The results obtained can be compared with those from similar studies carried out in the United Kingdom around the Dounreay and Sellafield reprocessing plants. The conclusion of the British studies was that the observed number of leukemia cannot be explained by releases from the nuclear facilities.

Furthermore, scenarios were examined in order to determine the effect of habits leading to higher individual doses. The habits considered are described in the case control study of D. Pobel and J.F. Viel published in 1997 (time spent on the beach, consumption of local fish, shellfish and crustaceans). Even prolonged presence on the beaches (1h20 per day) did not significantly increase the radiation-induced risk from all sources. The risk to an individual who consumes a large quantity of local seafood (500 g per day) increases by a factor of about 2, but this increase is largely related to the ingestion of radionuclides of natural origin in seafood.

- Task 2:

The results obtained for the particular scenarios of fishermen of Huquets and farmers of Pont-Durand give values 5 to 7 times higher than the values obtained for the critical groups selected by COGEMA in its estimates for regulatory purposes of the impact of its releases, on the basis of the same methodology as the Nord-Cotentin Group. This is due to differences in choices regarding habits. These results may be considered as a sensitivity study of these factors.

5. RECOMMENDATIONS

- Exposure sources other than nuclear facilities

The retrospective evaluation of exposures due to natural and medical sources shows that they contribute to the majority of the estimated dose to the red bone marrow for the cohort, and radiation-induced risks of leukemia. More detailed retrospective studies should be carried out locally of the exposure of young individuals and pregnant women during medical examinations.

It would also be important to widen the scope of the expertise to include other pollution sources (chemical pollution, etc.) and their synergy (if any) with ionizing radiation effects.

- Uncertainty study

Uncertainty studies on the effect of the variability of all data used, and particularly the variability of measurements, were carried out for the marine environment, but were not used in the dose calculation. It should be emphasized that an overall uncertainty study was not carried out in similar work done in the United Kingdom. This type of study could be done later.

- Monitoring

One of the important questions that arises from the Group's work relates to the objectives of monitoring and measurements in the environment by the various organizations involved. In particular, it is important to distinguish between routine measurements made to ensure that

the installation is functioning correctly (alert nature) and that authorized release limits are respected, and measurements made to estimate the dose received by groups of population. There is no doubt that both types of measurements are justified.

The Group made extensive use of the results of environment monitoring data, but also observed the need for more specific measurements for some radionuclides and lower detection limits in order to better evaluate the exposure of the population in the future.

Similarly, a more complete list of radionuclide measurements released by the operators and improved precision of their measurements, would help to provide a better estimation of the source-term of releases used in models for the transfer of radionuclides through the environment.

Finally, a framework needs to be defined for the cooperation between the various laboratories that contributed to building up the measurements in the environment database so that this database may continue to be updated and widened to include indicators that were not included at the present time.

- Multidisciplinary approach

The work is based on a multidisciplinary approach which was carried out with the active participation of experts from non governemental laboratories and foreign experts. The Nord-Cotentin Radioecology Group has benefited from unrestricted access to COGEMA files (COGEMA is the main operator affected by the study) and by its strong involvement in building up the data (source-term and measurements in the environment). Experts in the non governemental laboratories who made an important contribution to the Group's work also provided the results of their measurements in the environment and a critical examination of data which was possible because of their knowledge of the area. This integrating approach goes far beyond an information or communication action. It is a cooperative effort with the technical support of the IPSN. The multidisciplinary approach consisted of a critical analysis of the entire file and a better understanding of the behavioral characteristics of the groups of population considered. Foreign organizations formed an integral part of this expertise, they provided their personal scientific knowledge and also passed on some of the Group's questions to their national expert organizations.

Considering the reactions of these various players, it will be necessary to consider later the contribution of this type of expertise to the process for analyzing impact files in other situations.

- Document distribution

Reports written by the Nord-Cotentin Radioecology Group will be available for international authorities for their reactions, and all comments received will be published within a period of 6 months to one year.

6. COMMENTS BY MEMBERS OF THE GROUP[12]

All members of the Group approved the contents of the reports, except CRII-RAD experts.

Some members of the Group wrote comments that they would like to be included in the summary / conclusions text (Monique Sené) or as an Appendix to the final report (Pierre Barbey and the foreign experts).

[12] The General Appendices contain complete texts of comments and reservations made by some members of the Group.

Monique SENÉ (GSIEN)[13]:

The broad composition of the Nord-Cotentin Radioecology Group has the advantage of enriching the debates. However, in order to increase efficiency, experts from non governemental laboratories must have the human and financial resources necessary to carry out this type of task (similar to those of the industry and the inspection authorities).

Until now, measurements were mainly made to check that facilities were operating correctly, rather than to monitor the health of populations. Under these conditions, the uncertainties make it impossible to conclude that the releases are innocuous, even though the observed number of leukemia cannot be explained by the calculated exposures based on the releases which are themselves calculated. On the other hand, these uncertainties make it necessary to exercise greater caution, to limit releases, and continue further studies.

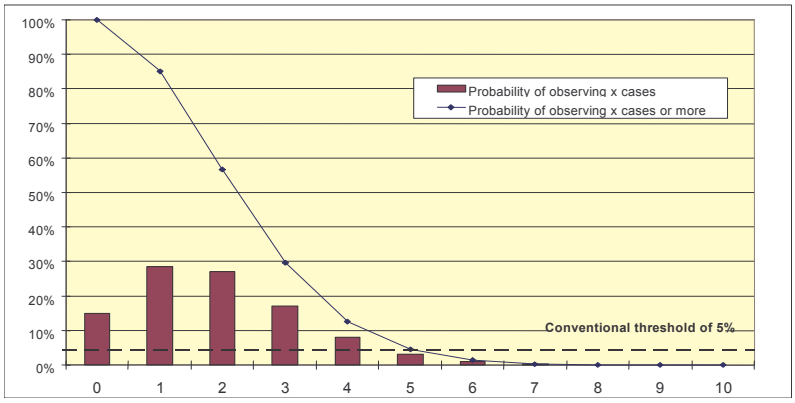
Irradiations from medical sources must also be minimized, and their impacts must be better analyzed.

There is now an inventory (and a register of cancers) that should be used and permanently established to enable genuine survey of populations and workers.

[13] See General Appendices for the meaning of the acronyms and abreviations (Appendix 3)

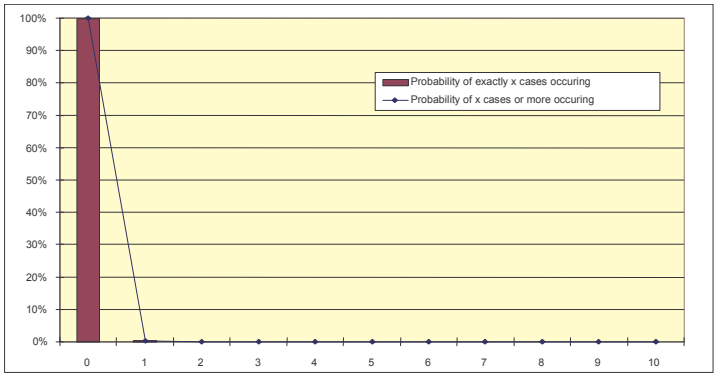
EXECUTIVE SUMMARY APPENDIX

Figure 1, Table I : **Probability of observing a number of cases x according to a Poisson distribution with mean 1.9**



Number of cases x	Probability of observing x cases exactly	Probability of observing x cases or more
0	$9{,}99\ 10^{-01}$	1
1	$1{,}40\ 10^{-03}$	$1{,}40\ 10^{-03}$
2	$9{,}79\ 10^{-07}$	$9{,}79\ 10^{-07}$
3	$4{,}57\ 10^{-10}$	$4{,}57\ 10^{-10}$
4	$1{,}60\ 10^{-13}$	$1{,}60\ 10^{-13}$
5	$4{,}48\ 10^{-17}$	$4{,}48\ 10^{-17}$

Figure 2, Table II : **Probability of number of cases x occuring following a Poisson distribution with mean 0.0014**



Number of cases x	Probability of exactly x cases occuring	Probability of x cases or more occuring
0	14,957%	1
1	28,418%	85,043%
2	26,997%	56,625%
3	17,098%	29,628%
4	8,122%	12,529%
5	3,086%	4,408%
6	0,977%	1,321%
7	0,265%	0,344%
8	0,063%	0,079%
9	0,013%	0,016%
10	0,003%	0,003%

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INTRODUCTION

1. BACKGROUND TO THE GROUP'S CREATION

In January 1997, Professor J.F Viel's team from the University of Besançon published in the *British Medical Journal* the results of an epidemiological study (« case control ») carried out in the Nord-Cotentin where are located the COGEMA La Hague reprocessing plants. This study demonstrated the association between some dose-relevant habits (time spent on local beaches, consumption of seafood, living in a granite house) and the development of cases of leukemia in individuals less than 25 year old within a radius of 35 km around COGEMA La Hague reprocessing plants. The authors suggested that there was a causal relation between this observation and exposure to radiation due to releases from the local nuclear facilities. The study was carried out following publications by the same team, particularly in 1995, about the incidence of leukemia in the same population category in the region, suggesting an excess number of cases of leukemia within the 10 km area (canton of Beaumont-Hague) at the limit of the statistical significance (4 cases observed between 1978 and 1992, compared with 1.4 cases expected).

In order to contribute to the debate that followed the conclusions of this work, Mrs. Corinne Lepage, Minister of the Environment and Mr. Hervé Gaymard, Secretary of State for Health and Health Insurance, set up a Scientific Committee in the month of February 1997 presided over by Professor Charles Souleau, dean of the Chatenay-Malabry Faculty of Pharmacy, to propose a «new epidemiological study in the Nord-Cotentin». Very soon after the Committee started its work, its members and its President found it essential that the field of its initial task should be significantly widened to include a retrospective scientific task to «reconstruct and evaluate radiation doses» that could have been received by populations of the Nord-Cotentin due to natural and medical sources, fallout from atmospheric nuclear tests and the Chernobyl accident, and from nuclear facilities.

The Committee President presented a first intermediate report to Mrs. Dominique Voynet, the new Minister of the Environment, and Internal development, and Mr. Bernard Kouchner, Secretary of State for Health, in July 1997.

Concerning the epidemiological aspect, one of the Committee's conclusions was that the incidence study on individuals less than 25 year old in the canton of Beaumont-Hague should be completed by data for recent years (1993 - 1996) not included in previous work done by J.F Viel. Recommendations were also made about the need to improve the epidemiological surveillance system around nuclear sites in France.

For the radiological aspect, the work carried out by a Group set up by the Committee ("Nord-Cotentin Radioecology Group"), consisting mainly of inspectors, governemental experts, operators, confirmed that measurements made in the environment by the different players were consistent, and produced an evaluation of doses to groups of population likely to be the most highly exposed, *based on operators' models*. Therefore, the Group wanted to continue its own work so that it would be in a position to confirm this evaluation.

Since the President of the Scientific Committee did not want to continue his task, in August 1997 the Minister of the Environment and Internal Development and the Secretary of State for Health decided to appoint Professor Alfred Spira to continue the epidemiological work, and Mrs. Sugier to continue the work being done by the "Nord-Cotentin Radioecology Group". A complementary mission letter was sent to Mrs. Sugier in November 1997.

Professor Spira handed over a report entitled «Ionizing radiation and health: measurements of exposure to radioactivity and surveillance of effects on health»[14] to the Ministers in July 1998, in which he presented the results of his work and proposed actions in the Nord-

[14] French documentation – Alfred Spira, Odile Bouton (see page 7)

Cotentin and for national health surveillance. He is currently continuing his work along the lines defined in his report.

The Nord-Cotentin Radioecology Group submitted two progress reports during 1997 and 1998, a methodological note in July 1998[15], and concluded its work in July 1999.

2. GROUP TASKS AND COMPOSITION

In accordance with the mission letter on August 25, 1997 (see General appendices), the Group's objectives were to:

- draw up an inventory of liquid and gaseous radioactive releases from nuclear facilities in the Nord-Cotentin,
- make a conclusion about surveillance of radioactivity in the various environmental media and products in the food chain,
- make a conclusion about doses delivered to the exposed populations, including doses due to natural and medical exposure,
- estimate the risk of leukemia associated with doses received.

In order to provide additional information to epidemiological studies carried out or being carried out in the Nord-Cotentin, the Group concentrated its work on the population of one canton (Beaumont-Hague) over a determined period equivalent to the period in J-F. Viel's study (1978 - 1992) and Dr Guizard's study (1993 - 1996).

The second mission letter dated November 27, 1997 (see General Appendices) specified that the Group's work should «be available in time to be considered in procedures to revise texts governing the operation of COGEMA La Hague reprocessing plants». The objective is to adopt a regulatory approach that is limited to COGEMA La Hague reprocessing plants. This approach, which is in line with the objective of protecting the entire population, makes it necessary to verify that groups *likely to be most highly exposed* only receive low doses. These doses are compared with limits fixed for an individual who may be exposed to several exposure sources (not including medical and natural exposure). Therefore, these groups and their dose-relevant habits need to be identified, considering their geographic situation with respect to releases.

Exposure estimates carried out for task 1 (dosimetric reconstruction and evaluation of leukemia risks) and for task 2 (doses received by the groups of population likely to be the most highly exposed to releases from COGEMA La Hague reprocessing plants) must be defined realistically wherever possible, despite the difficulties in practice in the case of a retrospective study. This approach is different from conservative *a priori* estimates made in the past.

The work carried out by the Nord-Cotentin Radioecology Group has a number of unique features among which its composition and its attempt to be as exhaustive as possible in its systematic critical analysis.

The composition of the Group (see General Appendices) was firstly limited to a few of the main participants concerned, and was subsequently broadened with the agreement of Ministers; thus it includes experts from a wide variety of organizations including governemental institutions of expertise and control bodies (OPRI, CNRS, IPSN), operators

[15] Progress report No. 1 (November 1997) No. 2 (May 1998), Methodological note (July 1998)

(EDF, COGEMA, ANDRA, French Navy), experts from the Special information Commission with the La Hague Plant and the experts from non governemental laboratories (ACRO, GSIEN, CRII-RAD) and experts from foreign institutes (British NRPB, German BfS, Swiss OFSP). Therefore, this is a multi-disciplinary expertise, but the large unbalance in the means (human, equipment and evaluation tools) available to the different players should not be concealed.

Specialized Groups were formed to ensure that experts participate to the detailed critical analysis work wherever possible, and were assigned objectives of dealing with different aspects of the Plenary Group's tasks. Thus, a total of about 50 experts worked on the project within these different Groups:

- the first Group critically examined releases declared by operators of Nord-Cotentin nuclear facilities and reconstructed missing data when necessary;

- the second Group collected and interpreted measurements made in the environment by the various players (institutional and non-institutional) since the facilities were put into service;

- the third Group compared models with each other and compared model predictions with measurements made in the environment;

- the fourth Group identified epidemiologically relevant cohorts in the Nord-Cotentin (task 1), and critical groups whose dose-relevant habits made them more highly exposed to local nuclear industrial sources (task 2), in order to evaluate the average level of exposures to which they were or are exposed; it also evaluated the average level of exposures received due to other radiation sources (natural, medical, fallout from atmospheric nuclear tests and the Chernobyl accident); and finally it estimated the risk corresponding to the sum of all considered exposures (task 1).

Parts A, B, C and D of this volume present the general conclusions of the work done by the Specialized Working Groups for which the objectives were described above; Part E presents the main results obtained making a distinction between tasks 1 and 2.

PART A

INVENTORY OF RADIOACTIVE RELEASES FROM NUCLEAR FACILITIES

1. OBJECTIVES

Operators measure activities contained in their liquid and gaseous releases and declare to the regulatory authorities the results of global alpha and beta activity and radionuclide activity measurements for which an individual measurement is necessary. On this basis, they started by supplying detailed tables to the Group presenting measured releases from their facilities since they were first put into service.

The facilities considered are COGEMA La Hague reprocessing plants, ANDRA's shallow land disposal center, EDF's nuclear power station at Flamanville and French navy facilities in Cherbourg.

Historically, measurement practices, the values of detection limits and the nature of identified radionuclides have changed as well as processing methods for liquid and gaseous effluents and retention processes for some radionuclides.

The objective of the Working Group N° 1 (called "GT1" throughout this text) consisted of analyzing operators' results in cooperation with operators, in order to validate, correct or reconstruct them. The following must be taken into account:

- controlled releases during normal operation, for which periodic measurements and statements are produced;
- releases due to an incident or accident event that could have caused pollution in the immediate environment.

The history of the facilities considered is summarized in tables 1, 2, 3.

The critical analysis of declared releases applies to the following points:

- the most exhaustive or realistic possible nature of the inventory of the "source term" forming the release;
- consistency, firstly between the activity existing in or passing through the installation (and whenever possible quantified by calculation programs) and secondly the activity in released effluents measured by operators at the release point and declared within the framework of regulatory release procedures;
- reconstruction of radionuclide releases present in effluents, not measured in the past or now, either because the corresponding releases were not considered as being significant, or due to limits to analytic techniques.

Essentially, the steps in the critical analysis described above may be applied satisfactorily for COGEMA La Hague reprocessing plants for which where known the annually reprocessed tonnage and the characteristics of spent fuels (nature, burn up and average cooling time) supplied by the operator. These data were input into existing calculation programs to determine annual quantities of the activity of the main radionuclides present in spent fuels at the time of reprocessing in the different plants (UP2 400, UP3, UP2 800). It must be stressed that for certain radionuclides which are not subject to measurement, release estimates made on this basis are not levels of release which have been demonstrated but rather an expert assessment adopted by the Group.

However, for the two reactors at EDF's Flamanville power station and for nuclear reactors in general, it is very difficult if not illusory to fix *a priori* the nature and activity of radionuclides that could be released in liquid and gaseous effluents.
The characteristics of radioactive releases depend on many parameters (nature of structural materials and corrosion phenomena through which activation products can pass into the primary circuit, proportion of loss of tightness defects in fuel assemblies during residence in the reactor, etc.).
Furthermore, many changes and improvements to purification processing and management of liquid effluents before their release have been made since the reactors were commissioned.

Changes to the source term since the reactor was commissioned are essentially related to:

- operating experience, that resulted in removing or adding some radionuclides;
- better management of radioactive effluents that has resulted in a drop in the activity of releases. This drop is variable depending on the radionuclides, and has the consequence of demonstrating some radionuclides with low activity.

Finally, at ANDRA's Manche shallow land disposal center, there is no simple relation between the radiological inventory of disposed waste and the activities of radionuclides measured in the environment (particularly in the Grand Bel and Sainte-Hélène rivers). In order to determine this relation, it would be necessary to know the variation of the state of packages and characteristics concerning the kinetics of radioactive substances during their transport through the subsoil (related to their solubility). The proposed solution consisted of restricting the study to the main radionuclides likely to be encountered taking into account the inventory and information supplied by the ANDRA, and measurements made in the environment by the different participants.

2. COGEMA LA HAGUE REPROCESSING PLANTS

Operators' declarations are based on measurements made on released effluents. In order to be identified, the quantity of a radionuclide present in the releases must be greater than the detection limit for the available measurement methods. The operator provided the Group with activities measured in liquid and gaseous releases, including global measurements (total alpha and total beta) that can be used for quantitative consistency checks.
The method used is described below.

2.1 Radionuclides considered

Remember that the irradiated materials contain three types of radioactive substances:

- fission products,
- uranium and plutonium isotopes and other transuranium isotopes,
- activation products.

The qualitative and quantitative spectrum for the first two families is calculated by means of appropriate programs taking into account reactor operating methods, the energy output (burn up) and the fuel type (UNGG, UOX).

Knowledge of the activity of activation products, the third family of radionuclides present in the fuel material, requires knowledge about the content of impurities in the various stable elements in its composition (non irradiated fuel). For "oxide" fuels, the values of these impurity contents are described in manufacturers' technical specifications. Since we only had partial information about UOX[16] fuels made in France (reprocessed in the UP2-800 plant) GT1 assumed that the real rates of impurities were equal to 50% of the limiting contents fixed in the technical specifications. However, as explained later, an exception was made for chlorine 36 due to its possible dosimetric impact in the case of gaseous releases; measurements made in the environment were used to estimate the maximum released activity.

For UNGG (Natural Uranium-Graphite-Gas) fuels, the nature and content of impurities present in metal uranium are not known. Consequently, activation products for this type of fuels have not been evaluated.

- *For fission products, uranium and transuranium isotopes*, we have taken into account that all products formed in the fuels when their activity, after three years of cooling, was equal to at least 37 MBq per tonne of initial metal uranium (1 $mCi.t^{-1}$ of Uranium metal).
  Released activities (or an overestimate value of these activities) were evaluated starting from this selection criterion, even in the case in which the radionuclides considered cannot be measured due to their low activity in the releases because it is below the detection limit of measurement instruments.
  Complete lists of products that could be present in effluents from the COGEMA La Hague reprocessing plants are listed in tables 4 and 5. This demonstrates radionuclides measured by COGEMA and radionuclides added by the Group.

- *For activation products*, we only considered impurities present in the non irradiated oxide fuel, usually identified by experts and corresponding to radionuclides with a life greater than two years, allowing for average cooling times of "light water" fuels before reprocessing of between 5 and 8 years.
  "Target isotopes" and the radionuclides formed are shown in table 6.

- *In addition to the 36 radionuclides identified by COGEMA and appearing in the summary tables of liquid and gaseous releases, 39 radionuclides were specifically studied in order to complete the releases statement.*

2.2. Methodology

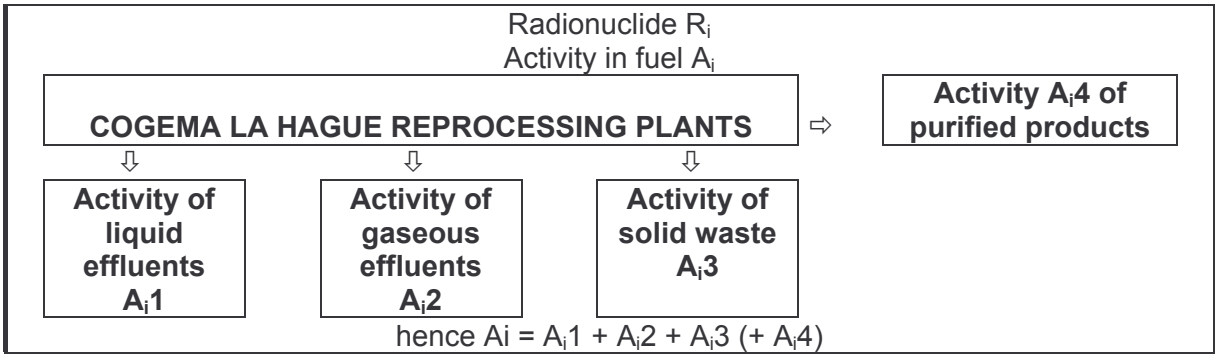
Operation of the COGEMA La Hague reprocessing plants can be represented as follows:

- an "input" (radionuclide activity present in the fuel at the time of reprocessing),

- three "outputs" in the effluents and releases (liquid effluents, gaseous effluents and solid waste for the radionuclide considered),

- an "output" to purified products.

[16] Fuels composed of uranium oxide enriched in ^{235}U



A "transfer function" can be established for each radionuclide R_i, between the "input" and each "output" defined as follows:

$$Fr_i = \frac{\textit{Measured activity in output flows}}{\textit{Calculated activity in the fuel}} \quad (1)$$

where:

$$Fr_i1 + Fr_i2 + Fr_i3 (+ Fr_i4) = \frac{Ai1}{Ai} + \frac{Ai2}{Ai} + \frac{Ai3}{Ai} + \left(\frac{Ai4}{Ai}\right) \quad (2)$$

This sum is approximately equal to 1[17].

The method selected to make a critical analysis of measurements made by the operator of activities released consisted of evaluating the consistency between the variation with time of calculated activities in fuels and the variation with time of measured activities released in effluents and the corresponding waste.

The activity of the various radionuclides present at the plant input at the time of reprocessing the spent fuels was evaluated making use of knowledge of quantities and characteristics of reprocessed UOX[16] and UNGG type fuels (initial content of uranium 235, irradiation rate, cooling time).

This was done using the most recent versions of existing programs (like CESAR 4.2[18]), referring to irradiation conditions in reactors that are used to define the list and activity of the various radionuclides present in the fuels at the time of their reprocessing, taking into account their radioactive decay throughout the selected cooling duration.

As indicated above, the three families of radionuclides considered are fission products, actinides (uranium and transuranium elements) and activation products, the activation products depending directly on knowledge of the nature and the quantity of impurities present in the non irradiated fuel and which can therefore differ according to the manufacturer (for foreign fuels).

[17] As a first approximation for continuous operation of the plant and negligible radioactive decay during the "product" transit time in the plant.

[18] CESAR version 4 validation file-Note CEA/DER/SPRC/LEDC 97/4028 DATE 13/02/97.

It is worth emphasizing the limits of this method of reconstituting releases. In particular, some effluent processing operations were applied after dissolution of the corresponding fuel. This resulted in a time lag between the flow of activity entering into the plant and the corresponding flow of released activities, which was ignored in the method used.

2.3. Application of the methodology

The following comments and examples illustrate the use of this function as an element for evaluating released activities:

- In the simple case of krypton 85, (figures 1a and 1b) purified products like liquid effluents and solid wastes contain almost none of this rare gas and the entire krypton 85 activity present in the fuel is evacuated with the gaseous effluents. The only transfer function to be considered relates to the source term and the gaseous effluents. It must be constant and equal to one.

  A comparison between calculated values in the fuels and measured values in gaseous effluents shows that there are differences. It appears preferable to use the value of the released activity obtained using the calculation program giving quantities of krypton 85 contained in the fuels during reprocessing, rather than measurement results which often appear less than the source term (recognized difficulties in making a representative measurement due to the air volumes involved, and in making a precise evaluation of the accumulated releases due to fluctuation of gaseous releases and concentrations of krypton 85 in time).

- In other cases, it is not as easy to evaluate the value of the transfer function. In these cases, the consistency of the variation of calculated activities in releases and the variations of measured activities were used to evaluate the validity of the various results.
  Thus in the case of cesium 137 in liquid effluents (figures 2a to 2d) , the measurement results are considered as being valid due to the observed consistency between the various results obtained in the long term (the total activity in reprocessed fuels entering the plant increases with the increase of the processing capacity of the plant); releases have been reducing regularly since 1990 due to improved effluent processing (except for the early years of operation); the same is true for the transfer function.

- An additional verification is applied when several radioactive isotopes of the same element are present in the fuel. This is the case particularly for cesium 134 and 137 isotopes. Since the physicochemical behavior of two isotopes of the same element are strictly identical, a significant difference observed between their transfer functions can only be due to an error in the evaluation of the source or of the evacuated activity (provided, however that the transit times between dissolution and releases are low compared with the shortest half life of the radionuclides considered). Thus, releases of some radionuclides with a short half life such as strontium 89 (figures 3a to 3e) and antimony 124 were recalculated.

- If data about liquid or gaseous releases are partially or completely missing, a search can be made in the periodic table of the elements for an element with a similar chemical behavior. In the absence of other means, the transfer function for this similar element will be used, although the behavior of the two elements is not necessarily identical during all steps of the process.
  Consider the following examples for calculating activities in liquid and gaseous effluents; chlorine 36 (figure 5), using the transfer function for iodine 129 (halogens: figures 4a and 4b); calcium 41, using the transfer function for strontium 90.

- Note two properties of transfer functions (see equations (1) and (2), previous page), assuming continuous operation of the plant:

® the transfer function is always less than or equal to 1 (since the released activity cannot be greater than the activity present in the fuel) ;

® the sum of transfer functions (F gas, F liquid and F solid, plus the transfer function corresponding to purified products) is equal to one. If plants do not retain a significant fraction of the activity present in the reprocessed fuels, this activity must be located in liquid effluents, gaseous effluents, and in solid waste and in purified products. However, this characteristic was not used for the calculation.

- Finally, the sum of the activities of the various radionuclides present in the releases must be consistent with the total α and β activity measurements.

2.4. Acquired results

- Liquid releases from COGEMA La Hague reprocessing plants

We will review the various radionuclides measured by COGEMA, with reference to tables 7.1 and 7.2. Note that some columns are only partially filled in, which means that releases corresponding to the radionuclides considered were not quantified, particularly during the early years of operation of the plant, and we were obliged to partially reconstruct the released activity. These radionuclides correspond either to elements for which the activity (or concentration) is less than a radiochemical (or chemical) detection limit, or which cannot be measured using available techniques.
Radionuclide releases not included in tables 7.1 and 7.2 are also reconstructed.

Tables 8-1 to 8-5 contain results validated by GT1.

We will not describe the methods of reconstituting the activities of the various radionuclides.

The following various cases may be considered schematically:

- radionuclides that were measured from the beginning, and for which measured values have been used. These radionuclides are:

zinc 65, the strontium-yttrium 90 pair, the ruthenium-rodium 106 pair, antimony 125, cesium 134 and 137, the cerium-praseodymium 144 pair, and plutonium 239 + 240.

- radionuclides for which measurements are not available for all years. Due to the lack of measurements, the values of releases were reconstructed using the average weighted value, or the value corresponding to the first year of measurement, of the transfer function for a period for which measurements are available. These radionuclides are:

tritium, manganese 54, cobalt 57, 58 and 60 isotopes, the zirconium-niobium 95 pair, technetium 99, silver 110m, europium 154.

- radionuclides for which measurements are only available for a few years, and for which releases were reconstructed using the transfer function for a measured isotope or chemical analog. These radionuclides are:

antimony 124, americium 241, curium 242, curium 244.

- radionuclides for which measurements are available for a few years, but it was still preferred to recalculate releases using the transfer function for another measured isotope. These are:

strontium 89, the ruthenium-rhodium 103 pair, europium 155, plutonium 238, plutonium 241.

- unmeasured radionuclides for which the activity in the releases was reconstructed using the transfer function for another isotope or a measured chemical analog. These radionuclides are:

beryllium 10, iron 55, nickel 59 and 63 isotopes, rubidium 87, yttrium 91, zirconium 93, niobium 94, molybdenum 93, palladium 107, cadmium 113m, tin 121, 121m and 126 isotopes, tellurium 127 and 127m isotopes, cesium 135, prometheum 147, samarium 151, europium 152, plutonium 236 and 242 isotopes, neptunium 237, americium 242, 242m and 243 isotopes, curium 243, 245 and 246 isotopes, and uranium 232, 233, 234, 235, 236 and 238 isotopes (calculated from the release of total uranium and the isotopic composition of the fuel).

- activation products of impurities in the fuel, for which activities in releases were calculated using a content in the fuel equal to one half of the commercial specification, and using the transfer function for a chemical analog (based on knowledge of its chemical behavior in the process, in the case of carbon 14). These radionuclides are:

carbon 14, chlorine 36, calcium 41.

Consistency check between the measured and calculated activity in liquid releases, and global alpha and beta measurements

In addition to alpha and gamma spectrometric analyses, COGEMA makes an alpha and beta count on the dry residue obtained after evaporation, from liquid samples taken before release.

The operator obtains two results called “global alpha” and “global beta”, taking into account the alpha and beta count efficiency of the measurement system. These two results are obtained assuming that all measured emergent alpha particles originate from plutonium 239+240 isotopes, and that all measured emergent beta particles originate from strontium-yttrium 90 alone.

These two items of data will be very useful for making a global evaluation of the relevance of the measurements and the various reconstructions made. By calculating the contribution of each radionuclide to the measurement made by the detector, in other words taking into account the real measurement efficiency of each, we obtain a “total calculated alpha and beta” by summation that we can compare with the “global alpha” and “ global beta” values.

Alpha activity and "global alpha" measurements

Figures 6a and 6b illustrate the contributions of reconstructed activities to measurements made by the operator. Thus, the sum of alpha emitter activities measured from 1966 to 1996 is 5.3 TBq, whereas the sum of measured or calculated alpha emitter activities reconstructed by GT1 is 10.4 TBq, which is almost double the former value. Figure 6c shows that the difference is particularly significant from 1976 (the year in which the HAO workshop was commissioned and the beginning of reprocessing of light water oxide fuels) to 1986.
This can be explained by the activity of transuranium alpha emitters such as plutonium 238 and 241 isotopes, americium 241 and curium 242 and 244 isotopes, gradually starting from 1986, the activity of these radionuclides in the liquid releases being negligible for the 1966-1975 period during which UNGG fuels were reprocessed.
Figures 6d and 6e show that the proportion of isotopes in the plutonium family is preponderant in the alpha activity of liquid effluents, throughout the period considered.
The total number of “expected” alpha particles calculated starting from the measured or reconstructed activity of each of the alpha emitter radionuclides considered, is compared (figure 6c) with the “global alpha” measurement (sum of the results of measurements made on dry residues of evaporated liquid samples).
Very good consistency is observed between these two values, which confirms the validity of the method used.
The sum of activities released between 1966 and 1996, minus the results of “global alpha” measurements, is practically equal to the value obtained from reconstructed values of activities (difference equal to 0.7%)

Beta activity and «global beta» measurements

Although all "alpha" particles emitted by radionuclides are measured in practice with the same efficiency (the "global alpha" measurement result is then directly proportional to the sum of alpha activities), the same is not true for "beta" particles.
The beta particles detection efficiency varies by a factor of more than 2 depending on the maximum beta energy of the radionuclides considered. Therefore there is no simple relation between the calculated sum of beta activities and the direct measurement of emitted particles (result called "global beta").

As a result of this situation, two types of evaluation are made:

© the sum of activities measured by the operator are compared with the sum of activities selected by GT1 - figure 7a

© the result of the global beta measurement supplied by the operator is compared with the "expected beta" number - figure 7b

In the first case (figure 7a) the sum of the individual activities of beta emitters (except for tritium), appearing in tables 7.1 and 7.2 of COGEMA measurements is compared with the sum of beta emitters (apart from tritium) in reconstructed tables 8.1 to 8.5. The curves are very similar since the activity of liquid releases is very largely dominated by about ten radionuclides measured since the plants were commissioned.

In the second case (figure 7b) there is very good agreement between the two curves for the 1966 - 71 and 1985 - 96 periods. But between 1972 and 1984, the reconstructed activity is still less than the "global beta" measurements by an average of 17.6%. However, there is good consistency between these measurement data and the calculation results.

Figure 7c illustrates the clear-cut predominance of ruthenium-rhodium 106 in liquid releases up to 1990.

- Gaseous releases from the COGEMA La Hague reprocessing plants

Although the methodology selected for reconstruction of the activities of radionuclides present in gaseous releases from the stack in the UP3 and UP2-800 plants is identical in principle to the methodology described above for liquid releases, however the number of radionuclides concerned is significantly lower.
Secondly, the possibility of validating, correcting or reconstituting radionuclide releases starting from existing measurements made by COGEMA, by setting up analogies between radionuclides with similar physicochemical behavior is less useful for the reasons described below.

Firstly, a distinction has to be made between two quite different sources of radionuclides released in gaseous effluents, namely:

- radionuclides formed in the reactor (by fission or by activation) and present in the fuel at the time of its reprocessing, and the quantities of which may be evaluated starting from fuel characteristics using “conventional” neutron calculation programs (CESAR program - version 4.2 in this case),

- volatile radionuclides generated inside the plant during reprocessing operations. These are fission products formed by the spontaneous fission of transuranium elements (mainly curium 244 for oxide fuels) during storage of concentrated solutions of fission products before vitrification. This phenomenon explains the presence of volatile radionuclides with short lives such as iodine 131 and 133 isotopes, selenium 75 and tellurium 125 m. However, we do not have an evaluation of the quantities formed, due to the lack of precise knowledge of stored quantities of curium 244 and spontaneous fission efficiency for the various radionuclides.

Another consideration is the various physical forms of radionuclides in what are called “gaseous releases”.

- **In the gaseous state**, there are elements for which the chemical form is volatile but stable at ambient temperatures. These are tritium, carbon 14, rare gases and halogens.

  Tritium is present mostly (more than 2/3) in the form of tritiated hydrogen, the remainder being in the form of tritium water vapor. But the total quantity thus released through the stack is less than 1% of the total quantity formed in the reactor.

  Almost all carbon 14 released through the stack is in the form of CO_2. The fraction thus released compared with the total quantity of carbon 14 present in the fuel depends on the process scheme and operating conditions in the plant (particularly the dissolution operation). Operating experience in recent years only (starting from 1990) for which measurements of atmospheric releases of carbon 14 are available, was used to estimate this fraction as being approximately 2/3 of the total activity present in the fuel, the remainder being released into the sea in liquid effluents.

  Among rare gases, only krypton 85 has a sufficiently long decay period to be present in a significant quantity in gaseous releases ($T_{1/2}$ = 10.8 years). All krypton 85 present in the fuel escapes in gaseous form.

  Halogens present in the stack include iodine 129, a fission product with a very long half life ($T_{1/2} = 1.6 \times 10^7$ years), iodine 131 and 133 isotopes with a very much shorter half life ($T_{1/2}$ of 8.05 days and 20.8 hours respectively) and chlorine 36 ($T_{1/2} = 3.01 \times 10^5$ years), formed by activation of chlorine 35 present in the form of impurities in non irradiated fuel. These two elements are released in elementary form (I_2, Cl_2).

- **In non-volatile form at ambient temperature**, there are also traces of radionuclides that are released during some operations carried out under special conditions, particularly operations carried out at high temperatures such as concentration and vitrification of fission products, intercycle evaporation and final production of plutonium oxide in the calcination furnace. These products change back to the solid state during the transfer of gases in processing circuits, usually in the form of fine oxide particles called solid aerosols. These phenomena are particularly applicable to ruthenium which, in an oxidizing environment, is released in the form of its volatile tetraoxide, $Ru0_4$. This tetraoxide decomposes as it comes into contact with release circuits into $Ru0_2$ in the form of very fine solid particles.

- **Finally, in the form of solid aerosols**, there are other products in a very divided state, in powder form in some operations (like the production of PuO_2 by calcination of plutonium oxalate). A very small quantity of these products corresponding to the finest size grading fraction, may be entrained as far as the outlet from the stack, depending on the efficiency of purification systems and particularly the stopping capacity of filtration devices (very high efficiency filters on the circuit before release).

Under these conditions, all that is sure is the conservation of isotopy for an element between source term and the release (except for spontaneous fission of curium 244). However, considering the large number of parameters mentioned above and their inaccuracy, deduction of the released activity of a radionuclide by analogy with the released activity of a similar element in the periodic table (chemical analog), is less rigorous and more uncertain, and therefore more subject to criticism, than what was done for liquid effluents.

Note also that consistency checks between “global” alpha and beta measurements and the results of activity measurements deduced from alpha and gamma spectrometric analyses only concern aerosol releases (that can be trapped on the filter being measured). Krypton 85, carbon 14 (in CO_2 form) and chlorine 36 are gases that are not trapped on the filter, whereas iodine, tellurium, antimony and mercury that can be fixed in trace form (a few %) must be adsorbed onto an active carbon cartridge before they can be measured. Considering the size of this cartridge (50 mm diameter and 25 mm high cylinder), it is only suitable for a gamma spectrometric measurement. Consequently, it is no longer possible to cross-check these analysis results with another “global beta” type measurement.

Finally, it is clear that currently available knowledge cannot guarantee the exhaustiveness of the list of radionuclides that could be present in trace state in gaseous releases.

Consequently, the critical analysis work on measurements of activities in gaseous releases done by COGEMA consisted of:

- revising released quantities for volatile radionuclides for which there is no purification treatment like rare gases (selected values of krypton 85 releases corresponding to the quantity present in the fuel at the time of reprocessing) and specify $^{14}CO_2$ releases.

- adding chlorine 36, which as a first approximation has been assumed to behave like iodine 129, rubidium 87, for which the volatility is similar to the volatility of cesium, and minor isotopes of radionuclides present in measurements of gaseous releases supplied by COGEMA (cobalt, antimony, and plutonium isotopes), to the list of radionuclides measured by COGEMA.

Although the exhaustiveness of the list of radionuclides cannot be guaranteed, it is reasonable to believe that no major radionuclides have been forgotten.

Globally, the major contributors in terms of effective dose are volatile radionuclides, namely carbon 14, iodine 129 and krypton 85, for which the activities have been estimated precisely or conservatively.

For radionuclides that can or could be present in the form of aerosols, considering the high efficiency of devices for the purification of gaseous effluents before release (particularly very high efficiency filters), the activity released in the stack is very low and the contribution in terms of impact should also be very low.

One means of checking the quality of the reconstruction of gaseous releases consists of firstly comparing measurements of the total beta and alpha activities, and secondly comparing calculated values of the total number of “expected” beta and alpha particles, deduced by adding the measured or reconstructed activities of radionuclides considered in the inventory, as for liquid releases.

An examination of the summary table of measurements supplied by COGEMA showed some very large variations of activities released in different years for some radionuclides, and corresponding variations in the transfer function.

Note that accumulated values of releases for each year are obtained by summating “nominal” releases corresponding to normal operation of the plant with fluctuations associated with the treatment efficiency of gaseous effluents and possibly incidental releases related to a dysfunction with variable duration and variable consequences (for example damage to the filter in the HADE workshop during 1985).

As an illustration, the increase in the release of iodine 131 by a factor of the order of 300 in 1968 compared with 1967 was due to the unplanned reprocessing of UNGG fuels that were cooled slightly, an event that gave rise to an incident declaration. There was another significant increase in the release of iodine 131 in 1972 and 1975. Following the request made by GT1, COGEMA specified that this increase was due to reprocessing of UNGG fuels that had been less cooled during these two years.

This method of counting and the lack of information that could explain these variations in the values of releases over time, make it more difficult and uncertain to reconstruct releases for years during which measurements are not available.

Finally, some workshops in which operations are carried out that contribute to releases of radionuclides in gaseous effluents, particularly vitrification workshops T7 (UP3) and R7 (UP2-800), were commissioned long after reprocessing of the fuel from which the solutions of treated fission products originated, and therefore vitrified fission products resulting from reprocessing campaigns that had been carried out several years earlier.
In this case, there is therefore a twofold phenomenon of accumulation and a time lag, which for some radionuclides means that the relation between the characteristics of fuels reprocessed annually using the transfer function described above, is no longer relevant.

Concerning sampling and measurement methods, gaseous releases make use of five sampling or measurement lines, the sampling device distributed over the entire diameter of the release stack being designed to ensure that the measured sample is representative. A number of different trapping and analysis techniques are used:

- krypton 85 is measured after filtration by means of a differential ionization chamber,
- tritium and hydrogen are measured after conversion into tritiated water (oxidation of the tritium present, more than 2/3 of which is in the form of tritiated hydrogen) by scintillation in the liquid phase,
- iodine and tellurium isotopes are absorbed on active carbon cartridges that are then analyzed by gamma spectrometry,
- carbon 14, in the form of CO_2 is trapped in four spargers in series containing a soda solution, and for which a specific measurement is made (its impact on the «differential chamber signal used for the krypton 85 measurement is undetectable, since the activity of krypton 85 is greater than the activity of carbon 14 by a factor of 10^4),
- aerosols are trapped on filters, and are then analyzed by alpha and gamma spectrometry (a small fraction of iodine and tellurium may also be adsorbed on this filter).

GT1 based its evaluation of the activity of radionuclides that could be present in gaseous releases at the exit from the stack, on the gaseous releases measurement table between 1966 and 1997 (table 9) supplied by COGEMA.

It was only partially possible to reconstruct radionuclides that had not been measured during the first years of operation, and radionuclides not identified in the releases (minor isotopes for which the activity is below the detection threshold), for the reasons mentioned above.

As for liquid effluents, radionuclides for which the activity is less than the detection limit, and which could not be measured due to the lack of available techniques, are identified by an asterisk, and those radionuclides that were not in table 9 and have been added, are identified by a double asterisk.

Results validated by GT1 are shown in tables 10-1 and 10-2.

Here again, they may be classified as follows, without repeating the method of reconstituting the activity described in the detailed report:

- Radionuclides measured since the beginning, for which measured values are reused. This is iodine 129.

- Radionuclides for which measurements are only available for some years, and for which the activity of missing years was reconstructed using the average weighted value for a period (or the value in the first year) in the transfer function for which measurements are available. These are:

tritium, cobalt 60, the ruthenium-rhodium 106 pair, antimony 125, iodine 129 and 133 isotopes, cesium 134 and 137 isotopes, plutonium 239 + 240.

- Radionuclides for which only a few measurements are available and for which there are no elements that can be used to reconstruct values for other years. These are:

selenium 75, the zirconium-niobium 95 pair, tellurium 125m, the cerium-praseodymium 144 pair, mercury 203.

- Radionuclides for which partial measurements are available, but for which the activity in releases was reconstructed on the basis of knowledge of their physicochemical behavior in the plant. These are:

carbon 14 and krypton 85.

- Unmeasured radionuclides for which the activity in releases was reconstructed using the transfer function for another measured isotope or chemical analog. These radionuclides are:

cobalt 57 and 58 isotopes, the ruthenium-rhodium 103 pair, antimony 124, cesium 135, plutonium 241, americium 241, curium 242, 243, 244, 245 and 246 isotopes.

- Finally, for chlorine 36, the maximum released activity was evaluated based on measurements in the environment, and corresponds to a value of the transfer function less than the value for iodine 129 by a factor of at least 400.

Verification on the consistency of measured and calculated results for activities

in gaseous releases with global alpha and beta measurements

This verification only applies to radionuclides that could be trapped on a paper filter. Furthermore, the comparison between ranges of total alpha and beta measurements made during the 1966-1996 period shows that the total measured alpha activity is 10^4 lower in gaseous effluents than in liquid effluents. Under the same conditions, the total measured beta activity is 10^6 lower in gaseous effluents than it is in liquid releases.

"Global alpha" measurements

Figure 8 contain curves showing compared variations of:

- the "global alpha" count,
- the number of alpha particles deduced from measured or reconstructed alpha activities (excluding uranium),
- the minimum measurable activity.

The activity calculated from the only available measurements is almost always less than the measurement limit. Since the only alpha measurements made by the operator (1984-1996) coincide with the period during which plants were operating with their best performances, it is probable that reconstruction of releases based on these figures would underestimate the reality of the releases.
The "global alpha" measurement is undoubtedly more representative of the reality of releases.

Figure 10a shows the sum of the activities of measured and calculated alpha emitters.

The sum of the activities of individually measured alpha emitters is 1.9×10^6 Bq, whereas the sum of activities calculated from reconstructed values is 1.1×10^7 Bq. This large difference (ratio of 5.8) is explained by the fact that all isotopes are taken into account, and the fact that the individual identification of the various alpha emitters in the gases only started in 1984.

"Global beta" measurements

For beta-gamma emitter radionuclides, we also studied compared variations in the "global beta" count, the expected number of beta particles, and the minimum measurable beta activity (figure 9).

The minimum detectable beta activity is almost always less than the measured or calculated beta activity.

The shape of the "global beta" curve is similar to the shape of the calculated beta activity. However, there are large differences for the 1972-1976 and 1979-1981 periods that we were unable to explain.
The contribution of GT1 to the reconstruction of releases was quantified by comparing the sum of beta emitter measurements with the sum of reconstructed values (figure 10b).

Thus, we compared the following in sequence:

- the sum of the activities of all radionuclides
- the sum of the activities of all radionuclides apart from krypton 85, since krypton 85 has a very high activity compared with other radionuclides
- the sum of the activities of non-volatile radionuclides (aerosols), ignoring krypton 85, tritium, carbon 14, chlorine 36 and iodine 129, 131 and 133 isotopes. The results of this comparison are summarized in the following table:

Activity in Bq (1966 to 1996 inclusive)	Total radionuclides	ditto apart from Kr 85	Aerosols
Reconstructed values	$2.0\ 10^{18}$	$6.4\ 10^{14}$	$1.7\ 10^{10}$
Measured values	$1.6\ 10^{18}$	$5.5\ 10^{14}$	$1.5\ 10^{10}$
Difference in %	+25	+16	+13

The difference of +25% for all radionuclides is due essentially to the difference between the activity of krypton 85 in reprocessed fuels and release measurements at the stack. The difference of +16% for all radionuclides apart from krypton 85 is largely due to carbon 14 ($1.2\ 10^{14}$ Bq for reconstructed values and $3.9\ 10^{13}$ Bq for measured values).

Finally, the difference for aerosols is due partly to added or reconstructed radionuclides like the ruthenium-rhodium 106 pair ($2.1\ 10^{9}$ Bq for reconstructed values and $8.6\ 10^{8}$ Bq for measured values).

3. THE CENTRE MANCHE SHALLOW LAND DISPOSAL CENTER (CM)

3.1 Introduction

As already mentioned in Section 1 in this document, there is no direct relation between the inventory of radioactive materials present on this site for low and medium activity waste and releases into the environment, since the function of this type of structure is to provide the most perfect possible confinement of radionuclides present in the waste packages.
In order to be able to understand and interpret observed activity releases into the near environment around this site since it was put into service, and which were caused essentially by incidents, it is necessary to understand the various operating phases of this site. In particular, in relation to the history of activities measured in the Sainte-Hélène and Grand Bel rivers it is directly related firstly to overflows of the separative network and secondly to the tritium incident. This is why these various points are described in detail in the following sections.

The CM was the first Center for the shallow land disposal of low or medium activity radioactive waste to be commissioned in France.

The first waste packages were delivered to the Center in November 1969.

The CM was managed firstly by the INFRATOME Company from 1969 to 1978, and then by the O.G.D. (*Office de Gestion des Déchets* - Waste Management Office) from 1978 to the end of 1979, and finally since 1979 by the ANDRA (*Agence Nationale pour la Gestion des Déchets Radioactifs* - National Agency for the Management of Radioactive Waste) initially created within the CEA and which later became an EPIC (*Etablissement Public Industriel et*

Commercial - Public Industrial and Commercial Establishment) through the December 30 1991 law.

The CM received its last waste packages in June 1994, which covers an operating period of 25 years.

After the Center was covered, and because requirements imposed for operation of the center may no longer be appropriate considering the nature of the beginning of the monitoring phase, a new creation authorization was requested based on an application for authorization to change to the monitoring phase. A public survey was held for this application at the end of 1995, after which the public survey commission chaired by Mr. Jean PRONOST issued a favorable opinion. Furthermore, the government set up a commission in February 1996 chaired by Mr. Michel TURPIN, with the task of evaluating the situation of the CM and giving an opinion on the impact of the Center. After seeing the recommendations of the TURPIN committee on the Center's methods of surveillance subsequently adopted by the ANDRA, the government wanted a new public survey to present these results. Therefore, the ANDRA made another authorization application taking into account these recommendations. This is how the principle of a two-phase surveillance was selected:

- A first “active” phase during which the ANDRA will have to remain present on the site for monitoring and maintenance of the Center, and surveillance of the environment. This period itself is broken down into two parts:
    - a “very active” phase of about 5 years, intended to observe the behavior of the existing coverage and to check the results in terms of impact;
    - the “active” phase itself lasting between 50 and 100 years, designed to add to operating experience and study any technical modifications that may be necessary to make the Center as passive as possible, in terms of surveillance.
- A second “passive” phase, during which the ANDRA will carry out reduced monitoring of the Center and its environment for precautionary purposes, but during which total abandonment of the Center would not cause unacceptable consequences for the environment. The only constraints during and after this phase will be limited to maintaining easements in order to remember the former presence of the Center.

3.2 Radiological inventory of the CM

This inventory is not intended to form an accounting statement of all radionuclides that are (or were) present on the site, but rather to specify the quantities of radionuclides that potentially make the largest contribution to the radiological impact during the monitoring phase.

Considering the age of the waste received at the CM and the fact that no packages have been received since July 1994, this inventory does not include radionuclides with a half life of less than 5 years (for example like zirconium 95, the ruthenium-rhodium 106 pair and cesium 134) for which diffusion and dispersion mechanisms in the environment are slow.

However, quantities of long life radionuclides that could be present in waste packages have been evaluated using the procedure described below.

3.3. Methodology for reconstituting the radiological inventory

The inventory in table 11 takes into account the activities of packages on the date of reception at the CM starting from the beginning of operations in 1969 until July 1994.

Two periods were considered in creating this inventory:

- the first period from 1969 to the end of 1984,

- the more recent period from 1985 to the end of 1994 during which improvements in the operation of the industrial facilities, together with the August 10 1984 “Quality” order, have resulted particularly in better characterization of waste packages.

The ANDRA has built up computer files for the period from 1969 to the end of 1984, making use of the following information:

- handwritten schedules prepared by waste producers,
- CM arrivals books,
- documents defining the positions of waste packages,
- special archives belonging to the ANDRA or supplied by producers.

For the second period starting from 1985, data supplied by producers were systematically computerized as deliveries were made, either by the producers themselves or by the ANDRA.

The computerized database now includes about 150 radionuclides.

The analysis of all these data has gradually minimized inaccuracies in the evaluation of the radiological inventory of the CM, particularly during the 1969-1984 period.

Concerning the global uncertainty associated with the various methods used to determine the activity of waste packages, the various packages can be sorted into three categories, namely:

- packages for which the selected activity was determined by a direct or indirect measurement (use of ratios corresponding to the activity ratio of some radionuclides) and for which an uncertainty can be calculated by statistical processing of the measurements. Although this uncertainty may be as high as several tens of a % for an isolated package, these uncertainties tend to cancel each other out on a large number of packages and the uncertainty on the total activity is of the order of a few percent;
- packages for which the activity is systematically overestimated, like packages for which the measured activity is below the measurement threshold and for which the activity used is equal to the measurement threshold;
- finally packages for which the activity is evaluated making use of the previous two groups of packages using different information such as:
    - the package producer,
    - the year of shipment,
    - the packaging method declared by the producer,
    - the predominant radionuclide(s).

This procedure gives more precise information about activities declared by the operator.

This methodology for rebuilding the radiological inventory was described by the ANDRA within the framework of the TURPIN Commission that had concluded that “considering the systematic choice of “maximization” selected by this organization, a critical value like the content of long life alpha is very probably less than 500 000 GBq for the entire site”

3.4. Changes to the effluent management mode at the CM

In order to analyze releases of activity into Sainte-Hélène river mentioned in the next section, it is necessary to know the technical methods used to release water collected in the CM between when it was commissioned and the present day.

The many changes that have resulted from operating experience correspond to three different periods corresponding to different choices for liquid releases into the natural environment.

- 1969-1979

During the first ten years of operation, all rainwater collected by the Center, referred to as “surface water”, was collected in ditches along the North and East border of the site and along the central road in the South-North direction.

These collection ditches emptied into a retention tank with a capacity of 50 m^3. Water thus collected passed through the water monitoring station before being discharged into the Sainte-Hélène river. This monitoring station was equipped with a recovery pump capable of diverting a fraction of the water towards the sea discharge facilities belonging to COGEMA La Hague reprocessing plants.

- 1980-1987

Following early operating experience and particularly the 1976 “tritium incident”, it was decided to set up a special collection network dedicated to collecting surface water in contact with the structures. This new network was called the “separative” network and in principle was independent of the “rainwater” network, but it proved to be too fragile (surface pipes broken causing mixing of the water). Therefore it was replaced by a sewer in 1982, placed in an inspectable underground tunnel, and therefore protected.

  - for the rainwater network, rainwater was firstly collected at the low point of the center, and was then discharged into Sainte-Hélène river through COGEMA La Hague reprocessing plants inspection station;
  - for the separative network, water was transferred to COGEMA's pumping station which directed it towards the sea release pipe. However, when the flow exceeded 10 $m^3.h^{-1}$, the water from the separative network was mixed with the rainwater.

- 1988 to present day

Starting from 1988, the water pumping capacity in the separative network was increased to make it possible to transfer all water collected from this network to the sea pipe.

The rainwater network also discharges water to the sea pipe except in the case of heavy rainfall during which this water, after being checked, is discharged into Saint-Hélène river. The rainwater collection network has been replaced by a new rainwater network since 1991, the year in which the coverage work was started.

- Planned changes for the monitoring phase

Since the work of covering the storage structures was completed including application of a bituminous sealing membrane, rainwater has been discharged to Sainte-Hélène. Water for which there is any risk will be directed to COGEMA's sea release pipe.

Effluent management schemes for each of these four periods are shown in figure 11.

3.5. 1976 tritium incident

This incident was detected in October 1976 following an SCPRI inspection that measured a tritium activity equal to 7400 $Bq.l^{-1}$ ($2.10^{-4}Ci.m^{-3}$) in Sainte-Hélène river.

The location of the source of this contamination was quickly identified, by interpreting the results of analyses of monthly measurements made by SPR/COGEMA on 50 water samples taken from the CM site. The problem was in concrete trench TB2 that had contained tritium waste in six boxes identified with numbers 69 to 74, since 26/06/1971. The initial inventory of tritium was of the order of 2200 TBq (60 000 Ci).

The tritiated waste was recovered between 22/10/1977 and 20/02/1978, except for a concrete monolith enclosing an activity of less than 200 TBq (~ 5000 Ci).

This waste was then repackaged in containers enabling degassing of tritium and most of it was transferred to other sites.

After a phase during which the site was kept inactive until September 1979, operations were resumed (trench compartments closed off again, storage of packaged waste, work to improve water collection, construction of the separative network). The closing work was complete in November 1979. The source of the contamination was due to the presence of water with a depth of several centimeters at the bottom of the concrete trench mark TB2, which was no doubt present at the time it was filled. The activity of this water due to tritium was of the order of 4 $TBq.m^{-3}$ (~ 100 $Ci.m^{-3}$). Diffusion of this tritiated water through the pores and cracks in the trench walls thus contaminated water in the drainage network. This deep drainage network located below the bottom of the trenches was designed to protect the trenches from run off water from adjacent low level waste disposal areas. Water collected by this network was recovered by a pump which transferred it into the main sewer settlement tank before being discharged into Saint Hélène river.

The combination of high rainfall at the end of 1976 and operating incidents on the recovery pump resulted in a surface overflow from the concrete trench drainage network. “Chronic” contamination of the Sainte-Hélène river by tritium was observed following this incident.

The ANDRA has estimated annual flows of tritium activity from 1977 to 1996, based on activity measurements per unit volume and an average flow at the measurement point (district of La Fosse). The maximum values were in the years 1979 (3960 GBq) and 1982 (3800 GBq).

An almost linear decrease in the flow of tritium activity has been observed since 1982, the values for the last two years (1996 and 1997) being 110 GBq.

Furthermore, the operation to recover tritiated waste in trench TB2 between December 1977 and March 1978 resulted in atmospheric releases of tritium, with a total activity estimated at 32 TBq.

3.6. Release of radionuclides other than tritium into Sainte-Hélène river

The occasional presence of artificial radionuclides other than tritium in the water in the Sainte-Hélène river was due to weak marking of surface water from the Center, released upriver a result of the different management modes described in the previous section.

Among the beta-gamma emitters, measured activities per unit volume are due essentially to cesium 137 (about 60%), and then to the ruthenium-rhodium 106 pair (~ 25%). Other contributors totaling a few % of the total activity are, in decreasing order, antimony 125, cobalt 60, cesium 134, europium 155 and cobalt 58.

For alpha emitters, spectrometry measurements made in the past by the ANDRA have shown the occasional presence of natural uranium 235 and 238 isotopes when the network overflows.

The ANDRA has supplied a more detailed analysis of these releases for the one-year period from June 1986 to June 1987, which is illustrated in figure 12.

This period was chosen because it is particularly interesting for the following reasons:

- it shows the maximum alpha and beta activities (excluding tritium) per unit volume measured in the Sainte-Hélène, due to the various overflow incidents in the separative network at this time,

- it provides a large number of measurements made by the IPSN for the purposes of a CM radiological study that can be compared with routine measurements made by the ANDRA.

Measurements made by the ANDRA in the water in the Sainte-Hélène at Pont-Durand (point R6) show up about a dozen peaks of total beta activity per unit volume between October 1986 and May 1987.

The maximum value of the beta activity per unit volume, excluding tritium, measured during this period (and consecutively throughout the entire CM operations period) was 9.2 $Bq.l^{-1}$ on October 20 1986.

The shape of the curve for the alpha activity per unit volume during this period is the same, the dates of the alpha peaks coinciding perfectly with the dates of the beta peaks.

Thus, the maximum value of the alpha activity per unit volume equal to 1.9 Bq/l was also obtained on October 20 1996 (see figure 13). The source of this contamination was directly related to the heavy rainfall that caused overflows from the water retention tanks in the separative network to the rainwater network, due to the fact that they were not completely separated at the time.

Figures 13 and 14 show the correspondence in time between the rainfall history and measurements of alpha and beta activities in Sainte-Hélène at Pont-Durand (point R6).

Furthermore, measurements made by IPSN in February 1987 at the same sampling point are consistent with measurements made by the ANDRA as shown in table 12. These same measurements by the IPSN demonstrated a very slight presence of americium 241 in the Sainte-Hélène.

Starting from an $\frac{\text{Activity } ^{241}\text{Am}}{\text{Activity } ^{137}\text{Cs}}$ ratio of 2%, the average activity per unit volume at Pont- Durand for the year 1996 can be estimated at about 15 $mBq.l^{-1}$ for americium 241.

Measurements made by the IPSN in the environment, in sediments and water plants in the Sainte-Hélène river identified plutonium 238, 239 and 240 isotopes, americium 241 and very occasionally neptunium 237, americium 243 and curium 244.

Activities measured in the sediments for each of these radionuclides were less than 20 $Bq.kg^{-1}$ of dry material (except for plutonium 238 for which the maximum observed value was 140 Bq. dw kg^{-1}).

Note that this IPSN study demonstrated that the presence of some of these radionuclides had also been detected in areas not subjected to the influence of the CM.

At the present time, no artificial radionuclides can be measured in the water in Sainte-Hélène river apart from tritium.

3.7. Release of radon into the atmosphere from the CM

Radon and related products present in the environment close to the CM originates from the disintegration of radium and uranium contained in the storage and in the natural environment. Radon is transported towards the outside of the CM by air displacement mechanisms, since air is the main vector. Air contained in the disposal works within the pores of existing materials (concrete, gravel, earth, natural ground, etc.) is subject to displacements controlled mainly by:

- mechanical ventilation of tunnels forming part of the RSGE (Réseau Séparatif Gravitaire Enterré - Buried gravity Separative Network),
- changes in meteorological conditions.

Since there is no ventilation in the RSGE tunnels, air present in the disposal works (and the radon contained in it) is controlled only by air circulation mechanisms resulting from natural phenomena, and particularly air expansion or compression effects due to changes in the atmospheric pressure. Thus an increase in atmospheric pressure will cause compression, which in turn improves the confinement of radon and its descendants within storage structures; conversely, a reduction in the atmospheric pressure will cause expansion, thus transferring radon from the disposal structure and RSGE tunnels, in a more general manner, towards all available air outlets (in diffuse form). Wind action amplifies natural drafts, and is additional to this "breathing" mechanism. When there is no ventilation in RSGE tunnels, the atmospheric concentrations of radon in the air in these tunnels is extremely variable, within the range of 100 to 100 000 $Bq.m^{-3}$.

Consequently, whenever any human intervention is necessary in the RSGE tunnels, the tunnels have to be ventilated so that the work can be done without heavy radiation shielding constraints (for example wearing a breathing apparatus). This ventilation is achieved by blowing, using two fans at the entrance to the East and West tunnels, at the ponds building.

Air is drawn in from the outside by two fans and blown into the tunnels at a flow rate of about 20 000 $m^3.h^{-1}$ at a pressure equivalent to a few millimeters of water (or several tens of Pascals); this air is released to the outside through an outlet (ventilation outlet) located on the roof of the tunnel to the South West of the Center. For a relatively short period (about fifteen minutes after ventilation has started and necessary for complete scavenging of the volume of the tunnels), the extracted air has an activity per unit volume of between 100 and 100 000 $Bq.m^{-3}$ at the ventilation outlet, before dilution in the atmosphere. Under balanced conditions, the slight dynamic pressure maintained by ventilation in the RSGE tunnels enables partial confinement of radon in the storage structures towards the upper parts of the coverage. Under these ventilation conditions, the atmosphere in the RSGE tunnels is practically radon free.

Furthermore, ventilation renews air in the tunnels by simple scavenging (at a rate of 4 to 5 renewals per hour).

Finally, the two radon dosimeters installed on the Center boundary fence do not detect any abnormal concentration of this radionuclide in the ambient air above the coverage.

3.8 Possible releases of other radionuclides in volatile form.

Carbon 14 may be released in the form of methane (CH_4) or carbon dioxide (CO_2), and the CO_2 form should be preponderant considering the physicochemical conditions of the shallow land disposal site, but it would be in equilibrium with the carbonate (CO^{2-}_3) and bicarbonate (HCO_3^-) forms in liquid media.

Low level measurements made since 1996 on water collected adjacent to structures have not demonstrated the presence of carbon 14. Similarly, since tritium cannot be detected in runoff water from the coverage, or in the rain gauge located on the coverage (apart from occasional external inputs) the shallow land disposal center does not release significant quantities of tritium in gas form above the coverage.

4. FLAMANVILLE NUCLEAR POWER STATION

4.1. Introduction

Within the framework of the study carried out by the Commission chaired by Professor Souleau, EDF had supplied two tables (tables 13 and 14) summarizing the measured activity of radionuclides released in liquid and gaseous form from Flamanville power station. This power station comprises two pressurized water reactors with a unit power of 1330 MWe coupled to the network in December 1985 and July 1986.

4.2. Additional information provided by GT1

The reconstruction work done by GT1 on these tables of measurement records supplied by the operator was limited to the addition of estimates of carbon 14 releases in liquid and gaseous effluents, and nickel 63 in liquid effluents.

- Carbon 14

Up to now, EDF has not monitored this radionuclide either in gaseous or liquid releases. The French public authorities decided that releases of this radionuclide should be specifically regulated in the future.

In order to estimate releases in previous years, GT1 used data obtained from the literature to estimate a value of the production rate expressed in terms of the electrical energy produced, equal to 15 GBq and 200 GBq per GWe.year for liquid and gaseous releases, respectively. These estimates are based on measurements made in some other countries (Germany, Switzerland) particularly for gaseous releases.

Releases of carbon 14 from 1985 to 1996 inclusive were reconstructed as shown in table 13, using the above assumptions, and starting from the energy produced each year.

The chemical form of carbon 14 in the gaseous releases is mainly methane (≅ 80%), the remainder being carbon dioxide.

- Nickel 63

This radionuclide, a pure beta emitter with a 96-year half-life, is produced by neutronic activation of the nickel 62 isotope.

The OPRI has made measurements of this radionuclide in liquid effluents since 1993.

Table 13 shows that the activity ratio between nickel 63 and cobalt 60 is relatively constant, of the order of 1.77.

This is the basis used by GT1 to reconstruct releases of nickel 63 activity in liquid releases from 1985 to 1992.

- Other radionuclides

The OPRI also specified that measurements in liquid releases have not demonstrated any significant quantity of strontium 89 and 90 (activity less than 10 $Bq.l^{-1}$) and chlorine 35 (activity less than 20 $Bq.l^{-1}$).

Note that the value declared by the operator for gaseous releases is equal to zero when the activity is less than the measurement limit of detection.

The operator justifies this by the fact that most gaseous effluents consist of ventilation air passing through rooms that could be contaminated. This air, with a high flow, is released through the stack and is continuously checked; when (very rarely) radioactivity peaks are observed, the source is searched for immediately so that the incident can be corrected, and these peaks are declared and counted. Radioactive effluents originating from gaseous phases in radioactive circuits are stored in decay tanks; they are then released after analysis

and after making a declaration of their radioactivity, passing through absolute filters and iodine traps if necessary.

The following comments can be made about table 13 showing liquid releases from Flamanville power station:

Concerning the nature of the measured radionuclides, they originate from two different sources:

- release of active products from structure materials in the reactor and fuel assemblies, into the primary circuit. These radionuclides are usually released in the form of metallic of colloidal particles by the combined action of corrosion, erosion and abrasion phenomena in pipes in the primary circuit and fuel cladding materials.
- the passage of traces of fission products present in the irradiated materials into the primary water circuit, this phenomenon no doubt being due to the presence of minor sealing defects in fuel assembly cladding during residence in the reactor (occurrence of micro-cracking at the temperature reached in reactors that can close again when «cold»). The presence of iodine 131 and cesium 134 and 137 can thus be assigned to this latter phenomenon (which is not surprising considering the very high mobility and solubility of cesium iodide that is formed chemically whenever iodine is present in irradiated uranium oxide).

Therefore strictly speaking, it is impossible to exclude the presence of other radionuclides originating from the fuel (iodine 129, cesium 135, cerium 144), with activity levels that are difficult or impossible to measure.

It was not considered significant to compare the value of these liquid releases with the value of foreign PWR reactors, considering the important influence of the nature of the materials used for the construction of the reactor and the method of management and processing of effluents on these releases.

Nevertheless, the list of radionuclides that were measured in liquid releases from the Swiss BEZNAU power station (pressurized water reactor with a power of 370 MWe) during 1996 was supplied. The following radionuclides that do not appear in table 13 were identified and measured.
Sodium 24, chromium 51, cobalt 57, zinc 65, strontium 89 and 90, zirconium 95 and 97, niobium 95, technetium 99m, ruthenium 103, antimony 122 and 125, iodine 133, lanthanum 140 and cerium 141 and 144.
This list clearly illustrates the contribution of fission products present in the fuel to the released activities, in this case.
It is obvious that the list of radionuclides measured in the liquid waste from Flamanville power station supplied by the operator is not intended to be exhaustive, but to guarantee that the regulatory release limits fixed by the safety authorities in the release authorization are respected, by identifying significant contributors to activity releases.

4.3. Reduction of activity releases in liquid effluents

EDF has supplied further information to explain the significant reduction in activities released in liquid effluents (apart from pure beta emitters) from Flamanville power station since 1990.

The actions that produced this result can be summarized as follows:

- technical modifications made to fuel assemblies for structural elements (grids, spacers, clusters);
- improvements in the collection of different liquid effluents (sorted at the source);
- better management of effluents generated during the various reactor operating phases, for example such as the reduction in released volumes, particularly during unit shutdowns;
- development of effluent decontamination techniques better adapted to the produced effluent type. Apart from filtration processes, and concentration processes by evaporation and demineralization, new techniques can still be estimated also by considering the

manner of processing the waste that they will produce, and the global dosimetric impact of their use.

This complete set of actions has reduced the total activity of beta-gamma emitters (apart from tritium and carbon 14, since quantities of nickel 63 were reduced like cobalt 60) in liquid releases from Flamanville power station, from 30 GBq/year to 2 GBq/year between 1990 and 1996 as shown in figure 15.

4.4. Regulatory monitoring of liquid and gaseous releases

Within GT1, the OPRI mentioned samples and regulatory checks that the operator of a nuclear power station must carry out on liquid and gaseous releases, and monitoring measurements specific to the OPRI.

5. CHERBOURG HARBOUR ARSENAL

The Ministry of Defense sent the “Nord-Cotentin Radioecology Group" a statement of activities released in liquid and gaseous effluents due to operation of Cherbourg Harbour arsenal from 1980 until 1997 and described in tables 15 and 16.

However, this statement expressed as the total activity excluding tritium, as the tritium activity for liquid effluents, and as a total activity and halogen activity for gaseous effluents, is incomplete. Furthermore, the nature of released radionuclides and the activity of each have only been supplied since 1992, the date on which measurement readings were computerized.

During the meeting of the “Nord-Cotentin Radioecology Group" on September 16 1998, comments were supplied by the representative of the French Navy GEA (*Groupe d’Etudes Atomiques* - Atomic studies Group).

For liquid releases, the increase in the total activity excluding tritium observed in 1985 and in 1988 is due to drainage and dismantling operations that resulted in higher released activities, particularly in cobalt 58 and 60.

Table 17 is more detailed, and shows that these two isotopes are the main contributors (apart from tritium) to the released activity, with antimony 124 and 125.
For gaseous releases, the total measured activities during the first years, and particularly in 1983 and 1984, must be considered as being non-significant, due to the very poor precision of measurement techniques used at the time.

Detailed measurements for each radionuclide are given in table 18 showing that the released activity is due mainly to xenon 133 and 135 isotopes.

Releases of halogens are due to iodine 131 used for periodic tests of the efficiency of gas cleaning devices before release (iodine filters).

In general, it is found that released activities are low compared with activities from other operators.

6. INVENTORY OF EVENTS THAT CAUSED ACTIVITY RELEASES THROUGH THE ENVIRONMENT

Apart from releases corresponding to normal operation of the facilities (nominal releases as defined above), the GT1 also listed malfunctions, accidents or incidents that caused a release of radionuclides in liquid or gaseous form outside the sites of each of the facilities located in the Nord-Cotentin region.

6.1. COGEMA La Hague reprocessing plants

The inventory of these events was made from the IPSN incidents monitoring file. This file is based on incident declarations made by operators and with safety authorities.
Events that had caused a release of activity into the environment were identified from this file.

They are mentioned briefly below in chronological order. Note that the two most significant accidents or incidents in terms of activity releases into the environment (perforation of the sea release pipe in 1980 and the silo fire that occurred in 1981) have been described in a summary note written by COGEMA and supplied for the purposes of the Souleau Commission.[1]

This document provides an evaluation of the health impact, in terms of dose to the most highly exposed populations, for each of these incidents.

- October 2 1968 incident that resulted in a release of iodine 131 from the UP2 stack (400)

During a UNGG fuel reprocessing campaign, the activity of gaseous releases of iodine 131, normally of the order of 10^{-8} Ci.s^{-1} (370 Bq.s^{-1}) suddenly increased to 10^{-4} Ci.s^{-1} (3.7 MBq.s^{-1}), the authorized limit being 10^{-6} Ci.s^{-1} (37 kBq.s^{-1}). This activity level remained constant for about 8 hours before it decreased over a period of fifteen hours to the authorized maximum value.

The quantity of iodine 131 activity released between the beginning of the incident (22:00 on 02/10) and 11:00 on 03/10, was estimated at 5 Ci (185 GBq). Later on, processing of effluents at the STE (effluent treatment station) for this campaign involving the dissolution of fuels that were not sufficiently cooled led to a release of iodine 129 in the gaseous releases between 07/10 and 31/10 estimated at 0.2 Ci (7.4 GBq), the maximum flow of released activity being 5.5 10^{-7} Ci.s^{-1} (20 kBq.s^{-1}) on 08/10. This incident was described in a CEA report published in 1970.[2]

This document contains the activities per unit area of iodine 131 on the ground over distances of between 500 and 1500 m from the emission location. The maximum measured value was 10 nCi.m^{-2} (370 Bq.m^{-2}). Activity measurements in the milk of cows feeding in these contaminated areas were used to calculate a transfer factor K equal to the activity per kg of dry grass / activity per liter of milk.

The values of this factor K were between 3 and 40 and the average value was 14.

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[1] Reference document: Etude d'impact de l'établissement de La Hague (La Hague Plant Impact Study). Note de synthèse (Summary note) NT COGEMA 008311/V/97.0070/Rev.0, 13/05/97.

[2] Reference document: Rejet accidentel de 131 iode à l'usine UP2 le 2 et 3 octobre 1968 (Accidental release of iodine 131 from the UP2 plant on October 2 and 3 1968).

CEA-R-4008 report by J. Scheidhauer, G. Cassabois and R. Gandon published in 1970.

An impact calculation was not carried out for the most highly exposed populations following this incident. No doubt information available in the reference documents would be sufficient to make this calculation if it is necessary.

- January 14 1970 incident during chemical decladding on line A in plant UP2 (400)

During a UNGG fuel decladding operation by chemical peeling (cold dissolution of the magnesium cladding), a runaway reaction occurred due to the abnormally high temperature of the fuel, causing the generation of hydrogen by reaction between uranium and water, followed by an explosion.

The activity recovered on the process gas cleaning circuit filter before release into the stack was estimated at 60 Ci (2.2 TBq) after 10 min and 100 Ci (3.7 TBq) during the next half hour, giving a total of 160 Ci (5.9 TBq). Therefore, these activities were not released, but were retained in the installation. The spectrographic inspection of the filter shows that 95% of the activity was due to antimony 125 and 5% due to iodine 131. But there is no record of any measurements being made in the environment following this incident.

- January 2 1980 incident that caused contamination of the Moulinets Bay following the of the sea release pipe break

A tear in the sea release pipe about 1 m long and 4 cm wide, about 200 m from the shore, was detected after it occurred as a result of activity measurements in the marine environment (measurements of activity on crustaceans, molluscs and fish) made in December 1979. The presumed date of this perforation was between early September and the end of November 1979.

The radiological impact of this incident was reconstructed based on consumption of sea food in the above mentioned document by COGEMA.[1]

COGEMA estimated the impact in terms of dose based on very conservative assumptions and using measurements of the activity of a number of radionuclides in the marine fauna (^{106}Ru-Rh, ^{144}Ce-Pr, ^{137}Cs, ^{125}Sb, ^{110m}Ag) and the estimated activity for ^{90}Sr which was not measured at the time, as being 0.121 mSv in 1979 and 0.104 mSv in 1980 for the reference group (children from 7 to 12 year old).

- January 6 1981 incident caused by a fire in the waste silo

The probable cause of this fire that occurred in the waste silo at about 5:00 in the morning was inflammation of uranium metal in divided and pyrophoric form under the effect of a mechanical shock caused by unloading magnesium seal welds and graphite liners.

The maximum level of atmospheric contamination was 700 Bq.m^{-3}, between 13:00 and 14:00 which was 10 hours after the fire started.

The measured released activity was mainly due to cesium 137. The IPSN estimated Its value in the analysis document for this accident at between 0.74 and 1.85 TBq[3] . The release of other radionuclides if any (iodine, rare gases, strontium) was not mentioned or estimated at the time.

The quantity of uranium involved in the fire estimated from releases of cesium 137 in document[4], is “of the order of a few tens of kilograms".

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[3] Reference document: Silo de stockage de chemises de graphite irradiées de l'établissement de la Hague de COGEMA (Irradiated graphite liner storage silo at COGEMA's La Hague plant. January 6 1981 incident. Report SASICC 82-012 of 29/04/1982.

[4] Reference document: Rapport des inspecteurs ISIA sur l'incident du silo (ISIA inspector's report on the silo incident). Note HC/ISIA 81-52 of 13 March 1981.

Starting from the characteristics of UNGG fuel reprocessed in 1980 supplied by COGEMA, assuming that the total amount of cesium in the irradiated metal uranium involved in the fire was released, the corresponding uranium mass would be 5 Kg.

The contamination on the ground per unit area outside the site to the south-east of the plant did not exceed 370 $Bq.m^{-2}$ (value determined by grass activity measurements). The total dose received by a 1- to 2-year-old child by exposure due to inhalation, deposition on the ground and ingestion of milk (preponderant term) during the months of January to May was estimated at about 0.1 mSv in the document written by COGEMA[1].

Additional information was provided about this incident, and questions were asked by the Plenary Group, particularly during the June 25 1998 meeting.

Subsequent to measurements in the environment available to GT2 for the year 1981 and with reference to document[4], GT4 was able to obtain an estimate of the released activity of cesium 137, namely about 0.74 TBq (20 Ci). This value was used to reconstruct the source term (activities of the main radionuclides that could have been released in the atmosphere during the fire).

- February 13 1990 incident that led to a release of cesium 137 from the Elan IIB stack

Cesium 137 was released into the atmosphere during a filter change on the “medium low pressure” ventilation network in the ELAN IIB workshop during a dismantling operation after a stack releases alarm was triggered for about 10 minutes. The operator declared an estimated release of 3.1 MBq on the same day. Subsequent analysis of the OPRI atmospheric filter on the ELAN IIB stack, for the purposes of creating regulatory statements of releases, gave a significantly lower value of releases than was included in the total for the year 1990.

6.2. Flamanville nuclear power station

A number of declared events appear in the gaseous effluents treatment file. However, none of these malfunctions caused significant releases of activity into the environment, in other words activities that are not very low (a few tens of TBq) compared with authorized daily releases (1650 TBq).

6.3. Centre Manche shallow land disposal center

The incident in which the ground water underneath the CM was contaminated by tritiated water (referred to as the «tritium incident») caused significant pollution of the Sainte-Hélène and Grand Bel rivers. Furthermore, subsequent episodes in which the separative network overflow led to occasionally higher marking in the Sainte-Hélène river (mainly tritium associated with traces of other artificial radioelements). The circumstances and consequences of these incidents are described in detail in Section 3.

6.4. Cherbourg Harbour arsenal

There is no information about accidental activity releases into the environment.

7. CONCLUSIONS

The purpose of the work done by GT1 was to reconstruct all activities of radionuclides that are or could be present in liquid or gazeous releases from the various nuclear industries installed in the Nord-Cotentin region, as completely as possible, within the framework of an "overestimate" approach.

GT1 finalized the inventory of the source term for the four nuclear facilities in the Nord-Cotentin (COGEMA La Hague reprocessing plants, EDF's Flamanville power station, ANDRA's CM, and the Cherbourg Harbour) during the period from 1966 to 1996 in accordance with this task. This work includes normal operation of the facilities and incidents that caused a release of activity into the environment.

The consistency of this inventory and the associated reconstruction methodology was verified within the limits of the state of the art and current knowledge. The source term is based mainly on validated results commented upon by the regulatory measurements and supplied by the various operators since their facilities were commissioned. Remember that within this regulatory framework, the responsible authorities defined the checks that are not intended to provide an exhaustive list of measured radionuclides or to search for the precise value of the released activity when it is below the measurement limit or the detection limit. Consequently, GT1 had to develop an innovative approach based on knowledge of the operation of facilities and processes in order to reconstruct and complete, and even in some cases correct, the source term. Thus, an individual quantification was made for some radioelements that are likely to be present but were not detected, not searched for or only measured globally in releases.

GT1's additions to the initial list of radionuclides supplied by operators are summarized below. It is found that in practice most of the work done to reconstruct activities released into the environment concern COGEMA La Hague reprocessing plants which, due to the nature of their activities, contribute to most radioactive release.

4 As far as COGEMA La Hague reprocessing plants are concerned, additions to the initial list of radionuclides appearing in the table of measurements made by the operator for liquid and gaseous releases concerned the following:

- For alpha emitters:
  - the various isotopes of uranium starting from the composition of the irradiated materials and the released mass flow measured by COGEMA;
  - "minor" isotopes of plutonium, americium and curium, for which low released activities made reliable measurements impossible, particularly during the early years of operation during which UNGG fuels exclusively were processed.

- For beta emitters:
  - "minor" isotopes of some fission products for which measurements of a major isotope were available (case of yttrium 91, zirconium 93, niobium 94, antimony 126, cesium 135, europium 152), starting from conservation of the isotopic ratio in the fuel in the releases, at the time of reprocessing;
  - some fission products, for which the value of the transfer function for an analog chemical element was used (in the sense of Mendeleïev's periodic table), since no other isotope measures were available and for which it can be assumed that the physicochemical behavior in the reprocessing process was similar, however this method is less rigorous than the previous method;

- activation products supplied by neutronic capture of elements present in the form of impurities as traces in the non irradiated fuel. Due to the lack of measurement results of the content of these various elements, it was decided jointly with COGEMA to use a value equal to half the commercial specification, which may be considered as being greater than their real content, at least for fuels made in France.

The following radionuclides were added to the initial list:

- 17 radionuclides produced by fission, increasing the total number of this family of radionuclides to 42,
- 14 radionuclides of uranium and transuranium elements (neptunium, plutonium, americium and curium) to give a total number of 21,
- 8 radionuclides produced by activation of impurities in the fuel, to increase the total number to 12.

Thus, 39 out of the 75 (namely 52%) radionuclides appearing in the releases tables reconstructed by GT1 had been added.

Also considering GT1's input in terms of added activity:

- in liquid releases, the sum of the activities of measured alpha emitters from 1966 to 1996 inclusive was 5.3 TBq. After reconstruction, this value was increased to 10.4 TBq, which was almost double. This addition mainly applies to the years 1976 to 1986 since all transuranium alpha emitters were included in the reconstruction starting from the beginning of reprocessing oxide fuels, although they were measured individually and only gradually before UP3 was commissioned.

  The very good consistency observed between the "global alpha" measurement made by the operator and the sum of the activities of each of the radionuclides used in the final inventory (difference of 0.7%) confirms the validity of the approach used for reconstruction of the release.

  For beta emitters, good agreement is observed between the "global beta" measurement and the measurement calculated for the 1966 to 1971 and 1985 to 1996 periods. However, an 18% difference between the measured value and the recalculated value was observed for the period between 1972 and 1984.

  The additional beta activity term compared with the sum of measured beta activities is marginal.

  This is due to the fact that major contributors (apart from tritium) in terms of activity, namely the ruthenium-rhodium 106 pair (representing 60 to 80% of the total activity between 1966 and 1990 and 20 to 40% from 1991 to 1996) and the strontium-yttrium 90 pair (10 to 30% from 1966 to 1990 and 30 to 60% from 1991 to 1996) were measured since the plants were commissioned.

- in gaseous releases, for alpha emitters and for the same reasons as mentioned above, namely that the measurement of these emitters only started in 1984, the sum of activities reconstructed from 1966 to 1996 is 11 MBq, whereas the sum corresponding to the measured activities is 1.9 MBq, however in any case these values are still low.

  For beta emitters, the difference between the total measured activity and the calculated activity is 16%. This addition is due to the assumption made by GT1 that any activity of krypton 85 present in the fuel at the time of reprocessing will be reflected in gaseous effluents.
  For aerosols, the 13% addition is largely due to reconstruction of ruthenium-rhodium 106 releases.

For some radionuclides such as cobalt 57 and 58 isotopes, for which the high activity levels in liquid releases may initially appear surprising considering their short radioactive half life

compared with the average cooling time of reprocessed fuels, the results of work done by GT2 and GT3 on measurements and transfer models in the marine environment respectively helped to obtain a better understanding of the source of this activity and to validate the value to be used for reconstruction of the releases.

Finally, for some radionuclides with a short half life, such as selenium 75, iodine 131 and 133 isotopes, their presence in liquid or gaseous release at a measurable level of activity is explained by their method of formation in the reprocessing plant by spontaneous fission of curium 244. However, GT1 was unable to validate the value of the measured activity due to the lack of a suitable and available program.

- As far as EDF's Flamanville power station is concerned, GT1's input was more limited since in this case, unlike in reprocessing plants, there is no relation between the activity inventory present in the reactor core and releases related to the method of operation, management and purification of liquid and gaseous effluents.

  Nevertheless, an evaluation of the carbon 14 activity in liquid and gaseous releases is given based on the variation of the energy produced and data in the literature (carbon 14 is now one of the radionuclides for which activity in the waste is subject to authorization).

  Similarly, the activity of nickel 63 in liquid releases was estimated since the power station was commissioned based on measurements made over several years by the OPRI.

- For the CM, GT1 specified the various water management phases for the rainwater network and the separative network, by analyzing and explaining the source of activities measured in water in the Sainte-Hélène river.

- Finally, for releases from the Cherbourg Harbour arsenal, GT1 was provided with the table containing measurements of activity in liquid and gaseous releases supplied by the Ministry of Defense, although this information had not been in the public domain in the past.

- Concerning operating incidents that led to releases of activity into the environment, two previously analyzed events were included in the more detailed work to reconstruct the source term. These were the break of the sea release pipe detected in January 1980 that caused contamination of the Moulinets bay, and the fire in the waste silo containing waste from reprocessing of UNGG fuel that occurred in January 6 1981, and for which radionuclides other than cesium 137 were evaluated, although the activity released into the atmosphere had only been estimated for cesium 137 at the time.

  The "tritium incident" concerning the CM which caused tritium contamination of Sainte-Hélène river in October 1976, was also described and analyzed in detail.

- This work provided GT3 with the necessary data to make a comparison between models and measurements. The proposed reconstruction is also very useful to satisfy the needs of GT4, when it is necessary to find substitute values for missing measurements in the environment when carrying out dose calculations directly from the source term and transfer models.

Considering a number of uncertainties, particularly those dependent on the end purpose of regulatory measurement methods, or uncertainties related to the actual contents of impurities present in the spent fuel, GT1 preferred to use the "overestimate" approach rather than an illusory "realistic" approach. It can be estimated that there is still room for progress concerning the precision of the methods and the assumptions in question. The calculation of the dosimetric impact of releases will help to identify which radionuclides can usefully be determined more accurately in the future, and their order of priority.

Despite some limitations, and having taken all evaluation elements into account, GT1 reached a consensus among all participants about the proposed source term that it considered satisfactory, or at least sufficient, to complete the task that was assigned to it.

PART A APPENDICES

Table 1

Operation of COGEMA La Hague reprocessing plants from 1966 to 1997

Start/end years	Installation name	Fuel type				Management of effluents		
		UNGG	Oxide	MOX	NR	STE_2	STE_3	NGE
1966/1987	UP2	X				X		
1976/…	UP2 400 (HAO)		X	X	X	X		
1989/…	UP3 (foreign fuels)		X				X	since 1990
1994/…	UP2-800 ("EDF" fuels)		X					X

UNGG : Natural Uranium-Graphite-Gas
Oxide : Light water reactor fuel (PWR and BWR)
MOX : Mixed "uranium-plutonium" oxide fuel for light water reactors
NR : Fast neutrons
STE : Effluent Treatment Plant
NGE : New Effluent Management

Table 2

Management of the Manche shallow land disposal center

Dates	Site Manager	Dates	Effluent management ❶
11/1969 **11/1979**	CEA/INFRATOME	1969 to 1979	All surface water discharged into Sainte-Hélène river with inspection. Possibility of discharging into the sea through the La Hague Center.
1979 **1991**	CEA/ANDRA ❷	1980 to 1987	Collection of rainwater through two distinct networks: rainwater network (apart from the shallow land disposal site) discharging into the Sainte-Hélène; separative network (low level waste disposal area), discharge into the sea through the La Hague Center with the possibility of discharging into the Sainte-Hélène.
1991 **to** **present day**	ANDRA ❸	1988 to present day	The two networks (rainwater and separative) discharge into the sea, with the possibility of discharging rainwater into the Sainte-Hélène.

❶ The configuration of the effluents management mode will change during the site monitoring phase.
❷ ANDRA created by inter-ministerial order.
❸ ANDRA becomes an EPIC as a result of the 30/12/91 law.
Operator change formulated by the 24/03/1995 decree.

Table 3

Data for EDF's Flamanville power station

Reactor	Power (MWe)		Became critical on	Coupled to network on	Industrial commissioning
	Gross	Net			
Flamanville 1	1382	1330	09/1985	04/12/85	12/1986
Flamanville 2	1382	1330	06/1986	18/07/86	03/1987

Table 4

List of fission products that could be present in effluents from COGEMA La Hague reprocessing plants

	Radionuclide	Studied: Individually measured and declared	Studied: Added by the GT	Activity ($Ci.t^{-1}$)**
Ternary				
	Tritium	X		580
	Beryllium 10		X	$2.4\ 10^{-4}$
Binary				
	Selenium 75°	X		
	Selenium 79		X	$3.279\ 10^{-1}$
	Krypton 85	X		$7.901\ 10^{3}$
	Rubidium 87		X	$2.106\ 10^{-5}$
	Strontium 89	X		$2.117\ 10^{-1}$
	Strontium 90	X		$6.816\ 10^{4}$
	Yttrium 90	X		$6.817\ 10^{4}$
	Yttrium 91		X	2.196
	Zirconium 93		X	1.791
	Zirconium 95	X		9.385
	Niobium 95		X	$2.082\ 10^{1}$
	Technetium 99	X		$1.379\ 10^{1}$
	Ruthenium 103	X		$5.639\ 10^{-3}$
	Ruthenium 106	X		$6.403\ 10^{4}$
	Rhodium 103	X		$5.639\ 10^{-3}$
	Rhodium 106	X		$6.403\ 10^{4}$
	Palladium 107		X	$1.031\ 10^{-1}$
	Silver 110 m	X		$3.507\ 10^{3}$
	Cadmium 113 m		X	$2.451\ 10^{1}$
	Tin 121 m		X	$1.810\ 10^{1}$
	Tin 121		X	$1.404\ 10^{1}$
	Tin 126		X	$5.758\ 10^{-1}$
	Antimony 124	X		$1.856\ 10^{-3}$
	Antimony 125	X		$3.478\ 10^{3}$
	Antimony 126		X	$5.758\ 10^{-1}$
	Tellurium 127 m	X		$1.003\ 10^{1}$
	Tellurium 127		X	9.790
	Iodine 129	X		$2.993\ 10^{-2}$
	Iodine 131°	X		
	Iodine 133°	X		
	Cesium 134	X		$5.005\ 10^{4}$
	Cesium 135		X	1.505
	Cesium 137	X		$8.781\ 10^{4}$
	Cerium 144	X		$7.486\ 10^{4}$
	Praseodymium 144	X		$7.486\ 10^{4}$
	Promethium 147		X	$7.962\ 10^{4}$
	Samarium 151		X	$4.203\ 10^{2}$
	Europium 152		X	$4.641\ 10^{-2}$
	Europium 154	X		$5.169\ 10^{3}$
	Europium 155	X		$5.855\ 10^{3}$

° Produced by spontaneous fission of curium 244.

* Criteria selected by the group for added radionuclides:
Activity per unit mass > 37 $MBq.t^{-1}$ ($1mCi.t^{-1}$) and half life > 6 months (except for Rb87).

** Activity per unit mass after three years cooling for an UOX_1 fuel with an initial enrichment in ^{235}U equal to 3.25% and an irradiation rate of 33 $GWj.t^{-1}$.

Table 5

List of isotopes of uranium and transuranium elements that could be present in effluents from COGEMA La Hague reprocessing plants

Radionuclide	Studied		Activity ($Ci.t^{-1}$)*
	Identified	Added by the GT	
Uranium 232**		X	$2.088\ 10^{-2}$
Uranium 233**		X	$1.383\ 10^{-5}$
Uranium 234**		X	1.020
Uranium 235**		X	$2.221\ 10^{-2}$
Uranium 236**		X	$2.766\ 10^{-1}$
Uranium 238**		X	$3.146\ 10^{-1}$
Neptunium 237		X	$3.053\ 10^{-1}$
Plutonium 236		X	$2.929\ 10^{-1}$
Plutonium 238	X		$3.011\ 10^{3}$
Plutonium 239	X		$3.479\ 10^{2}$
Plutonium 240	X		$5.045\ 10^{2}$
Plutonium 241	X		2.874
Plutonium 242		X	1.870
Americium 241	X		$7.625\ 10^{2}$
Americium 242		X	$3.376\ 10^{-2}$
Americium 243		X	$2.014\ 10^{1}$
Curium 242	X		$4.444\ 10^{2}$
Curium 243		X	$1.478\ 10^{1}$
Curium 244	X		$1.944\ 10^{3}$
Curium 245		X	$2.079\ 10^{-1}$
Curium 246		X	$5.583\ 10^{-2}$

* Activity per unit mass after three years cooling for an UOX_1 fuel with an initial enrichment in ^{235}U equal to 3.25% and an irradiation rate of 33 $GWj.t^{-1}$.

** A global weight measurement is made for uranium.

Table 6

Activation products with the half life greater than two years related to impurities present in uranium oxide

Target	Impurity* Content (ppm)	Radionuclide Formed	Half life (years)
Carbon	100	$^{13}C(n,\gamma)^{14}C$	5.73×10^3
Nitrogen	10	$^{14}N(n,p)^{14}C$	
Oxygen		$^{17}O(n,\alpha)^{14}C$	
Chlorine	25	$^{35}Cl(n,\gamma)^{36}Cl$	3.02×10^5
Calcium	300	$^{40}Ca(n,\gamma)^{41}Ca$	1.03×10^5
Iron	500	$^{54}Fe(n,\gamma)^{55}Fe$	2.7
Nickel	300	$^{58}Ni(n,\gamma)^{59}Ni$	7.6×10^4
		$^{62}Ni(n,\gamma)^{63}Ni$	96
Niobium	20	$^{93}Nb(n,\gamma)^{94}Nb$	2.03×10^4
Molybdenum	300	$^{92}Mo(n,\gamma)^{93}Mo$	4.0×10^3
Samarium	0.6	$^{150}S(n,\gamma)^{151}Sm$	90

NOTE: only carbon 14 is included in the list of measurements in gaseous releases.

* The assumed contents of impurities are values guaranteed by fuel manufacturers (commercial specifications in ASTM international standards).

uid releases

Table 7-1

quid releases from COGEMA La Hague reprocessing plants

3H	14C	54Mn	57Co	58Co	60Co	63Ni	65Zn	89Sr	90Sr+Y	95ZrNb	99Tc	103Ru	106RuRh
0E+00	-	-	-	0.0E+00	-	-	-	1.0E+12	2.1E+12	1.9E+10	-	5.4E+12	1.4E+13
0E+00	-	-	-	-	-	-	-	6.4E+11	8.5E+11	2.7E+12	-	1.2E+13	4.9E+13
0E+00	-	-	-	-	-	-	-	7.8E+11	2.7E+12	6.7E+12	-	6.0E+12	6.0E+13
0E+00	-	-	-	-	-	-	-	2.5E+11	1.4E+12	5.8E+11	-	6.9E+11	5.3E+13
E+13	-	-	-	-	-	-	-	3.6E+11	4.0E+12	2.8E+12	-	3.4E+12	2.0E+14
3E+13	-	-	-	-	-	-	-	7.7E+11	1.7E+13	2.7E+12	-	6.9E+12	2.9E+14
3E+13	-	-	-	-	AAD	-	-	2.5E+12	3.2E+13	1.2E+13	-	1.7E+13	2.8E+14
E+14	-	-	-	-	4.2E+11	-	-	1.2E+12	3.8E+13	2.3E+12	-	4.3E+12	2.6E+14
3E+14	-	-	-	-	3.9E+10	-	8.1E+10	8.6E+12	1.0E+14	2.9E+13	-	8.9E+12	5.4E+14
E+14	-	-	-	-	2.2E+11	-	1.7E+09	8.7E+12	7.5E+13	2.1E+13	-	1.5E+13	8.3E+14
3E+14	-	-	-	-	2.0E+11	-	-	8.0E+11	4.0E+13	5.4E+12	-	2.2E+12	5.6E+14
3E+14	-	1.0E+10	2.0E+10	-	2.2E+11	-	-	2.7E+12	7.3E+13	2.0E+12	-	1.2E+12	5.4E+14
3E+14	-	-	-	-	3.5E+11	-	1.0E+10	7.9E+11	1.4E+14	5.0E+11	-	9.5E+10	8.0E+14
3E+14	-	-	-	-	1.1E+12	-	+	1.1E+12	1.1E+14	8.9E+11	-	2.1E+11	7.5E+14
3E+14	-	-	-	-	2.7E+12	-	1.2E+10	2.8E+11	5.9E+13	1.2E+11	-	1.3E+11	7.7E+14
E+14	-	-	-	-	4.0E+12	-	+	3.1E+11	5.4E+13	1.2E+11	-	1.1E+11	6.6E+14
E+14	-	2.5E+10	1.7E+10	1.6E+10	3.1E+12	-	8.3E+08	4.7E+11	1.7E+14	5.5E+11	-	+	9.4E+14
2E+15	-	6.7E+10	2.5E+10	1.7E+11	1.4E+13	-	7.2E+10	8.3E+11	2.8E+14	1.1E+12	1.2E+13	9.5E+09	6.7E+14
5E+15	-	1.6E+11	3.2E+10	4.1E+11	2.5E+13	-	2.8E+11	1.1E+12	2.2E+14	8.6E+10	1.5E+13	+	7.0E+14
5E+15	-	2.0E+11	4.5E+10	4.5E+11	1.5E+13	-	1.2E+11	2.9E+11	9.4E+13	9.0E+09	2.5E+13	2.1E+10	8.7E+14
5E+15	-	1.4E+11	2.1E+10	4.6E+11	1.2E+13	-	1.4E+11	9.1E+11	1.4E+14	1.7E+11	1.2E+13	5.0E+10	8.1E+14
0E+15	-	2.5E+11	2.3E+10	1.6E+11	7.5E+12	-	7.3E+10	8.4E+11	1.1E+14	3.9E+10	1.6E+13	1.4E+10	1.1E+15
5E+15	-	2.4E+11	2.4E+10	1.0E+11	6.6E+12	-	9.7E+10	5.2E+11	7.9E+13	5.3E+08	1.0E+13	+	5.2E+14
7E+15	-	1.3E+11	1.1E+10	5.1E+10	5.8E+12	-	1.4E+10	3.2E+11	5.7E+13	+	7.1E+12	+	5.5E+14
5E+15	-	2.3E+11	4.9E+09	5.4E+10	4.5E+12	-	6.7E+09	1.4E+11	3.2E+13	+	5.7E+12	+	3.0E+14
7E+15	-	4.5E+11	2.4E+09	3.3E+10	2.7E+12	-	8.6E+08	2.7E+11	6.0E+13	+	9.1E+11	+	3.6E+13
5E+15	-	9.5E+10	1.2E+09	1.3E+10	1.2E+12	-	3.9E+08	1.1E+11	3.5E+13	6.9E+07	4.7E+11	9.3E+07	2.3E+13
2E+15	-	9.1E+10	1.7E+09	8.4E+09	1.8E+12	-	1.3E+09	2.4E+11	4.9E+13	1.1E+08	6.4E+11	2.3E+08	1.7E+13
E+15	-	2.1E+10	1.3E+09	2.8E+10	5.3E+11	-	5.7E+08	1.7E+11	3.1E+13	+	3.7E+11	2.8E+08	2.8E+13
5E+15	-	3.1E+10	7.7E+09	1.5E+10	5.5E+11	-	7.9E+07	2.9E+11	3.0E+13	+	1.0E+11	+	1.5E+13
E+16	9.9E+12	1.5E+10	8.5E+08	1.8E+10	3.9E+11	-	2.7E+09	9.4E+10	1.1E+13	1.7E+08	1.2E+11	+	1.7E+13

uid releases

Table 7-2

quid releases from COGEMA La Hague reprocessing plants

133I	134Cs	137Cs	144CePr	154Eu	155Eu	Total 1	239/40Pu	241Pu	241Am	242Cm	244Cm	Total
-	2.8E+11	7.3E+12	4.3E+09	-	-	3.1E+01	1.6E+09	-	-	-	-	1.6E+09
-	4.3E+11	1.6E+13	3.2E+11	-	-	8.3E+01	1.2E+10	-	-	-	-	1.2E+10
-	1.2E+12	2.8E+13	4.6E+12	-	-	1.1E+02	3.2E+10	-	-	-	-	3.2E+10
-	1.3E+12	2.0E+13	5.3E+11	-	-	7.9E+01	1.3E+10	-	-	-	-	1.3E+10
-	1.4E+13	8.9E+13	9.4E+11	-	-	3.2E+02	2.4E+10	-	-	-	-	2.4E+10
-	4.8E+13	2.4E+14	1.3E+13	-	-	6.2E+02	1.5E+11	-	-	-	-	1.5E+11
-	6.2E+12	3.3E+13	5.4E+12	-	-	4.1E+02	6.6E+10	-	-	-	-	6.6E+10
-	8.4E+12	6.9E+13	6.6E+12	-	-	4.6E+02	8.1E+10	-	-	-	-	8.1E+10
-	9.0E+12	5.6E+13	4.2E+13	-	-	8.6E+02	5.5E+11	-	-	-	-	5.5E+11
-	4.3E+12	3.5E+13	2.1E+13	-	-	1.1E+03	2.6E+11	-	-	-	-	2.6E+11
-	6.6E+12	3.5E+13	5.8E+12	-	-	6.9E+02	1.6E+11	-	-	-	-	1.6E+11
-	9.6E+12	5.1E+13	5.0E+12	-	-	7.4E+02	2.4E+11	-	-	-	-	2.4E11
-	7.8E+12	3.9E+13	1.1E+13	-	-	1.1E+03	2.2E+11	-	-	-	-	2.2E+11
-	3.6E+12	2.3E+13	1.3E+13	-	-	9.6E+02	2.5E+11	-	-	-	-	2.5E+11
-	3.7E+12	2.7E+13	5.5E+12	-	-	9.2E+02	1.9E+11	-	-	-	-	1.9E+11
-	6.0E+12	3.9E+13	8.1E+12	-	-	8.2E+02	1.6E+11	-	-	-	-	1.6E+11
-	8.4E+12	5.1E+13	6.3E+12	1.0E+11	1.0E+11	1.3E+03	1.9E+11	-	-	-	-	1.9E+11
-	4.9E+12	2.3E+13	4.8E+12	6.8E+10	3.7E+10	1.2E+03	8.1E+10	-	-	-	-	8.1E+10
-	4.8E+12	3.0E+13	6.4E+12	1.3E+11	6.5E+10	1.1E+03	1.4E+11	-	-	-	-	1.4E+11
-	8.2E+12	2.9E+13	4.4E+12	2.4E+11	1.7E+11	1.2E+03	1.4E+11	-	-	-	-	1.4E+11
-	1.4E+12	9.6E+12	3.2E+12	6.1E+10	1.9E+10	1.1E+03	8.1E+10		4.4E+11	1.4E+10	1.1E+11	7.0E+11
-	1.2E+12	7.6E+12	3.3E+11	3.6E+10	7.7E+09	1.4E+03	8.6E+10		1.7E+11	1.3E+10	5.7E+10	4.1E+11
-	1.3E+12	8.5E+12	7.6E+10	4.0E+10	2.4E+10	7.2E+02	6.3E+10		1.5E+11	1.0E+10	5.1E+10	3.2E+11
-	2.8E+12	1.3E+13	2.5E+10	5.4E+10	9.6E+09	7.2E+02	5.6E+10		9.3E+10	1.1E+09	6.4E+10	2.9E+11
-	1.9E+12	1.3E+13	1.4E+10	1.9E+10	3.4E+09	3.9E+02	5.3E+10		1.2E+11	5.3E+08	4.6E+10	3.0E+11
-	5.9E+11	5.6E+12	1.3E+10	1.4E+10	5.5E+09	1.3E+02	2.3E+10	2.5E+12	3.8E+10	7.7E+06	1.8E+10	1.2E+11
-	3.0E+11	3.0E+12	3.7E+09	8.1E+09	1.6E+09	8.2E+01	1.5E+10	1.1E+12	1.8E+10	2.5E+08	1.2E+10	7.2E+10
2E+08	4.5E+11	4.4E+12	2.1E+09	1.6E+10	4.1E+09	8.1E+01	1.2E+10	9.7E+11	1.4E+10	8.9E+07	1.2E+10	5.8E+10
0E+09	1.2E+12	1.1E+13	1.0E+09	7.4E+09	2.6E+09	8.0E+01	9.8E+09	9.1E+11	9.7E+09	3.5E+07	6.9E+09	4.6E+10
6E+09	3.6E+11	4.6E+12	8.5E+08	6.5E+09	2.6E+09	5.5E+01	5.7E+09	4.8E+11	9.5E+09	-	7.1E+09	3.4E+10
3E+09	1.7E+11	2.4E+12	3.0E+08	4.6E+08	+	4.4E+01	4.6E+09	2.2E+11	4.6E+09	5.6E+05	1.9E+09	2.0E+10

uid releases

Table 8-1

ue reprocessing plants - GT1 source term

	41Ca	54Mn	55Fe	57Co	58Co	60Co	59Ni	63Ni	65Zn	79Se	87Rb
		6.85E-03		1.19E-08	2.10E-05	6.25E-03	1.87E-04	2.56E-02			1.83E-09
		1.79E-02		3.13E-08	4.45E-05	1.72E-02	5.15E-05	7.05E-03			4.05E-09
		5.15E-02		8.91E-08	9.35E-05	5.41E-02	1.62E-04	2.22E-02			6.77E-09
		5.55E-02		9.62E-08	1.11E-04	5.64E-02	1.69E-04	2.31E-02			4.88E-09
		3.52E-02		6.10E-08	6.69E05	3.64E-02	1.09E-04	1.49E-02			2.14E-08
		6.48E-02		1.11E-07	8.52E-05	8.34E-02	2.50E-04	3.42E-02			5.44E-08
		9.62E-02		1.65E-07	1.29E-04	1.22E-01	3.64E-04	4.98E-02			7.43E-09
		8.52E-02		5.52E-07	4.16E-04	4.21E-01	1.26E-03	1.73E-01			1.54E-08
		2.52E-01		5.21E-08	3.97E-05	3.94E-02	1.18E-04	1.62E-02	8.12E-02		1.19E-08
		1.94E-01		2.59E-07	1.83E-04	2.19E-01	6.56E-04	8.98E-02	1.67E-03		7.47E-09
	7.82E-07	1.43E-01	7.36E-03	1.43E-02	2.48E+01	2.00E-01	5.99E-04	8.20E-02		7.37E-04	7.68E-09
	1.75E-06	*1.84E-01*	7.54E-03	*7.80E-03*	4.00E-01	2.16E-01	6.47E-04	8.86E-02		1.30E-03	1.09E-08
	4.81E-06	2.56E-01	2.13E-02	2.24E-02	2.82E+00	3.54E-01	1.06E-03	1.45E-01	1.02E-02	2.02E-03	8.25E-09
	5.55E-06	1.94E-01	9.27E-02	1.72E-02	2.19E-01	1.10E+00	3.30E-03	4.51E-01		2.94E-03	4.85E-09
	3.33E-06	1.77E-01	2.44E-01	1.31E-02	3.32E-02	2.69E+00	8.06E-03	1.10E+00	1.15E-02	3.47E-03	5.83E-09
	3.12E-06	1.92E-01	4.16E-01	1.44E-02	6.53E-02	3.97E+00	1.19E-02	1.63E+00		3.05E-03	8.37E-09
	1.05E-05	2.45E-02	3.29E-01	1.72E-02	1.56E-02	3.12E+00	9.35E-03	1.28E+00	8.26E-04	6.13E-03	1.10E-08
	2.08E-05	6.74E-02	2.22E+00	2.48E-02	1.66E-01	1.35E+01	4.04E-02	5.54E+00	7.16E-02	1.58E-02	5.12E-09
	1.59E-05	1.63E-01	3.27E+00	3.21E-02	4.08E-01	2.46E+01	7.37E-02	1.01E+01	2.76E-01	1.29E-02	6.45E-09
	7.53E-06	2.03E-01	2.89E+00	4.49E-02	4.54E-01	1.53E+01	4.58E-02	6.27E+00	1.22E-01	1.14E-02	6.32E-09
	1.11E-05	1.36E-01	1.85E+00	2.13E-02	4.60E-01	1.21E+01	3.62E-02	4.96E+00	1.43E-01	1.81E-02	2.09E-09
	9.31E-06	2.50E-01	1.36E+00	2.26E-02	1.58E-01	7.50E+00	2.25E-02	3.08E+00	7.29E-02	2.08E-02	1.59E-09
	6.70E-06	2.41E-01	1.16E+00	2.40E-02	9.99E-02	6.62E+00	1.98E-02	2.71E+00	9.67E-02	1.24E-02	1.82E-09
	4.95E-06	1.32E-01	1.04E+00	1.08E-02	5.07E-02	5.81E+00	1.74E-02	2.38E+00	1.44E-02	1.13E-02	2.69E-09
	2.79E-06	2.25E-01	7.15E-01	4.94E-03	5.35E-02	4.48E+00	1.34E-02	1.84E+00	6.73E-03	5.45E-03	2.78E-09
	5.38E-06	4.51E-01	4.22E-01	2.36E-03	3.34E-02	2.70E+00	8.09E-03	1.11E+00	8.60E-04	6.38E-03	1.29E-09
	3.10E-06	9.50E-01	1.85E-01	1.18E-03	1.30E-02	1.20E+00	3.59E-03	4.92E-01	3.90E-04	4.04E-03	6.76E-10
	4.45E-06	9.11E-02	2.50E-01	1.65E-03	8.39E-03	1.78E+00	5.33E-03	7.30E-01	1.25E-03	1.50E-03	9.91E-10
	2.89E-06	2.12E-02	7.39E-02	1.33E-03	2.84E-02	5.32E-01	1.59E-03	2.18E-01	5.67E-04	2.08E-03	2.44E-09
	2.79E-06	3.06E-02	6.90E-02	7.73-04	1.52E-02	5.48E-01	1.64E-03	2.25E-01	7.90E-05	1.14E-03	1.11E-09
	1.00E-06	1.51E-02	4.68E-02	8.51E-04	1.78E-02	3.85E-01	1.15E-03	1.58E-01	2.67E-03	6.82E-04	5.67E-10

he activity of reprocessed fuels.
activities).

sing UNGG fuels could not be calculated due to lack of knowledge of their activity in the reprocessed fuel.

uid releases

Table 8-2

ue reprocessing plants - GT1 source term

	94Nb	95ZrNb	93Mo	99Tc	103RuRh	106RuRh	107Pd	110mAg	113mCd	121Sn	121mSn	126S
		1.87E-02		5.32E-02	*4.25E-02*	1.44E+01		5.98E-05				
		2.71E+00		1.49E-01	*9.94E-02*	4.92E+01		3.03E-04				
		6.69E+00		4.88E-01	*7.30E-02*	6.02E+01		2.10E-03				
		5.77E-01		5.00E-01	*7.55E-02*	5.30E+01		1.72E-03				
		2.81E+00		3.26E-01	*2.61E-01*	2.00E+02		1.27E-03				
		2.66E+00		8.25E-01	*1.39E-01*	2.85E+02		8.09E-03				
		1.19E+01		1.19E+00	*1.99E-01*	2.80E+02		1.03E-02				
		2.28E+00		1.11E+00	*2.26E-01*	2.63E+02		5.16E-02				
		2.85E+01		3.25E+00	*3.60E-01*	5.37E+02		1.03E-02				
		2.14E+01		2.93E+00	*4.59-01*	8.30E+02		2.13E-02				
	6.65E-07	5.37E+00	1.15E-03	1.79E+00	*2.88E-01*	5.55E+02	4.27E-05	2.74E-02	4.37E-05	2.99E-02	8.65E-03	1.18E-03
	4.88E-07	2.02E+00	2.50E-03	3.30E+00	*2.38E-01*	5.40E+02	7.62E-05	2.08E-02	6.24E-05	5.70E-02	1.65E-02	2.35E-03
	2.35E-07	5.02E-01	5.01E-03	4.86E+00	*2.56E-01*	8.01E+02	1.56E-04	1.66E-01	5.07E-04	8.92E-02	2.57E-02	3.65E-03
	9.23E-07	8.90E-01	7.68E-03	5.28E+00	*2.20E-01*	7.47E+02	2.70E-04	5.45E-03	3.96E-05	1.22E-01	3.53E-02	5.02E-03
	1.79E-07	1.21E-01	1.04E-02	6.43E+00	*2.34E-01*	7.74E+02	4.14E-04	1.41E-03	1.60E-05	1.45E-01	4.18E-02	6.03E-03
	2.10E-07	1.19E-01	1.22E-02	7.34E+00	*1.78E-01*	6.63E+02	3.60E-04	2.00E-03	2.03E-05	1.27E-01	3.66E-02	5.24E-03
	1.35E-06	5.48E-01	1.53E-02	8.61E+00	2.43E-01	9.38E+02	6.91E-04	5.13E-03	7.71E-05	2.54E-01	7.35E-02	1.06E-02
	8.15E-06	1.08E+00	2.41E-02	1.17E+01	*9.10E-02*	6.74E+02	7.59E-04	5.43E-03	1.19E-04	6.43E-01	1.86E-01	2.66E-02
	4.34E-07	8.57E-02	3.08E-02	1.55E+01	1.27E-01	7.02E+02	7.81E-04	6.05E-03	1.34E-04	5.48E-01	1.58E-01	2.30E-02
	1.37E-07	8.95E-03	5.55E-02	2.54E+01	*5.97E-02*	8.74E+02	1.15E-03	1.26E-02	2.54E-04	5.00E-01	1.45E-01	2.10E-02
	2.85E-06	1.66E-01	2.55E-02	1.18E+01	*8.01E-02*	8.06E+02	1.69E-03	2.28E-03	9.98E-05	7.73E-01	2.23E-01	3.28E-02
	1.03E-06	3.85E-02	3.50E-02	1.59E+01	*5.14E-02*	1.05E+03	1.68E-03	8.02E-03	2.18E-04	9.00E-01	2.59E-01	3.79E-02
	2.58E-06	*1.95E-05*	2.29E-02	1.01E+01	2.34E-09	5.18E+02	1.08E-03	1.42E-02	5.65E-04	5.38E-01	1.55E-01	2.27E-02
	3.99E-06	3.48E-04	1.62E-02	7.13E+00	*8.64E-05*	5.49E+02	1.44E-03	7.04E-04	3.39E-05	4.95E-01	1.43E-01	2.11E-02
	4.53E-06	4.43E-04	1.29E-02	5.67E+00	1.23E-04	2.99E+02	1.72E-03	6.36E-05	9.58E-06	2.32E-01	6.70E-02	9.99E-03
	6.82E-06	1.48E-09	2.08E-03	9.12E-01	*5.47E-17*	3.57E+01	4.86E-04	1.07E-03	4.99E-04	2.66E-01	7.69E-02	1.16E-02
	6.07E-06	*1.04E-08*	1.08E-03	4.75E-01	6.13E-16	2.26E+01	2.09E-04	2.40E-04	7.02E-05	1.69E-01	4.86E-02	7.31E-03
	7.95E-06	*6.06E-09*	1.44E-03	6.37E-01	*1.28E-16*	1.66E+01	1.73E-04	4.70E-05	1.68E-05	6.31E-02	1.82E-02	2.76E-03
	1.27E-05	2.65E-10	8.45E-04	3.70E-01	*1.34E-18*	2.75E+01	5.55E-04	9.23E-05	7.54E-05	8.70E-02	2.52E-02	3.83E-03
	1.61E-05	4.45E-12	2.28E-04	1.00E-01	*1.44E-21*	1.52E+01	6.53E-04	1.40E-05	3.27E-05	4.66E-02	1.35E-02	2.07E-03
	1.59E-05	*1.28E-11*	2.66E-04	1.17E-01	*6.92E-21*	1.69E+01	5.93E-04	5.04E-05	9.10E-05	2.84E-02	8.21E-03	1.26E-03

e characters.
functions and the activity of reprocessed fuels.
ced measured activities).
roduced while reprocessing UNGG fuels could not be calculated due to lack of knowledge of their activity in the reprocessed fuel.

uid releases

Table 8-3

ue reprocessing plants - GT1 source term

7mTe	129I	131I	133I	134Cs	135Cs	137Cs	144CePr	147Pm	151Sm	152Eu	154Eu	155Eu
	6.04E-04			2.84E-01		7.27E+00	4.26E-03		3.21E-04		4.75E-05	6.19E-04
	1.74E-03			4.33E-01		1.64E+01	3.19E-01		7.80E-04		1.94E-04	1.76E-03
	5.94E-03			1.20E+00		2.84E+01	4.61E+00		2.00E-03		1.04E-03	5.93E-03
	6.00E-03			1.32E+00		2.02E+01	5.29E-01		2.23E-03		9.16E-04	6.04E-03
	3.94E-03			1.38E+01		8.91E+01	9.36E-01		1.39E-03		6.50E-04	3.94E-03
	1.06E-02			4.80E+01		2.43E+02	1.31E+01		2.27E-03		3.22E-03	1.02E-02
	1.53E-02			6.15E+00		3.29E+01	5.36E+00		3.39E-03		4.41E-03	1.47E-02
	1.44E-02			8.41E+00		6.93E+01	6.55E+00		2.99E-03		4.49E-03	1.38E-02
	4.20E-02			9.03E+00		5.60E+01	4.15E+01		8.82E-03		1.28E-02	4.02E-02
	3.89E-02			4.28E+00		3.45E+01	2.10E+01		6.72E-03		1.47E-02	3.68E-02
0E-02	2.38E-02			6.57E+00	3.12E-05	3.47E+01	5.83E+00	3.84E-01	4.13E-03	3.62E-05	1.19E-02	2.48E-02
7E-03	4.48E-02			9.56E+00	6.13E-05	5.08E+01	5.00E+00	3.02E-01	6.90E-03	4.46E-05	3.01E-02	5.05E-02
5E-03	6.71E-02			7.84E+00	6.51E-05	3.91E+01	1.05E+01	1.10E+00	9.17E-03	9.47E-05	5.46E-02	8.14E-02
6E-03	7.26E-02			3.61E+00	5.09E-05	2.25E+01	1.33E+01	2.71E+00	1.12E-02	1.97E-04	5.61E-02	7.79E-02
8E-04	8.90E-02			3.72E+00	6.76E-05	2.68E+01	5.53E+00	1.42E+00	1.16E-02	2.60E-04	7.19E-02	9.29E-02
4E-04	1.02E-01			5.96E+00	1.11E-04	3.85E+01	8.06E+00	2.19E+00	1.28E-02	2.51E-04	9.24E-02	1.15E-01
7E-04	1.20E-01			8.41E+00	1.42E-04	5.05E+01	6.34E+00	2.30E+00	1.49E-02	3.80E-04	9.98E-02	*1.21E-01*
0E-04	1.63E-01			4.93E+00	8.32E-05	2.30E+01	4.76E+00	3.09E+00	9.01E-03	2.48E-04	6.82E-02	*7.71E-02*
7E-04	1.82E-01			4.80E+00	9.22E-05	2.98E+01	6.35E+00	3.56E+00	1.75E-02	5.18E-04	1.34E-01	*1.53E-01*
3E-04	3.00E-01			8.18E+00	1.09E-04	2.94E+01	4.35E+00	3.22E+00	2.29E-02	6.16E-04	2.40E-01	*2.63E-01*
6E-04	2.33E-01			1.39E+00	3.28E-05	9.60E+00	3.18E+00	3.42E+00	7.23E-03	2.50E-04	6.13E-02	*6.50E-02*
2E-04	3.21E-01			1.17E+00	2.72E-05	7.60E+00	3.30E-01	3.13E-01	3.69E-03	1.11E-04	3.55E-02	*3.84E-02*
9E-04	2.02E-01			1.34E+00	2.89E-05	8.47E+00	7.57E-02	1.04E-01	4.42E-03	1.54E-04	3.98E-02	*4.24E-02*
2E-04	2.62E-01			2.75E+00	4.53E-05	1.26E+01	2.50E-02	4.02E-02	5.25E-03	1.65E-04	5.41E-02	*5.60E-02*
0E-06	3.27E-01			1.85E+00	4.73E-05	1.25E+01	1.36E-02	4.54E-02	2.04E-03	6.40E-05	1.86E-02	*1.79E-02*
1E-07	4.55E-01			5.89E-01	2.47E-05	5.60E+00	1.30E-02	9.23E-02	1.52E-03	4.08E-05	1.40E-02	*1.24E-02*
2E-07	4.79E-01			3.03E-01	1.20E-05	2.96E+00	3.74E-03	1.92E-02	9.37E-04	2.79E-05	8.11E-03	*7.46E-03*
7E-07	6.46E-01	2.23E-03	7.18E-04	4.45E-01	1.66E-05	4.37E+00	2.05E-03	1.20E-02	1.98E-03	6.39E-05	1.64E-02	*1.50E-02*
1E-08	1.12E+00	3.71E-03	1.99E-03	1.17E+00	4.46E-05	1.05E+01	1.03E-03	1.05E-02	8.28E-04	2.34E-05	7.38E-03	*6.28E-03*
6E-10	1.53E+00	7.02E-03	1.59E-03	3.63E-01	2.08E-05	4.62E+00	8.46E-04	1.72E-02	7.85E-04	2.15E-05	6.49E-03	*5.17E-03*
9E-09	1.69E+00	7.21E-03	2.34E-03	1.67E-01	1.01E-05	2.41E+00	3.00E-04	5.13E-03	5.62E-05	1.67E-06	4.59E-04	*3.75E-04*

ne activity of reprocessed fuels.
activities).
reprocessing UNGG fuels could not be calculated due to lack of knowledge of their activity in the reprocessed fuel.

uid releases

Table 8-4

ue reprocessing plants - GT1 source term

	U234	235U	U236	238U	237Np	236Pu	238Pu	239/240Pu	241Pu	242Pu
	1.44E-03	5.56E-05	1.95E-05	1.29E-03	7.07E-08		2.11E-05	1.60E-03	3.27E-03	
	3.80E-03	1.43E-04	7.57E-05	3.43E-03	5.53E-07		2.52E-04	1.19E-02	4.94E-02	
	3.28E-03	1.16E-04	1.07E-04	3.00E-03	1.58E-06		1.24E-03	3.15E-02	2.96E-01	
	1.70E-03	6.14E-05	4.78E-05	1.55E-03	6.54E-07		4.32E-04	1.34E-02	9.92E-02	
	2.31E-03	1.21E-04	7.91E-05	2.37E-03	1.18E-06		8.57E-04	2.38E-02	2.01E-01	
	2.66E-03	1.07E-04	1.56E-04	2.50E-03	8.43E-06		1.31E-02	1.45E-01	3.06E+00	
	3.35E-02	1.06E-03	1.88E-03	3.13E-02	3.80E-06		5.56E-03	6.63E-02	1.32E+00	
	1.74E-02	5.34E-04	1.18E-03	1.64E-02	4.76E-06		7.74E-03	8.12E-02	1.79E+00	
	2.54E-02	7.87E-04	1.52E-03	2.39E-02	3.21E-05		5.10E-02	5.52E-01	1.19E+01	
	1.83E-02	5.23E-04	1.63E-03	1.75E-02	1.65E-05		3.40E-02	6.62E-01	7.30E+00	
	5.10E-03	1.48E-04	4.10E-04	4.37E-03	1.31E-05	3.42E-06	4.18E-02	1.57E-01	6.52E+00	2.75E-05
	8.11E-03	2.19E-04	7.25E-04	6.94E-03	2.50E-05	1.14E-05	1.40E-01	2.39E-01	1.16E+01	9.58E-05
	9.68E-03	2.41E-04	1.04E-03	7.69E-03	2.74E-05	1.63E-05	1.78E-01	2.16E-01	1.36E+01	1.30E-04
	1.02E-02	2.40E-04	1.17E-03	6.43E-03	3.49E-05	1.50E-05	1.99E-01	2.45E-01	1.85E+01	1.75E-04
	1.14E-02	2.56E-04	1.40E-03	6.68E-03	2.93E-05	1.21E-05	1.79E-01	1.86E-01	1.53E+01	1.65E-04
	1.20E-02	2.59E-04	1.63E-03	6.54E-03	3.04E-05	1.58E-05	2.13E-01	1.64E-01	1.45E+01	1.65E-04
	1.05E-02	2.22E-04	1.42E-03	5.36E-03	3.37E-05	1.36E-05	2.14E-01	1.94E-01	1.74E+01	1.98E-04
	2.02E-02	4.01E-04	3.03E-03	7.07E-03	1.83E-05	8.63E-06	1.26E-01	8.10E-02	8.74E+00	1.06E-04
	3.66E-02	7.12E-04	5.40E-03	1.61E-02	2.65E-05	1.15E-05	1.83E-01	1.36E-01	1.39E+01	1.81E-04
	1.46E-02	2.46E-04	2.62E-03	5.04E-03	3.35E-05	2.27E-05	3.15E-01	1.36E-01	1.69E+01	2.67E-04
	2.22E-02	3.89E-04	3.64E-03	8.03E-03	1.79E-05	7.50E-06	*1.36E-01*	8.12E-02	9.10E+00	1.35E-04
	3.74E-02	6.32E-04	6.50E-03	1.25E-02	2.10E-05	1.56E-05	*1.70E-01*	8.59E-02	1.04E+01	1.58E-04
	5.05E-03	8.47E-05	8.59E-04	1.69E-03	1.41E-05	6.35E-06	*1.07E-01*	6.34E-02	7.52E+00	1.13E-04
	2.08E-02	3.20E-04	3.87E-03	6.70E-03	1.42E-05	7.53E-06	*1.23E-01*	5.59E-02	6.94E+00	1.19E-04
	7.88E-03	1.26E-04	1.42E-03	2.40E-03	1.30E-05	5.09E-06	*1.14E-01*	5.33E-02	6.20E+00	1.08E-04
	4.89E-03	7.51E-05	9.34E-04	1.26E-03	7.26E-06	2.34E-06	*6.63E-02*	2.33E-02	*2.70E+00*	5.24E-05
	4.43E-03	7.14E-05	8.00E-04	1.25E-03	4.16E-06	1.34E-06	*3.47E-02*	1.52E-02	*1.73E+00*	3.08E-05
	7.45E-03	1.19E-04	1.32E-03	2.31E-03	2.87E-06	8.29E-07	*2.31E-02*	1.15E-02	*1.27E+00*	2.26E-05
	1.32E-02	1.98E-04	2.51E-03	3.66E-03	2.89E-06	7.97E-07	*2.62E-02*	9.80E-03	*1.10E+00*	2.23E-05
	5.88E-03	8.83E-05	1.12E-03	1.54E-03	1.77E-06	3.81E-07	*1.60E-02*	5.69E-03	*6.11E-01*	1.30E-05
	9.77E-03	1.47E-04	1.83E-03	2.80E-03	1.31E-06	2.80E-07	*1.14E-02*	4.61E-03	*4.89E-01*	1.02E-05

e characters.
functions and the activity of reprocessed fuels.
ced measured activities).
roduced while reprocessing UNGG fuels could not be calculated due to lack of knowledge of their activity in the reprocessed fuel.

uid releases

Table 8-5

ue reprocessing plants - GT1 source term

Am	242Cm	243Cm	244Cm	245Cm	246Cm	total α calculated (GT1)	total β calculated (GT1)	total α measured	total β measured	activity Σ of β emitters (excluding H3)	
										measured (COGEMA)	reconstructed (GT1)
E-10	8.58E-07	1.70E-10	4.84E-10			4.44E-03	2.03E+01	5.77E-03	3.60E+01	3.06E+01	2.44E+01
E-08	2.86E-05	8.50E-09	2.61E-08			1.98E-02	5.65E+01	1.88E-02	8.62E+01	8.29E+01	7.04E+01
E-07	4.67E-04	2.38E-07	8.52E-07			4.06E-02	8.57E+01	3.75E-02	1.23E+02	1.11E+02	1.05E+02
E-08	1.15E-04	47.97E-08	1.69E-07			1.76E-02	6.36E+01	1.68E-02	8.18E+01	7.87E+01	7.86E+01
E-07	2.74E-04	1.30E-07	4.52E-07			3.04E-02	2.54E+02	2.86E-02	3.31E+02	3.15E+02	3.12E+02
E-06	1.55E-02	1.56E-05	7.56E-05			1.90E-01	5.16E+02	1.50E-01	6.63E+02	6.19E+02	6.12E+02
E-06	6.11E-03	5.78E-06	2.73E-05			1.50E-01	3.08E+02	1.14E-01	4.29E+02	4.06E+02	3.89E+02
E-06	9.69E-03	1.02E-05	5.07E-05			1.41E-01	3.64E+02	1.33E-01	5.07E+02	4.60E+02	4.56E+02
E-05	6.21E-02	6.36E-05	3.13E-04			7.60E-01	6.82E+02	1.00+00	9.35E+02	8.63E+02	8.50E+02
E-05	5.76E-02	7.70E-05	4.52E-04			4.20E-01	8.29E+02	4.94E-01	1.18E+03	1.08E+03	1.06E+03
E-04	5.58E-02	1.01E-04	7.63E-03	4.23E-07	6.54E-08	2.96E-01	5.43E+02	3.67E-01	7.14E+02	6.90E+02	7.16E+02
E-04	6.35E-02	6.52E-04	8.35E-02	7.97E-06	2.14E-06	6.02E-01	5.86E+02	6.26E-01	7.66E+02	7.39E+02	7.40E+02
E-03	9.63E-02	8.58E-04	1.10E-01	1.02E-05	2.70E-06	6.86E-01	8.52E+02	5.17E-01	1.09E+03	1.06E+03	1.07E+03
E-03	4.68E-02	7.42E-04	7.83E-02	5.94E-06	1.19E-06	7.04E-01	7.63E+02	6.87E-01	9.97E+02	9.55E+02	9.64E+02
E-03	2.64E-02	7.06E-04	7.87E-02	6.31E-06	1.33E-06	6.05E-01	7.26E+02	5.11E-01	9.38E+02	9.23E+02	9.34E+02
E-03	3.21E-02	9.23E-04	1.05E-01	9.53E-06	2.14E-06	6.40E-01	6.50E+02	5.33E-01	7.99E+02	8.18E+02	8.31E+02
E-03	2.65E-02	8.47E-04	9.34E-02	7.57E-06	1.59E-06	6.89E-01	1.01E+03	6.44E-01	1.14E+03	1.25E+03	1.27E+03
E-04	6.96E-03	5.03E-04	5.51E-02	4.73E-06	9.78E-07	3.75E-01	9.57E+02	4.83E-01	1.02E+03	1.17E+03	1.18E+03
E-03	1.17E-02	7.77E-04	9.28E-02	7.73E-06	1.75E-06	6.04E-01	9.27E+02	7.09E-01	1.08E+03	1.14E+03	1.15E+03
E-03	1.33E-02	1.61E-03	2.20E-01	2.21E-05	5.99E-06	8.51E-01	9.14E+02	7.23E-01	1.17E+03	1.16E+03	1.18E+03
E-03	1.36E-02	6.14E-04	1.06E-01	6.90E-06	1.67E-06	8.13E-01	8.88E+02	4.48E-01	9.26E+02	1.13E+03	1.14E+03
E-03	1.28E-02	8.26E-04	5.68E-02	1.01E-05	2.57E-06	5.55E-01	1.07E+03	4.56E-01	1.11E+03	1.38E+03	1.39E+03
E-04	1.04E-02	4.96E-04	5.09E-02	5.58E-06	1.37E-06	3.89E-01	5.68E+02	3.65E-01	5.76E+02	7.25E+02	7.31E+02
E-03	1.07E-03	6.39E-04	6.42E-02	8.80E-06	2.45E-06	3.71E-01	5.61E+02	3.67E-01	5.89E+02	7.20E+02	7.27E+02
E-04	5.32E-04	5.59E-04	4.60E-02	7.50E-06	1.98E-06	3.48E-01	3.04E+02	3.69E-01	3.14E+02	3.86E+02	3.92E+02
E-04	7.70E-06	3.31E-04	1.80E-02	5.28E-06	1.47E-06	1.53E-01	1.16E+02	1.53E-01	1.16E+02	1.31E+02	1.37E+02
E-04	2.46E-04	1.66E-04	1.21E-02	2.28E-06	5.93E-07	8.74E-02	7.21E+01	1.07E-01	7.65E+01	8.17E+01	8.65E+01
E-04	8.88E-05	1.10E-04	1.20E-02	1.46E-06	3.78E-07	7.20E-02	7.67E+01	1.01E-01	7.32E+01	8.08E+01	8.72E+01
E-04	3.47E-05	1.33E-04	6.92E-03	2.16E-06	6.16E-07	7.29E-02	7.41E+01	9.73E-02	7.02E+01	7.99E+01	8.86E+01
E-04	3.21E-05	7.93E-05	7.12E-03	1.33E-06	3.79E-07	4.73E-02	5.51E+01	7.01E-02	5.29E+01	5.53E+01	6.59E+01
E-04	5.60E-07	5.65E-05	1.89E-03	8.99E-07	2.54E-07	3.74E-02	3.47E+01	4.61E-02	2.94E+01	4.43E+01	4.55E+01

e characters.
functions and the activity of reprocessed fuels.
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seous releases

Table 9

aseous releases from COGEMA La Hague reprocessing plants.

75Se	85Kr	95ZrNb	106RuRh	125Sb (1)	125mTe (1)	129I (1)	131I (1)	133I (1)	134Cs	137Cs	144CePr	203Hg (1)	238Pu	239+240 Pu	241Am	Annual volume (2)
-	4.8E+14	-	-	4.4E+05	-	-	5.2E+08	-	-	-	-	3.0E+08	-	-	-	7.2E+09
-	5.9E+14	-	-	4.4E+05	-	-	8.1E+08	-	-	-	-	1.3E+09	-	-	-	7.0E+09
-	1.5E+15	-	-	2.0E+08	-	-	2.7E+11	-	-	-	-	9.6E+08	-	-	-	7.0E+09
-	9.6E+14	-	-	-	-	-	2.2E+10	-	-	-	-	-	-	-	-	7.0E+09
-	2.3E+15	-	-	6.7E+07	-	-	2.6E+08	-	-	-	-	7.4E+07	-	-	-	7.2E+09
-	4.4E+15	1.1E+07	-	3.7E+07	-	-	7.4E+09	-	-	8.1E+08	-	3.8E+08	-	-	-	8.0E+09
8.5E+05	8.9E+15	-	-	-	-	-	1.0E+11	-	-	-	-	1.1E+09	-	-	-	8.9E+09
-	8.5E+15	-	-	5.2E+07	-	-	2.6E+10	-	-	-	-	4.8E+08	-	-	-	9.2E+09
-	2.7E+16	-	-	9.4E+07	9.3E+05	-	1.9E+10	-	-	1.6E+06	-	4.1E+09	-	-	-	1.0E+10
2.1E+07	2.4E+16	-	-	-	-	-	6.7E+10	-	-	-	-	1.4E+09	-	-	-	1.0E+10
5.7E+06	1.3E+16	-	-	3.6E+08	-	2.2E+09	1.1E+10	-	-	-	-	2.4E+08	-	-	-	1.1E+10
27E+06	2.5E+16	-	2.2E+06	3.9E+08	-	1.0E+10	6.9E+07	1.0E+05	-	2.2E+05	4.1E+06	1.6E+08	-	-	-	1.0E+10
-	2.9E+16	1.7E+05	6.6E+07	4.3E+05	-	7.4E+09	1.0E+08	4.8E+06	1.6E+06	7.5E+06	2.3E+07	6.0E+06	-	-	-	1.0E+10
-	2.4E+16	-	2.3E+05	-	-	1.7E+10	2.8E+10	-	-	-	5.6E+05	2.0E+06	-	-	-	1.0E+10
-	3.0E+16	-	-	-	-	9.8E+09	3.3E+08	5.9E+08	-	3.3E+03	-	-	-	-	-	1.0E+10
-	3.6E+16	-	-	1.3E+06	-	1.5E+10	3.1E+08	7.8E+08	-	4.4E+05	-	-	-	-	-	1.4E+10
-	5.1E+16	-	-	-	-	2.1E+10	1.8E+08	1.9E+08	-	-	-	-	-	-	-	1.7E+10
-	5.0E+16	-	-	-	-	2.7E+10	5.0E+08	1.1E+07	-	3.8E+06	-	-	-	-	-	1.8E+10
-	2.7E+16	-	-	-	-	2.1E+10	5.1E+08	1.5E+08	2.2E+04	5.4E+04	-	-	-	3.5E+04	-	2.1E+10
-	7.1E+16	-	7.5E+08	1.3E+08	-	1.1E+10	5.7E+08	-	3.2E+07	7.5E+07	8.3E+07	-	-	1.5E+06	-	2.1E+10
-	2.9E+16	-	7.2E+06	1.5E+07	-	1.4E+10	4.1E+08	-	7.6E+05	3.1E+06	-	-	-	1.4E+04	-	2.1E+10
-	3.5E+16	-	-	8.2E+04	8.1E+07	2.1E+10	5.4E+08	-	-	1.8E+06	-	-	-	8.6E+04	-	2.1E+10
-	2.7E+16	-	3.7E+03	-	-	2.7E+10	5.9E+08	-	-	-	-	-	-	1.7E+04	-	2.5E+10
-	4.2E+16	-	-	-	9.7E+08	1.8E+10	7.7E+08	4.3E+08	-	7.1E+04	-	-	-	3.0E+04	-	2.7E+10
-	6.3E+16	-	1.4E+06	-	-	2.3E+10	5.3E+08	6.2E+08	-	1.7E+06	-	-	-	3.1E+04	-	2.8E+10
-	1.0E+17	-	-	-	1.8E+07	1.1E+10	7.4E+08	2.0E+08	-	3.0E+05	-	-	5.9E+04	3.5E+04	3.2E+04	2.8E+10
-	9.5E+16	-	7.8E+05	-	1.1E+05	1.0E+10	3.8E+08	1.1E+08	-	1.6E+05	-	-	1.1E+04	1.1E+04	-	3.1E+10
-	1.2E+17	-	-	-	7.5E+04	2.1E+10	5.8E+08	2.3E+08	-	1.5E+05	-	-	1.3E+04	9.1E+03	-	3.1E+10
-	1.8E+17	-	1.4E+06	-	-	3.2E+10	4.9E+08	2.2E+08	-	3.9E+05	-	-	9.0E+03	6.4E+03	-	3.1E+10
-	2.3E+17	-	1.5E+07	-	4.9E+04	3.8E+10	7.8E+08	2.7E+08	-	1.4E+05	-	-	7.3E+03	5.1E+03	-	3.1E+10
-	2.6E+17	-	1.3E+07	-	3.6E+04		1.5E+09	4.1E+08	-	3.5E+05	-	-	1.6E+04	8.1E+03	-	3.1E+10

no detectable activity (1) Radionuclide measured on an active carbon cartridge
(values reconstructed by GT1 based on the commissioning date of the various facilities).

Liquid releases

Table 10-1

ague reprocessing plants - GT1 source term

	36Cl	57Co	58Co	60Co	75Se	85Kr	95ZrNb	103RuRh	106RuRh	124Sb	125Sb (1)	125mTe
		6.1E-04	1.1E+00	3.2E+03		*3.1E+14*		3.9E+03	1.3E+06	9.1E+00	4.4E+05	
		1.6E-03	2.3E+00	8.9E+02		*8.4E+14*		7.9E+03	3.9E+06	9.5E+00	4.4E+05	
		4.6E-03	4.8E+00	2.8E+03		*2.9E+15*		1.7E+04	1.4E+07	4.6E+03	2.0E+08	
		5.0E-03	5.7E+00	2.9E+03		*2.8E+15*		2.0E+04	1.7E+07	2.4E+02	1.0E+07	
		3.1E-03	3.4E+00	1.9E+03		*1.6E+15*		1.2E+04	9.3E+06	1.5E+03	6.7E+07	
		5.7E-03	4.4E+00	4.3E+03		*4.2E+15*	1.1E+07	1.7E+04	3.4E+07	9.1E+02	3.7E+07	
		8.5E-03	6.7E+00	6.3E+03	8.5E+05	*6.1E+15*		2.5E+04	3.5E+07	6.5E+02	2.6E+07	
		7.5E-03	5.7E+00	5.8E+03		*5.6E+15*		2.2E+04	2.5E+07	1.3E+03	5.2E+07	
		2.2E-02	1.7E+01	1.7E+04		*1.6E+16*		6.4E+04	9.6E+07	2.3E+03	9.4E+07	9.3E+05
		1.7E-02	1.2E+01	1.4E+04	2.1E+07	*1.4E+16*		4.7E+04	8.4E+07	1.7E+03	6.5E+07	
	1.9E+06	1.3E-02	7.8E+00	7.7E+03	5.7E+06	*8.9E+15*		3.0E+04	5.7E+07	1.9E+03	4.2E+07	
	1.6E+06	1.6E-02	9.6E+00	1.3E+04	2.7E+06	*1.6E+16*		9.7E+02	2.2E+06	6.7E+03	3.6E+08	
	9.9E+06	2.8E-02	9.8E+00	2.1E+04		*2.2E+16*	1.7E+05	2.1E+04	6.6E+07	6.5E+03	3.9E+08	
	1.1E+07	1.4E-02	7.3E+00	1.5E+04		*2.4E+16*		6.8E+01	2.3E+05	4.8E+00	4.3E+05	
	2.7E+07	1.5E-02	7.0E+00	1.6E+04		*2.8E+16*		2.7E+04	9.0E+07		1.1E+08	
	1.6E+07	1.3E-02	7.0E+00	1.7E+04		*2.9E+16*		2.7E+04	1.0E+08		1.3E+06	
	2.6E+07	1.4E-02	6.3E+00	1.9E+04		*3.4E+16*		2.5E+04	9.6E+07		1.3E+08	
	4.2E+07	1.2E-02	3.3E+00	1.9E+04		*4.9E+16*		1.3E+04	9.5E+07		1.6E+08	
	5.2E+07	8.5E-03	3.0E+00	1.4E+04		*5.2E+16*		2.0E+04	1.1E+08		1.8E+08	
	4.4E+07	2.6E-02	4.0E+00	4.4E+04		*8.5E+16*		5.1E+04	7.5E+08		1.3E+08	
	2.3E+07	7.4E-03	2.0E+00	2.1E+04		*6.3E+16*		7.2E+02	7.2E+06		1.5E+07	
	3.0E+07	3.5E-02	4.0E+00	7.3E+04		*7.0E+16*		7.6E+03	1.6E+08		8.2E+04	8.1E+07
	4.5E+07	1.7E-02	1.4E-03	5.0E+04		*6.2E+16*			3.7E+03		2.0E+08	
	6.1E+07	2.0E-02	1.0E-02	7.2E+04		*9.2E+16*			1.1E+08		2.9E+08	9.7E+08
	3.9E+07	1.0E-02	1.7E-02	9.3E+04		*9.8E+16*			1.4E+06		2.4E+08	
	5.0E+07	3.3E-03	3.0E-07	7.8E+04		*1.4E+17*			3.5E+07		2.6E+08	1.8E+07
	2.4E+07	5.1E-03	1.7E-06	8.0E+04		*1.3E+17*			7.8E+05		2.7E+08	1.1E+05
	2.2E+07	5.0E-03	9.5E-07	9.5E+04		*1.6E+17*			5.4E+07		3.4E+08	7.5E+04
	4.6E+07	3.4E-03	6.3E-08	1.3E+05		*2.4E+17*			1.4E+06		4.2E+08	
	6.9E+07	1.6E-03	1.7E-09	1.5E+05		*2.9E+17*			1.5E+07		4.0E+08	4.9E+04
	8.2E+07	2.2E-03	4.5E-09	1.6E+05		*2.9E+17*			1.3E+07		4.4E+08	3.6E+04

e characters.
functions and the activity of reprocessed fuels.
ced measured activities).

Liquid releases

Table 10-2

ague reprocessing plants - GT1 source term

135Cs	137Cs	144CePr	203Hg	238Pu	239+240Pu	241Pu	241Am	242Cm	243Cm	244Cm	245Cm	246Cm
	4.5E+04		3.0E+08	3.1E+00	2.4E+02	4.9E+02	1.3E+00	1.3E-01	2.5E-05	7.2E-05		
	1.3E+05		1.3E+09	1.4E+01	6.7E+02	2.8E+03	7.7E+00	1.6E+00	4.8E-04	1.5E-03		
	4.2E+05		9.6E+08	8.6E+01	2.2E+03	2.1E+04	6.2E+01	3.3E+01	1.7E-02	6.0E-02		
	4.3E+05			7.3E+01	2.3E+03	1.7E+04	4.9E+01	1.9E+01	8.4E-03	2.8E-02		
	2.8E+05		7.4E+07	5.3E+01	1.5E+03	1.2E+04	3.7E+01	1.7E+01	8.0E-03	2.8E-02		
	8.1E+08		3.8E+08	3.3E+02	3.7E+03	7.8E+04	2.7E+02	3.9E+02	4.0E-01	1.9E+00		
	1.0E+06		1.1E+09	4.5E+02	5.3E+03	1.1E+05	3.7E+02	4.9E+02	4.6E-01	2.2E+00		
	9.7E+05		4.8E+08	4.7E+02	5.0E+03	1.1E+05	3.9E+02	5.9E+02	6.2E-01	3.1E+00		
	1.6E+06		4.1E+09	1.3E+03	1.4E+04	3.1E+05	1.1E+03	1.6E+03	1.7E+00	8.2E+00		
	2.6E+06		1.4E+09	1.7E+03	1.3E+04	3.6E+05	1.4E+03	2.8E+03	3.8E+00	2.2E+01		
1.4E+00	1.6E+06		2.4E+08	1.9E+03	7.1E+03	3.0E+05	1.0E+03	2.5E+03	4.6E+00	3.5E+02	1.9E-02	3.0E-03
2.7E-01	2.2E+05	4.1E+06	1.6E+08	7.2E+03	1.2E+04	6.0E+05	2.9E+03	3.3E+03	3.4E+01	4.3E+03	4.1E-01	1.1E-01
1.2E+01	7.5E+06	2.3E+07	6.0E+06	1.4E+04	1.7E+04	1.1E+06	5.0E+03	7.5E+03	6.7E+01	8.5E+03	7.9E-01	2.1E-01
1.0E+01	4.6E+06	5.6E+05	2.0E+06	1.4E+04	1.7E+04	1.3E+06	7.8E+03	3.2E+03	5.1E+01	5.4E+03	4.1E-01	8.2E-02
8.3E-03	3.3E+03			1.9E+04	2.0E+04	1.6E+06	1.2E+04	2.8E+03	7.5E+01	8.3E+03	6.7E-01	1.4E-01
1.3E+00	4.4E+05			2.7E+04	2.1E+04	1.8E+06	1.3E+04	4.1E+03	1.2E+02	1.3E+04	1.2E+00	2.7E-01
2.1E+01	7.3E+06			2.8E+04	2.5E+04	2.2E+06	1.8E+04	3.4E+03	1.1E+02	1.2E+04	9.8E-01	2.0E-01
1.4E+01	3.8E+06			4.6E+04	3.0E+04	3.2E+06	2.6E+04	2.5E+03	1.8E+02	2.0E+04	1.7E+00	3.6E-01
1.7E-01	5.4E+04			4.7E+04	3.5E+04	3.6E+06	3.1E+04	3.0E+03	2.0E+02	2.4E+04	2.0E+00	4.5E-01
2.8E+02	7.5E+07	8.3E+07		3.4E+06	1.5E+06	1.8E+08	1.5E+06	1.4E+05	1.7E+04	2.4E+06	2.4E+02	6.4E+01
1.1E+01	3.1E+06			2.3E+04	1.4E+04	1.5E+06	1.5E+04	5.6E+02	1.0E+02	1.3E+04	1.2E+00	2.8E-01
6.4E+00	1.8E+06			1.7E+05	8.6E+04	1.0E+07	9.0E+04	5.3E+03	8.2E+02	1.1E+05	1.0E+01	2.6E+00
4.6E+01	1.3E+07			3.0E+04	1.7E+04	2.1E+06	1.9E+04	4.3E+02	1.4E+02	1.8E+04	1.5E+00	3.8E-01
2.6E-01	7.1E+04			6.5E+04	3.0E+04	3.7E+06	3.6E+04	6.8E+02	3.4E+02	4.7E+04	4.7E+00	1.3E+00
6.4E+00	1.7E+06			6.6E+04	3.1E+04	3.6E+06	4.5E+04	2.3E+02	3.3E+02	4.3E+04	4.4E+00	1.2E+00
1.3E+00	3.0E+05			5.9E+04	3.5E+04	4.1E+06	*6.1E+04*	2.2E+02	5.0E+02	6.6E+04	7.9E+00	2.2E+00
6.5E-01	1.6E+05			1.1E+04	1.1E+05	1.3E+07	1.7E+05	6.4E+02	1.2E+03	1.5E+05	1.6E+01	4.3E+00
5.7E-01	1.5E+05			1.3E+04	9.1E+03	1.0E+06	1.4E+04	4.35E+01	8.7E+01	1.1E+04	1.2E+00	3.0E-01
1.7E+00	3.9E+05			9.0E+03	6.4E+03	7.2E+05	1.2E+04	3.6E+01	8.7E+01	1.2E+04	1.4E+00	4.0E-01
6.3E-01	1.4E+05			7.3E+03	5.1E+03	5.5E+05	1.0E+04	2.9E+01	7.1E+01	9.3E+03	1.2E+00	3.4E-01
1.5E+00	3.5E+05			1.6E+04	8.1E+03	8.6E+05	1.6E+04	4.1E+01	9.9E+01	1.3E+04	1.6E+00	4.5E-01

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functions and the activity of reprocessed fuels.
ced measured activities).

Table 11

Centre Manche:
Inventory of the main radionuclides affecting safety (in GBq)

Period 1969 - 1994		
Radionuclide	Period (year)	Activity (GBq)
^{3}H	12.3	1.27 E+06
^{10}Be	1.6×10^{6}	1.39 E+00
^{14}C	5730	2.77 E+05
^{36}Cl	3×10^{5}	2.60 E+03
^{41}Ca	1.4×10^{5}	3.46 E+01
^{59}Ni	7.5×10^{4}	4.35 E+04
^{60}Co	5.2	1.49 E+07
^{63}Ni	100	5.42 E+06
^{79}Se	6.5×10^{4}	2.77 E+01
^{90}Sr	29	2.59 E+06
^{93}Mo	3500	6.91 E+00
^{93}Zr	1.5×10^{6}	3.50 E+02
^{94}Nb	2.5×10^{4}	2.40 E+03
^{99}Tc	2.1×10^{5}	1.75 E+03
^{107}Pd	6.5×10^{6}	1.57 E+01
^{108}Ag	127	6.93 E+03
^{121}Sn	50	1.39 E+02
^{126}Sn	10^{5}	6.24 E+01
^{129}I	1.6×10^{7}	4.27 E+00
^{135}Cs	2.3×10^{6}	3.68 E+02
^{137}Cs	30	1.13 E+07
^{151}Sm	90	6.35 E+04
^{226}Ra	1620	9.08 E+03
^{228}Ra	5.7	3.23 E+04
^{232}Th	1.4×10^{10}	1.11 E+03
^{232}U	70	9.94 E+01
^{233}U	1.6×10^{5}	5.35 E+00
^{234}U	2.2×10^{5}	3.31 E+03
^{235}U	7×10^{8}	2.61 E+02
^{236}U	2.3×10^{7}	1.04 E+01
^{238}U	4.5×10^{9}	3.25 E+03
^{237}Np	2.1×10^{6}	1.20 E+02
^{238}Pu	88	9.11 E+04
^{239}Pu	2.4×10^{4}	2.17 E+05
^{240}Pu	6550	4.42 E+04
^{242}Pu	3.7×10^{5}	2.24 E+02
$^{241}Pu\ \beta$	14.4	1.06 E+07
^{241}Am	432	3.80 E+04
^{243}Am	7400	2.66 E+02
^{242}Cm	0.5	8.48 E+02
^{243}Cm	28.5	2.55 E+01
^{244}Cm	18.1	2.15 E+04

Table 12

Centre Manche:
Comparison table of activities per unit volume of beta emitters measured by the IPSN and ANDRA in the Sainte-Hélène (Point R6)

DATE	IPSN MEASUREMENTS		ANDRA MEASUREMENTS
	Radionuclides	Activity per unit volume	Total beta activity per unit volume
02/02/1987			1.5 $Bq.l^{-1}$ including 0.3 $Bq.l^{-1}$ of ^{40}K
03/02/1987	^{137}Cs ^{134}Cs ^{60}Cs	1052 $mBq.l^{-1}$ 15.2 $mBq.l^{-1}$ 25.5 $mBq.l^{-1}$	
06/02/1987			2.6 $Bq.l^{-1}$ including 0.52 $Bq.l^{-1}$ of ^{40}K
09/02/1987			5 $Bq.l^{-1}$ including 0.6 $Bq.l^{-1}$ of ^{40}K
11/02/1987	^{137}Cs ^{134}Cs ^{60}Cs	1267 $mBq.l^{-1}$ 29.6 $mBq.l^{-1}$ 22.9 $mBq.l^{-1}$	
13/02/1987			1.3 $Bq.l^{-1}$ including 0.42 $Bq.l^{-1}$ of ^{40}K

Table 13

Flamanville liquid releases

1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
5.20	14.00	3.90	1.10	0.70	0.08	0.17	0.10	0.03	0.03
220.00	359.00	53.80	13.8	16.8	2.1	1.78	2.60	0.95	0.73
9.10	25.40	17.70	9.50	4.80	2.12	1.54	1.10	0.58	0.33
5.90	14.00	8.50	5.30	6.60	2.74	1.14	1.30	0.22	0.19
18.20	49.50	2.40	0.40	5.70	0.44	0.31	0.42	0.12	0.1
1.93	1.45	0.50	0.10	0.40	0.15	0.16	0.09	0.03	0.03
0.72	2.30	1.50	0.50	1.30	1.33	0.67	0.95	0.46	0.12
1.12	3.60	1.80	0.70	1.60	1.65	0.88	1.20	0.80	0.35
6.12***	45.00***	31.30***	16.80***	8.50***	3.75***	2.50*	1.60*	1.40*	0.79*
25.80	25.70	24.30	26.80	24.80	29.40	30.90	27.80	29.70	32.2
42	36	33	48	37	34	35	30	31	35

/Gwe.year

$$1.77\left(\frac{\sum_{1993}^{1996}\text{releases } {}^{63}Ni \text{ activity}}{\sum_{1993}^{1996}\text{releases } {}^{60}Co \text{ activity}}\ \text{ratio}\right).$$

ence of Sr 89 and 90 (<10 $Bq.l^{-1}$) and ^{36}Cl (<20 $Bq.l^{-1}$).

Table 14

Flamanville gazeous releases

Xe	^{135}Xe	^{41}Ar	^{3}H	^{131}I	^{133}I	^{58}Co	^{60}Co	^{134}Cs	^{137}Cs	^{14}C*
d.	n.d.	n.d.	1.5E+09	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	6.6E+08
E+13	4.5E+07	3.2E+10	4.2E+11	9.7E+06	n.d.	7.5E+05	2.1E+06	n.d.	6.7E+02	1.7E+11
E+13	2.2E+10	1.5E+11	1.8E+12	1.3E+07	2.4E+06	7.4E+06	7.7E+03	1.3E+05	3.8E+01	3.4E+11
E+11	1.8E+09	1.3E+11	1.1E+12	2.6E+07	n.d.	2.8E+06	6.0E+05	n.d.	n.d.	3.4E+11
E+11	2.6E+09	1.0E+11	1.8E+12	1.5E+07	2.8E+06	1.1E+01	3.5E+02	n.d.	n.d.	3.2E+11
E+10	1.0E+07	5.5E+10	1.5E+12	8.0E+06	n.d.	2.0E+05	2.6E+03	n.d.	n.d.	3.6E+11
E+11	3.2E+08	6.5E+10	1.1E+12	6.3E+07	3.9E+05	1.8E+05	1.7E+05	1.8E+05	2.1E+05	3.3E+11
E+11	n.d.	5.8E+10	1.3E+12	2.8E+08	n.d.	1.3E+02	5.3E+03	1.2E+04	2.7E+05	3.9E+11
E+11	1.3E+09	1.2E+11	1.5E+12	2.7E+07	2.4E+05	6.3E+05	2.2E+06	3.7E+03	2.3E+04	4.1E+11
E+11	n.d.	1.2E+11	1.1E+12	7.9E+07	5.0E+06	8.1E+05	1.3E+06	n.d.	n.d.	3.7E+11
E+09	2.3E+07	1.2E+11	1.3E+12	2.7E+06	2.5E+03	1.1E+06	7.2E+04	n.d.	n.d.	4.0E+11
E+10	n.d.	7.0E+10	1.8E+12	3.1E+07	4.0E+06	3.4E+05	1.3E+04	n.d.	n.d.	4.3E+11

GBq/GWe.year
sed for the impact study for EDF's Gaseous Releases Authorization Request (DAR).

Table 15

Details of liquid releases from the Cherbourg Harbour

	RELEASES	
Year	Activity ^{3}H (MBq)	Activity without ^{3}H (MBq)
1980	/	0.81
1981	/	0.85
1982	/	14.84
1983	/	6.55
1984	/	64.97
1985	/	2846
1986	/	1154
1987	/	801.3
1988	/	3011.24
1989	/	442.35
1990	/	281.67
1991	/	230.03
1992	/	804
1993	1604	826
1994	289	342
1995	1790	623
1996	50	100
1997	660	223

Table 16

Details of gaseous releases from the Cherbourg Harbour

	RELEASES	
Year	Gas Activity (MBq)	Halogen activity (MBq)
1980	/	/
1981	/	/
1982	/	/
1983	334	/
1984	540	/
1985	31.45	/
1986	7.51	/
1987	4.84	/
1988	3.4	/
1989	/	/
1990	/	/
1991	5.02	/
1992	12.46	0.617
1993	0.055	0.3
1994	18.9	1.48
1995	8.5	2.35
1996	4.8	0.48
1997	/	0.28

Table 17

Details of liquid releases from the Cherbourg Harbour Arsenal (in MBq)

clide	Activity per radionuclide
o	5.34E+00
o	5.18E+02
n	6.16E+00
o	8.57E+00
o	1.92E+01
g	3.02E+01

clide	Activity per radionuclide
o	4.08E-01
o	7.38E+02
n	1.01E+01
o	3.10E-02
o	1.97E+01
g	2.65E+01
s	6.22E-01
	1.60E+03

clide	Activity per radionuclide
lated ty	3.42E+02
	2.89E+02

1995	Radionuclide	Activity per radionuclide
	^{58}Co	9.63E+01
	^{60}Co	8.95E+01
	^{54}Mn	4.11E+01
	^{124}Sb	2.42E+02
	^{125}Sb	7.22E+00
	^{110m}Ag	1.41E+00
	^{137}Cs	1.54E-01
	^{24}Na	2.68E+01
	^{59}Fe	1.53E+00
	^{76}As	5.73E-01
	^{99}Mo	4.96E+01
	^{99}mTc	4.99E+01
	^{122}Sb	2.68E+01
	^{187}W	2.36E+00
	^{51}Cr	8.29E-01
	^{3}H	1.79E+03

1996	Radionuclide	Activity per radionuclide
	^{58}Co	1.01E+00
	^{60}Co	9.32E+01
	^{54}Mn	2.35E+00
	^{124}Sb	2.74E+00
	^{125}Sb	8.01E-01
	^{110m}Ag	1.41E-01
	^{3}H	5.00E+01

1997	Radionuclide	Activity per radionuclide
	^{58}Co	1.03E+02
	^{60}Co	1.11E+02
	^{54}Mn	5.44E+00
	^{125}Sb	3.06E-01
	^{110m}Ag	2.96E+00
	^{3}H	6.67E+02

Table 18

Details of gaseous releases from the Cherbourg Harbour Arsenal (in MBq)

uclide	Activity per radionuclide
e	8.41E+00
r	8.34E-01
e	3.08E+00
Xe	1.34E-01
	6.17E-01

uclide	Activity per radionuclide
e	5.10E-02
e	4.40E-03
	3.03E-01

uclide	Activity per radionuclide
e	1.88E+01
e	3.38E-02
	1.48E+00

1995	Radionuclide	Activity per radionuclide
	^{133}Xe	8.23E+00
	^{41}Ar	6.87E-02
	^{133m}Xe	2.27E-01
	^{135}Xe	2.28E-02
	^{131}I	2.34E+00

1996	Radionuclide	Activity per radionuclide
	^{135}Xe	1.80E-03
	^{133}Xe	2.83E+00
	^{133m}Xe	3.04E-02
	^{131}I	4.80E-01

1997	Radionuclide	Activity per radionuclide
	^{131}I	2.89E-01

Table 19

Reconstruction of the source term associated wih the silo fire on January 6, 1981

Isotope	Total reprocessed activity in 1980 (Bq)	Maximum estimate of released Cs 137 (Bq)	Suspension coefficient	Corrected factor	Estimated released activity (Bq)
Cs 137	9.49E+16	7.4E+11	50.0%	7.8E-06	7.4E+11
Cs 134	1.45E+16	(20 Ci)	50.0%	7.8E-06	1.13E+11
Ru 106*	9.0E+16		25.0%	3.9E-06	3.5E+11
Rh 106*	9.0E+16		2.0%	3.1E-07	2.8E+10
Sr90 (Y90)	7.06E+16		2.0%	3.1E-07	2.2E+10
H3	3.50E+14		100.0%	1.56E-05	5.46E+09
I129	2.82E+10		75.0%	1.17E-05	3.3E+05
Sb 125	4.53E+15		2.0%	3.1E-07	1.4E+09
Kr85	8.65E+15		100.0%	1.56E-05	1.35E+11
Ce 144	2.73E+17		0.5%	7.8E-08	2.13E+10
Ag 110m	2.37E+15		0.5%	7.8E-08	1.85E+08
Co60	6.96E+14		2.0%	3.1E-07	2.16E+08
Pu238	2.73E+14		0.5%	7.8E-08	2.13E+07
Pu239	9.88E+14		0.5%	7.8E-08	7.7E+07
Pu240	8.26E+14		0.5%	7.8E-08	6.4E+07
Pu241	5.46E+16		0.5%	7.8E-08	4.26E+09
Am241	2.17E+14		0.5%	7.8E-08	1.69E+07

* Activities updated on 06/01/1981 (estimated release = total reprocessed activity x corrected factor)

Table 20

Comments on reconstruction of the source term due to the silo fire On January 6, 1981

Two types of radioelements can be distinguished:

- volatile radioelements: Gases (Kr, H), I, Cs, Ru, Rh, Sr, Sb, Co
- non-volatile radioelements: Pu, Am. Ce

For volatile radioelements, the results are output from the American reference CEGB report - RD/B/6230/R89 - "The release of fission products from Uranium metal: a review by PC Minshall" - March 1989.

This report describes experiments on the oxidation of irradiated uranium metal in air between 800 and 1200°C.

We used the values corresponding to 1200°C, knowing that the ratio between the suspension coefficients for cesium and ruthenium (other major contributors in terms of released activity) does not vary much between 800°C and 1200°C.

Compared with Cesium, we took the suspension coefficient for gases (Kr, H) and iodine and multiplied it by 2 and 1.5 respectively, to take account firstly of the temperature gradient in the silo, and secondly of their emission that becomes significant at lower temperatures.

For non-volatile radio-elements, the results are output from the American report DOE - HDBK - 3010 - 94 - "Airborne release fractions/rates and respirable fractions for non-reactor nuclear facilities" - Dec 94.

This report describes results concerning emissions of aerosols following oxidation of metallic uranium.

We assumed that the fraction put into suspension is 1% corresponding to the oxidation of molten metal droplets, taking into account the presence of uranium in powder form in the silo and the assumed temperatures.

PART B

CRITICAL REVIEW OF MEASUREMENTS IN THE ENVIRONMENT

1. OBJECTIVES

The objective of this group is to collect and interpret the results of measurements made in the environment by the various participants. The adopted approach consists of performing the following in sequence:

- establishing an inventory of all samples and measurement types that have been made from when the facilities were first commissioned;
- standardizing the presentation of measurement results and collecting them in the form of tables and curves;
- interpreting the results thus collected.

It is not sufficient to collect results, the variability of measurements within a single laboratory, and between different laboratories, also needs to be analyzed. The parameters that influence radioactivity levels in the environment and that could explain the observed differences then need to be defined.

This work forms a basis for validating the values used for comparison with the results of models for transfers into the environment (action by GT3) and/or used directly for dosimetric reconstruction (action by GT4).

The laboratories that made radioactivity measurements in the Nord-Cotentin provided an organization team with the data. This team produced summary documents which were corrected by all members of the group and discussed in GT2 meetings.

GT2 did everything possible to be exhaustive in the inventory of sampling and measurement types. However, for measurement results, considering the large number of data to be collected and verified within a limited time, it was decided to give priority to information essential to GT3 (comparison between models and methods) and GT4 (estimate of doses to populations). Therefore, the following selection criteria were applied:

- Give priority to processing of results for which several organizations have taken samples at the same location and at the same time, so that they can be compared with each other;
- Prefer to use indicators[21] for which long series of measurements are available, and for which existing sampling stations can give the best coverage of the Nord-Cotentin area, so that the variation of radioactivity with time can be monitored;
- Emphasize points of special interest such as some elements of food chain (milk), or the impact of an incident localized in time and in space, for each individual case;
- Give the priority to results available in computer form so that they can be processed quickly.
- Only results after 1978 are considered. Starting from the end of the 1970s, a lot of data were computerized but measurements also improved in quality, particularly due to the use of GeLi detectors for gamma spectrometry to replace NaI detectors and which give better results. Finally, the study covers the period up to 1997, whenever measurement results for the year 1997 are available.

[21] NOTE: The term “indicator” is used here to mean a sample type (sea water, sediment, animal, vegetable, etc.) for which a radioactivity measurement was made.

The work sequence adopted by GT2 was followed in order to satisfy the priorities formulated by GT3 and GT4. This hierarchy is maintained in the presentation of the results.

GT2 includes representatives of laboratories that took samples and radioactivity measurements in the Nord-Cotentin.

These organizations are ACRO (Association pour le Contrôle de la Radioactivité dans l'Ouest - Association for Radiation Inspection in the West), ANDRA (Agence Nationale pour la gestion des Déchets Radioactifs - National Agency for the Management of Radioactive Waste), COGEMA (COmpagnie GÉnérale des MAtières nucléaires - General Nuclear Materials Company), CRII-RAD (Commission de Recherche et d'Information Indépendante sur la RADioactivité - Independent Research and Information Commission on Radioactivity), EDF (Electricité De France – French Electricity Generating Board), IPSN/LERFA (Institut de Protection et de Sûreté Nucléaire / Laboratoire d'Etudes Radioécologiques de la Façade Atlantique - Nuclear Protection Safety Institute / Atlantic Seaboard Radioecological Studies Laboratory), LDA (Laboratoire Départemental d'Analyses - Departmental Analysis Laboratory), Marine Nationale (French Navy) - GEA (Groupe d'Etudes Atomiques - Atomic Studies Group) and the OPRI (Office de Protection contre les Rayonnements Ionisants - Office for Protection against Ionizing radiations).

This group also includes persons well known for their expertise in studies of radioactivity in the environment.

2. HOMOGENEITY AND VARIABILITY PROBLEMS

This work involves a large amount of data (more than 500 000 determinations of radionuclides – see Appendix 1, inventory). These data are heterogeneous. Their interpretation involves comparisons between the results supplied by the various laboratories, namely concentrations of radionuclides in the various indicators. The indicators treated are not necessarily indentical in the different laboratories; the same is true for the locations from which samples are taken, and their frequencies.

Furthermore, the principles of sampling, processing of samples, and measurements vary from one laboratory to another, leading to different results between laboratories for the same indicator taken at the same location at the same time (*in particular, a result may be below the detection limit for one laboratory, while it is above the detection limit for another laboratory).*

These differences are largely related to the **end purpose of measurements for different participants:**

- the task of some laboratories is radiological monitoring; therefore, the purpose is to verify that regulatory requirements are respected, in other words that releases do not exceed authorized limits; they thus take samples and make measurements within the framework of this inspection task, which explains why their detection limits are sufficiently low to satisfy authorization requirements, but are relatively high considering current technical possibilities;
- other laboratories carry out research work in order to explain transfer mechanisms and to predict the future of radionuclides in as much detail as possible. This involves detailed investigations of the distribution of radionuclides, making it essential to use the lowest possible detection limits;
- non governmental laboratories carry out measurements whenever necessary.

Thus, data need to be compared with caution due to the difference in procedures at different laboratories.

Other sources of variability may be considered in addition to the above, that can have an influence on radionuclide concentrations in indicators and which need to be taken into account for correct radioecological interpretation. The main factors on which radioecologists have been working (outside the Nord-Cotentin Radioecology Group) are:

- “response" times (to create an equilibrium) of indicators to fluctuations in releases;
- physicochemistry and bioavailability of radionuclides;
- seasonal physiological cycles (growth, reproduction, etc.);
- ecology of animal and vegetable species (immersion time, etc.);
- transfer pathways (role of sediments, sea spray, etc.);
- size grading and mineralogy of sediments;
- sources other than industrial (background noise due to fallout, etc.)

3. INVENTORY OF SAMPLES AND MEASUREMENT TYPES

3.1. General methodology

GT2 set down a strategy by which each participating organization supplies:

- firstly a list of methods (of sampling, processing and measurement);
- secondly, an inventory of samples and measurement types that it made, in the form of a table, specifying:
  - the species or sample type (sea water, sediment, living species, etc.);
  - the location from which the sample was taken;
  - the sampling method;
  - the method of processing the sample and the fraction concerned by the measurement;
  - the measurement type;
  - the year of the measurement, the frequency, the start date and the end date in the case of a periodic measurement.

The following columns have been added to make it easier to read the table:

- an Environment code (MAR (SEA), TER (LAND), Continental Aquatic),
- a Nature code, corresponding to categories of sample types,
- the name of the responsible laboratory (the owner of the sample and the measurement result),
- the name of the laboratory that made the measurement.

The first difficulty encountered was the result of differences in the labels used by organizations to fill in uncoded items such as “the species or sample type”, “the sampling location”, etc. Therefore, one major task that had to be done at the beginning was to do everything possible to harmonize these descriptions, taking care to check their interpretation with each organization. A second task was then to identify these labels and to prepare lists. These lists are attached to the inventory table itself.

The second difficulty was to choose a presentation method that makes it possible to quickly access information contained in this inventory. The table includes hundreds of thousands of measurements and although it is presented in the form of a paper listing, it is not very easy to read it in this form. Data were stored in a Microsoft EXCEL version 5.0 file, so that the inventory can be more easily used. This folder contains several worksheets, with a rudimentary interface that facilitates viewing the data. A preliminary selection tool extracts data as a function of "Environment code", "Nature code", "Responsible laboratory" and "Measurement type" criteria. Data are available in table form and can be imported by database management programs.

The EXCEL file cover page is as follows:

Inventories of samples taken and types of radioactivity measurements made in the Nord-Cotentin

Nord-Cotentin Radioecology Group
GT2 "Critical review of measurements in the environment"
ACRO / ANDRA / COGEMA / CRII-RAD / EDF / GEA / IPSN / LDA 50 / OPRI
(Organization team: B. Fiévet, P. Germain, M. Masson, IPSN/LERFA)
January 1999

Access to the complete inventory	**Preliminary selection**
List of laboratories, contacts	Processing codes, fraction
Environment, nature codes	Sample location codes
List of indicators, species	Measurement frequency codes
Sampling method codes	Measurement type codes

The third difficulty is to evaluate the number of measurements listed in the inventory. Note that this inventory lists measurements of clearly identified radio-elements, and also measurements of the total activity, like the alpha or beta activity, and also complete analyses like gamma spectrometry that can be used to determine several radio-elements. Therefore, it was agreed to attempt to evaluate the number of "determinations of radionuclide concentrations or total activity". In order to satisfy this definition, it is necessary to know the number of radioelements measured during gamma spectrometry measurements. However, this number is variable within a very wide range since it depends on each analyzed spectrum. Furthermore, it has changed over the years as a function of the sensitivity of detection instruments and radioactivity levels in the environment. In order to get around this problem, it was decided that on average, one gamma spectrometry analysis was equivalent to five radionuclide determinations. This arbitrary and debatable figure probably results in an underestimate of the required result, but an approximation is essential in order to produce a total count.

Finally, measurements made continuously (for example ambient gamma radiation) were counted like daily measurements, which also results in an underestimate.

3.2. Inventory of sampling, and sample processing and measurement methods (Appendix 1.1)

Description of the methods used to take samples, and to process and measure samples supplied by laboratories are appended, using the presentation adopted by each laboratory.

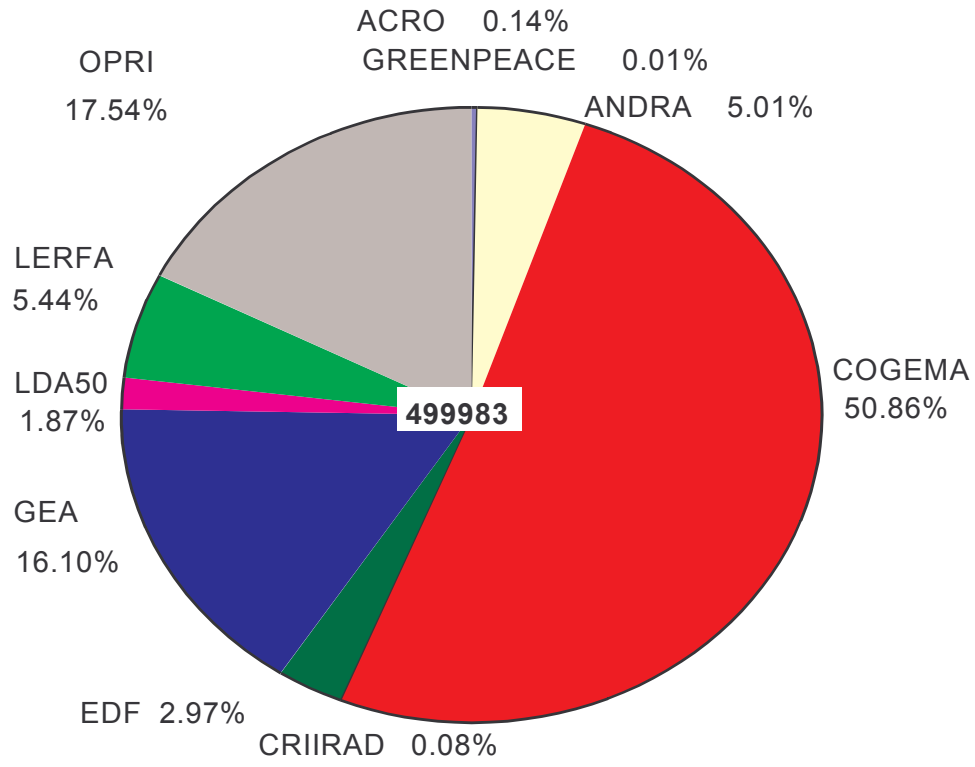
3.3. Inventory of samples and measurement types (Appendix 1.2)

As emphasized in the introduction, it is essential to remember that the participating organizations only listed samples archived in computer form, within the allowed deadlines. A number of data do not appear in this inventory, thus:

- many samples were taken for the purposes of monitoring the environment and were not archived in a computer form compatible with the format of this inventory.
- papers have been presented describing the large amount of scientific work carried out by the IPSN on specific problems. Data are not archived in computer form. Their scope generally goes beyond the Nord-Cotentin region and it is not easy to extract part of the data from a more general study context.

The total number of "determinations of the radionuclides concentration or total activity", and the contribution of each organization, were determined based on calculations carried out using the methods described in 4.1. and are show in the table and pie chart below:

~ 500 000*	ACRO	ANDRA	COGEMA	CRII-RAD	EDF	GEA	GREENPEACE	LDA50	IPSN	OPRI
Nb. of determinations	703	25058	254285	376	14828	80480	35	9334	27200	87684
%	0.14	5.01	50.86	0.08	2.97	16.10	0.01	1.87	5.44	17.54



* This number is evaluated approximately from the inventory. In particular, is it underestimated for gamma spectrometry analyses.

4. CRITICAL REVIEW OF THE RESULTS

4.1. General methodology

The annual arithmetic mean was selected as the magnitude representing radioactivity levels in the environment. However, the result obtained is less than the detection limit for many measurements. Consequently, the principle of taking the average over a year as the "reference value" was considered to be insufficient. Therefore, it was decided to supply all the following information for each radionuclide, for each year, and for each indicator at a location:

- The annual arithmetic mean:

When the series of results contains values less than the detection limit (<LD), these values are replaced by the value of the LD, and the average is then preceded by the < character. A great deal of discussion was carried out on this method of calculating the average. However, if all values exceed the LD, the average is preceded by the = or a blank character.

- The standard deviation:

This is the standard deviation s of the annual average "estimated from a population sample",

$$s = \sqrt{\frac{n\sum x^2 - (\sum x)^2}{n(n-1)}}$$ (when n>1)

- The minimum value and the maximum value of activity levels recorded during the year:

When the maximum value corresponds to a measurement for which the result is less than LD, this value is displayed preceded by the < character. Otherwise, it is preceded by the = character or a blank character.

- The annual number of measurements and the number of results exceeding the detection limit.

- Results are expressed in Bq. kg^{-1} wet weight (ww) for living species, in Bq. kg^{-1} dry weight (dw) for soils and sediments, in $mBq.l^{-1}$ for sea water and drinking water, and in $Bq.l^{-1}$ for milk.

The organizing team drew up summary tables for each indicator and for each radionuclide, specifying the following for each organization and each location:

- the annual average;
- the standard deviation s;
- the maximum recorded value during the year;
- > LD/N: the number of measurement results exceeding LD, compared with the total number of measurements N during the year;

For example: ^{137}Cs in limpets in Saint-Martin Bay, analyzed by the GEA

Organization: Saint-Martin Bay GEA						
year	=	min.	s	=	max.	>LD/N
1978						
1979						
1980	=	0.38	0.12	=	0.51	6/6
1981	=	0.71	0.32	=	1.28	12/12
1982	=	0.74	0.48	=	1.94	12/12
1983	=	0.80	0.43	=	1.48	12/12
1984	=	0.61	0.33	=	1.38	12/12
1985	=	0.67	0.38	=	1.43	12/12
1986	=	0.40	0.30	=	0.95	12/12
1987	<	0.39	0.19	=	0.79	10/12
1988	=	0.42	0.27	=	1.13	12/12
1989	<	0.37	0.16	=	0.66	10/11
1990	<	0.29	0.07	=	0.44	10/12
1991	<	0.20	0.15	=	0.60	7/10
1992	<	0.16	0.05	=	0.24	9/12
1993	<	0.18	0.08	=	0.37	11/12
1994	<	0.16	0.06	=	0.31	8/12
1995	<	0.17	0.03	=	0.21	6/11
1996	<	0.13	0.05	=	0.24	11/12
1997						

In most cases, these summary tables are combined with graphs presenting the variation with time of the annual averages obtained by the different organizations for a radionuclide, an indicator, a location or a sampling area; the maximum values are also shown on graphs to give an additional indication on the graphs, it being understood that the **maximum values must be used with precaution since they only correspond to a single measurement**. The maximum values may be marked on the same graphs as the averages using distinctive symbols, or they may be marked on another graph, depending on the amount of information contained in the graphs.

A comment is then written on the tables and graphs in a standard format with four headings:

- sampling/processing/measurement: this item summarizes the information about sampling, processing and measurement procedures used by the various organizations, which can give different results;

- representativeness (values < LD): this item draws attention to the number of measurements made during the year, and the number of results less than the LD. This observation is very important. Graphs show annual averages calculated from monthly measurements exceeding the LD, annual averages calculated from measurements below the LD, or a single annual measurement, without any distinction. It is obvious that these results do not all have the same statistical weight, and the **graphs must be interpreted with reference to the tables containing all this information;**

- dispersion (standard deviations, maximum): this item gives a quantified idea about the dispersion of results about the average value, and also of the upper limit of the range of observed values. Standard deviations are not marked on the graphs to improve readability;

- specific comments: this item provides details about each radionuclide and the distribution of the concentration in space and in time;

- conclusion: this item summarizes the most important information in a few phrases.

A map of sampling stations is attached to the file for most indicators. Finally, the conclusion, that summarizes the main information to be retained is repeated in the body of this report, while the tables of results, graphs and detailed comments are contained in Appendix 2.

The method used by GT2 for processing data was studied by a Working Group run by Mrs. Sené. The members of this group concentrated particularly on statistical aspects. The conclusions agree with the procedure adopted by GT2.

4.2. Discussion of results

As explained in the introduction, the chronology for processing measurement results in six phases was designed to satisfy the essential needs of GT3 and GT4.

PHASE	RADIONUCLIDES AND INDICATORS
1st phase	• Main gamma emitters: ^{137}Cs, ^{125}Sb, ^{106}RuRh, ^{60}Co, ^{40}K. • Marine environment and terrestrial environment.
2nd phase	• Alpha, beta emitters and iodine isotopes and ambient gamma radiation: ^{3}H, ^{14}C, ^{90}Sr, ^{99}Tc, ^{131}I, ^{129}I, ^{238}Pu, $^{239\&240}$Pu, ^{241}Am, ^{244}Cm, ^{210}Po. • Marine environment and terrestrial environment depending on the availability of results for each radionuclide.
3rd phase	• Other gamma emitters: ^{54}Mn, ^{58}Co, ^{65}Zn, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{110m}Ag, ^{134}Cs, ^{144}Ce, ^{154}Eu. • Limpets (only).
4th phase	• Other gamma emitters (same as 3rd phase). • Various sea and land indicators.
5th phase	• The main gamma emitters, counts, total alpha, total beta and tritium. • Waterways.
6th phase	• Main gamma emitters, ^{90}Sr, tritium, total beta. • Incidents. • Various indicators.

Thus, the first phase applies to the five gamma emitters for which most information is available, in other words which give results for the main indicators in marine and terrestrial environments.
However in order to validate the model, it is also important to take into account measurement results for other emitters, particularly alpha and beta emitters (2nd phase) and "other gamma emitters" (limpets in the 3rd phase and other marine and land emitters in the 4th phase).

Finally, it was agreed to make a distinction for the special case of waterways (5th phase) and the results of measurements in different indicators following incidents (6th phase).
These various phases will be examined in sequence.
A number of measurements, for example concerning gases, rainwater, etc., are listed in the inventory. The corresponding results were not discussed by GT2 within the allocated time, due to the constraints mentioned above.

Warnings

- The comments about the representativeness of results should be treated with caution. A lack of data in an annual average cell in the spreadsheets received by the organization team may be due to:

    - the fact that one or more radionuclides were not included in the interpretation of a spectrum,
    - or that the result is less than the detection limit, and that this detection limit was not identified.

- The methodology used by GT2 and presented in section 4.1 specifies the use of the detection limit (LD) for annual average calculations. However, not all laboratories archive the LD for each measurement result, some archive the decision threshold (SD) rather than the LD. Consequently for practical reasons, **the LD term used in the work done by GT2 covers the following three concepts:**

    - The detection limit (LD) *stricto sensu* (calculated for each measurement).
    - The decision limit (= LD/2).
    - An average detection limit calculated for the entire period concerned (1978-1997).

- The data for ruthenium 106 are expressed by the sum ^{106}RuRh (= twice ^{106}Ru).

- Data for cerium 144 are expressed by the sum ^{144}CePr (= twice ^{144}Ce).

- The BETOX measurement (total Beta of the oxalates precipitate) corresponds to <u>at least twice the ^{90}Sr</u> (actually ^{90}Sr + ^{90}Y + possibly Barium and other rare earths).

- The organization group received results **<u>after September 1998</u>**. Therefore they could not be analyzed with the others and are included in the appendices as they were received.

4.2.1. First phase: ^{137}Cs, ^{125}Sb, ^{106}RuRh, ^{60}Co, ^{40}K in various indicators

The choice was made initially on the following main gamma emitting radionuclides: ^{137}Cs, ^{125}Sb, ^{106}RuRh, ^{60}Co and the natural element ^{40}K. These radionuclides represent a large number of data concerning indicators for which long series of samples have been taken, and for which the results are frequently greater than the LD values. Their physicochemical characteristics are different (they influence dispersion and bio-availability processes), providing GT3 with a spectrum of a small number of elements, but containing a great deal of information that they are useful for considering various transfer types within the framework of comparing measurement results with model estimates. The following indicators were examined in priority, to satisfy the needs of the other GT (GT3 and GT4):

- For the marine environment: sea water, marine sediments, fucus (seaweed), molluscs (limpets, mussels, oysters), crustaceans, fish.

- For the terrestrial environment: drinking water (for human consumption), cow milk, vegetables, grass, sediments in rivers.

The results of this first phase are grouped <u>by indicator</u>.

Marine environment

Sampling locations were grouped within specific areas whenever possible, particularly for mobile species such as crustaceans and fish. These areas are defined by means of radioecological studies carried out in the region concerned, and which have demonstrated a spatial distribution of radionuclides in indicators that depends on the particular hydrodynamic conditions around the North-West Cotentin, in the Gulf of Normandy/Brittany and close to Barfleur (presence of eddy currents).

These areas are as follows, working from the South-West towards the East: the West Coast (Gulf of Normandy/Brittany as far as the Cap du Rozel); La Hague (Cap du Rozel to Saint-Martin Bay); North Coast (from Saint-Martin Bay to Barfleur); East Coast (South of Barfleur). However, note that the results supplied by COGEMA concerning fish and crustaceans indicated as originating from the West Coast area actually correspond to species that could come from the West Coast or La Hague areas as defined above.

- Sea water

COGEMA, OPRI, GEA, IPSN/LERFA and CRII-RAD have taken samples.

Sea water was sampled offshore at the Le Rozel, Cap Jobourg, Cap La Hague, Cap Jardeheu stations, and on the coast by the Granville, Barneville, Sénival Bay, Goury, Querqueville, Cherbourg Bay, Brick Bay, Barfleur stations.

  - The distribution of radionuclides within the mass of water close to the La Hague release points is not yet uniform.
  - For ^{106}RuRh and ^{60}Co, the higher measurement dispersion is related particularly to the complex physicochemical properties of these elements.
  - Some results from different laboratories show large differences for the same location, for example like ^{106}RuRh in 1987 off Jobourg:
    - COGEMA: average 1590 mBq.l^{-1}, maximum 4400 mBq.l^{-1}
    - GEA: average 199 mBq.l^{-1}, maximum 227 mBq.l^{-1}
  - Nevertheless in general, measurements provided by the various laboratories are consistent and their variation in time shows a reduction in levels since the 80-85 period, which is in agreement with the variation in releases from COGEMA La Hague reprocessing plants.
  - The co-precipitation technique starting from large volumes of sea water with a long count time, have provided values exceeding detection limits for a large number of measurements. Thus, it is proposed to use the GEA and IPSN results for the objectives of GT3 and GT4, while using values obtained by other laboratories particularly for the period before 1982, for which there were no GEA or IPSN results.

- Marine sediments

Samples were taken by COGEMA, OPRI, GEA, CRII-RAD.

The stations used were Barneville-Carteret, Sciotot, Flamanville, Vauville, Moulinets Bay, Ecalgrain Bay, Goury, Cap Voidries, Saint-Martin Bay, Querqueville, Cherbourg Bay, and Brick Bay.

  - The interpretation of observed differences was very much hindered by the lack of data about size grading, mineralogy and the organic fraction of sediments.
  - However, in general there is good consistency between the results obtained by the different laboratories.
  - When samples are taken on the coast and offshore, activity levels are higher offshore.

- For ^{60}Co, there is no obvious relation between the change in concentrations and quantities released by the La Hague plant. There are no doubt many factors, including variable physicochemical forms and badly understood interactions with particles.
- The ^{137}Cs, $^{106}RuRh$ and ^{125}Sb results of samples taken by COGEMA in 1980 from the Moulinets Bay, are very significantly different from other measurements. These exceptional levels are due to the release pipe break that occurred between the beginning of September and the end of November 1979. This rupture modified the dispersion pattern, and resulted in an increase in radioactivity levels on the shore.
- Results are expressed in Bq. kg^{-1} dw, which could have an incidence on external irradiation calculations for GT4 since the sediment is actually wet. Concerning this latter point, the GEA determined dw / ww ratios (in %) of shore sediments taken from several beaches in the Nord-Cotentin area, namely Cherbourg (Lucifer) 72.8 ± 1.3 (n = 5), Querqueville 79.7± 0.7 (n = 5) , Urville 77.7 ± 0.6 (n = 5), Saint-Martin Bay 82.7 ± 1.1 (n=5) and Goury 84.3 ± 2.4 (n = 5). The average of the dw / ww ratio for all samples is 79.4 ± 4.5 %.

An extension to this section describes the results of measurements on gamma-emitting radionuclides fixed on sediments located at a permanently immersed point sheltered by Querqueville dike, in Cherbourg Bay (49°40.15 N;1°40.40 W). Maximum markings in marine sediments were detected in this location. Data for this point are additional to the data presented above for marine sediments in Cherbourg Bay.

This sediment sampling point in Cherbourg Bay in the Nord-Cotentin coastal area is the most marked, since it is an area in which sediments consist of fine particles. Elements with long half lives (cobalt, americium), well fixed on particles, accumulate within the sediment mass over time. The reduction in concentrations is caused by variations in releases, partial evacuation of the sediment stock, and modification to the composition of the sediment; variable physicochemical forms and their interactions with particles (for example cobalt) may affect the change in radioactivity levels. The variation of maximum values is very similar to the variation of annual averages, with a few exceptions - ^{137}Cs in 1996, ^{134}Cs in 1996, ^{154}Eu in 1992, ^{214}Pb in 1993, although these exceptions have not been explained.

- Fucus (seaweed)

COGEMA, OPRI, GEA, EDF, LDA50, IPSN/LERFA took samples.

The stations used were: Barneville-Carteret, Sciotot, Flamanville, Diélette, Moulinets Bay, Goury, Barfleur, Gatteville.

- Fucus seaweed is the vegetable bio-indicator for which the largest number of data are available.
- The results of measurements of artificial radionuclides made by the different organizations are generally similar.
- We consider that GT3 can use the results for stations at which samples were taken by a single organization (for example Sciotot, Gatteville) for the purposes of comparisons between calculated values and measured values.

- Limpets (molluscs)

COGEMA, OPRI, GEA, LDA50, CRII-RAD and IPSN/ LERFA took samples.

The stations used were Barneville-Carteret, Sciotot, Flamanville, Diélette, Moulinets Bay, Sénival Bay, Ecalgrain Bay, Goury, La Crecque, Saint-Martin Bay, Urville, Querqueville, Barfleur.

- Limpets (gastropod molluscs) are the animal bio-indicator that laboratories monitored most closely. Results concern the soft parts.
- When several laboratories took measurements at the same location and the same time, the results were similar.
- Concentrations reduced during the 1980's, and since 1990 for ^{137}Cs, ^{106}RuRh, ^{125}Sb, they were very frequently less than the LD. Maximum values rarely exceed twice the value of the average.
- Higher contents were observed for ^{137}Cs, ^{106}RuRh, ^{125}Sb in 1979 and 1980 in the Moulinets Bay, due to the release pipe break that caused dispersion of radionuclides towards the coast.

- Mussels

COGEMA, GEA, IPSN/LERFA took samples.

There are no mussels between Carteret and Barfleur. Mussel beds are located on the West Coast and East Coast of the Cotentin. Samples taken in Cherbourg Bay are related to a population that was artificially and temporarily put into place for experimental purposes only.

- For the West Coast, the number of measurements is lower and standard deviations are such that differences between laboratories are not significant. For the East Coast, it is observed that values obtained by COGEMA and the IPSN are very similar. Maximum values reach 3 to 4 times the average value.
- Differences in the results for the natural element ^{40}K are observed, which can be assigned to natural variability, and undoubtedly methods of sampling and processing samples.
- Greater marking is observed on the East Coast than on the West Coast for all artificial radionuclides, as would be expected considering the hydrodynamic characteristics of the region.

- Oysters

Samples were taken by COGEMA, GEA and OPRI.

Oyster beds are located on the East Coast (Saint-Vaast) and on the West Coast (Blainville and Pirou).

- A small number of measurements was taken.
- When measurements were made by several laboratories at the same location and the same time, results were similar.
- In general, the trend is that levels have been reducing since the 1980s.

- Crustaceans

Samples were taken by COGEMA, OPRI, GEA, EDF, CRII-RAD and GREENPEACE.

Samples were classified in a number of areas, namely the West Coast, La Hague (Herqueville, Moulinets Bay, Release pipe, Les Huquets, Pointe du Houpret, Auderville-Goury, Flamanville), North Coast (Cherbourg, Cap Lévy-Fermanville, Cosqueville). However, note that the results provided by COGEMA for crustaceans indicated as originating from the West Coast area actually relate to species that may originate from the West Coast or La Hague areas as defined above.

- The results are applicable to the edible crab and spider-crab, possibly the flesh and soft parts without gills, or possibly the entire animal. There is no significant difference between concentrations in edible crabs and spider-crabs.

- Concentrations of ^{137}Cs, $^{106}RuRh$, ^{125}Sb and ^{60}Co have been reducing during the 1990s.
- The results of measurements of artificial radionuclides are generally similar in different laboratories. Maximum values rarely exceed twice the average value.
- In September 1997, several samples made at the end of the pipe from COGEMA La Hague reprocessing plants showed higher values (x 100) than the average values recorded at the end of the 1990s in near areas in which crustacean pot fishing is authorized (for example Les Huquets).

- Fish

Samples were taken by COGEMA, OPRI, GEA, EDF, CRII-RAD.

Fishing areas are shown on map 9 and include the West Coast, La Hague (Moulinets Bay, La Schôle, Les Huquets, Flamanville), North Coast (Cherbourg, Cap Lévy Fermanville). However, note that the results supplied by COGEMA for fish indicated as originating from the West Coast area actually relate to species that may originate from the West Coast or La Hague areas as defined above.

- There are many different species the nature of which is not always known, and results are applicable to complete gutted fish or flesh. Concentrations of ^{40}K (natural element) are usually close to 100 Bq/ww kg^{-1}. However, differences of a factor of 5 are observed between minimum and maximum values.
- Despite this variability, the results of measurements of artificial radionuclides made by different laboratories are generally similar.
- ^{137}Cs is frequently present; the highest concentrations are in the Huquets area; contents have been dropping since the 1985-1987 period.
- The ^{125}Sb, $^{106}RuRh$ and ^{60}Co radionuclides are either occasional, or are present in concentrations that are generally below detection limits.
- The maximum value very exceptionally reaches 3 times the average value.

Terrestrial environment

- Drinking water

Samples were taken by COGEMA, EDF and LDA50.

Samples were taken of water that could be consumed by the population. These samples were taken from the drinking water network (tap water) or from boreholes in the ground water used to supply treatment stations for the drinking water network.

- Since 1988, almost all results obtained (gamma spectrometry, tritium, Betot, Betox, Altot) show that artificial radioactivity levels in the drinking water network, and in the ground water that supplies network stations, are less than detection limits.

- Sediments in rivers

Samples were taken by the IPSN, OPRI, ANDRA, LDA50, ACRO and CRII-RAD.

Results are applicable to the Moulin, Sainte-Hélène and Grand-Bel rivers.

- Interpretation of observed differences is hindered by the lack of data about size grading, mineralogy and concentration of organic materials in sediments. The precise position at which samples were taken (for example the bed or bank of a river) has a major influence on the result.

- However, good agreement between the results is observed when measurements are made by different organizations on samples taken from stations very close to each other using the same preparation techniques.
- Maximum values are for ^{137}Cs and were observed in the Sainte-Hélène during the years 1986-1987.
- Globally, a reduction in levels has been observed since the 1980s, and concentrations reduce from the upriver towards the downriver part of the river.
- The $^{238}Pu/^{239-240}Pu$ isotope ratios are greater than the corresponding ratio due to atmospheric tests of nuclear weapons (0.05), consequently confirming an industrial source (CM-ANDRA).

- Grass

Grass samples were taken by the OPRI, COGEMA, GEA, and EDF.

Samples were grouped in four areas, namely the Cap La Hague (Omonville, Beaumont, Herqueville), the immediate area around COGEMA La Hague reprocessing plants, a relatively wide area around Flamanville (Les Pieux, Diélette) and finally a station located in the Cherbourg Urban Community at La Glacerie.

- The only one of the four artificial radionuclides included in the tables (^{137}Cs, $^{106}RuRh$, ^{125}Sb and ^{60}Co) that is occasionally detected in the Nord-Cotentin outside the periphery of COGEMA La Hague reprocessing plants, is ^{137}Cs.
- The slightly higher maximum values of ^{137}Cs in 1986 are related to the Chernobyl accident.
- Two comments may be made about the areas immediately surrounding COGEMA La Hague reprocessing plants:

    - The ^{137}Cs, $^{106}RuRh$, ^{60}Co and ^{125}Sb radionuclides are detected at variable levels until 1987, and they have been no longer detected since 1988, except for some values of ^{137}Cs.
    - The silo fire that occurred on January 6 1981 resulted in significant marking for these four radionuclides around the plant. The concentrations of these radionuclides generally returned to their level preceding the fire during 1982.

- Vegetables

Samples of vegetables and cereals were taken by OPRI, COGEMA, GEA, and EDF.

The stations used were Surtainville, Herqueville, Beaumont, Digulleville, Omonville la petite, Gréville and Val de Saire.
The vegetables sampled were leeks, carrots, lettuce, potatoes, parsley, wheat, radishes and turnips.

- Gamma spectrometry concentrations exceeded LDs only for ^{137}Cs and natural ^{40}K.
- Measurement results obtained in the different laboratories are usually similar.
- The use of seaweed for soil improvement has to be taken into account for vegetables, in addition to the three sources of artificial radionuclides (atmospheric releases from plants, fallout from firing nuclear weapons, sea spray).

- Milk

Milk samples were taken by OPRI, COGEMA, GEA, EDF, the LDA 50 from about twenty producers located in the North West quarter of the Cotentin.

- Milk is the best monitored land indicator and analyzed samples are taken from clearly identified local farms.
- Almost all results obtained by gamma spectrometries are for ^{137}Cs and the natural element ^{40}K.
- ^{137}Cs and ^{90}Sr levels have been reducing since 1980s, except for some samples taken at Jobourg in 1981 after the silo fire on 6/01/81 at COGEMA La Hague reprocessing plants, and in 1986 for ^{137}Cs (Chernobyl accident).
- Measurement results obtained by the different laboratories for artificial radionuclides are generally similar.

4.2.2. Second phase: ^{3}H, ^{14}C, ^{90}Sr, ^{99}Tc, ^{131}I, ^{129}I, $^{238,239-240}Pu$, ^{241}Am, ^{244}Cm, ^{210}Po

In a second phase, the list of radio-elements concerned was extended to include the following additional gamma, alpha and beta emitters: ^{3}H, ^{14}C, ^{90}Sr, ^{99}Tc, ^{129}I, ^{131}I, ^{210}Po, ^{238}Pu, $^{239-240}Pu$, ^{241}Am, ^{244}Cm, and ambient gamma radiation. The results of this second series were grouped by radio-element for several indicators.

- ^{238}Pu, $^{239-240}Pu$: results were supplied by COGEMA, OPRI, IPSN/LERFA and EDF.
  - Most data for sea water are less than high LDs, and it is recommended that GT3 and GT4 should use IPSN/LERFA values.
  - The results given by the various laboratories for fucus and limpets are fairly similar. Note a reduction of concentrations with time.
  - For other samples, the fairly small number of results and heterogeneity of stations and the nature of samples made it impossible to compare data.
  - The $^{238}Pu/^{239-240}Pu$ isotopic ratio calculated using average annual concentrations is between 0.25 and 1.9. It identifies the industrial origin of the waste, since the isotopic ratio from fallout from former weapons tests was close to 0.05.

- ^{241}Am, ^{244}Cm: results were supplied by IPSN/LERFA, OPRI, COGEMA, and GEA.
  - Data are insufficient to be able to evaluate the representativeness and dispersion of values.
  - For ^{241}Am, more credit should be given to alpha spectrometry measurements, but there are far fewer of these measurements then there are gamma spectrometry measurements.

- ^{210}Po: results apply to samples of fucus, mussels, shrimps, fish, sediments, and sea water taken from several stations along the French coast of the English Channel.

Only two laboratories (IPSN/LERFA and OPRI) provided results about the various natures of samples taken at different stations along the French Coast of the English Channel for the 1990s. These data are the only data available for this natural alpha emitting radionuclide.

- ^{14}C: results were supplied by OPRI, COGEMA and IPSN.

Results are obtained from different stations for limpets, fucus, edible crabs, fish, milk, grass and furze for the years 1996-1997.

  - There are insufficient data to make any comment about the representativeness and dispersion of results.
  - Any result exceeding 250 $Bq.kg^{-1}$ of carbon in a sea or terrestrial environment confirms recent anthropogenic input.

- ^{3}H: results were supplied by COGEMA, OPRI, IPSN/LERFA and EDF.

The results are applicable mainly to sea water, drinking water and milk.

- Levels in drinking water have been less than the LD except for five monthly values between 1980 and 1982 (namely < 10 $Bq.l^{-1}$ in the 1990s).
- The highest levels for milk were recorded between 1980 and 1982. Few data have reached the LD since the 1980s (namely < 11 to 30 $Bq.l^{-1}$).
- There are a few isolated values of tritium in cheese, cider, carrots, limpets, lobsters and fucus samples.
- Levels measured in sea water are between 1 200 $mBq.l^{-1}$ recorded off Flamanville during low release periods and about 17 800 $mBq.l^{-1}$ recorded at Goury in 1997.

Other results of ^{3}H measurements in rivers were supplied by the ANDRA, COGEMA, OPRI, IPSN/LERFA, LDA50, CRII-RAD, ACRO, and are discussed in section 4.2.5.

- ^{129}I, ^{131}I: results were supplied by IPSN, OPRI, COGEMA, CRII-RAD, in sea water, marine sediments, fucus, limpets, edible crabs, lobsters, spider-crabs, plaice, river sediments, grass and milk.

  - There are not enough data to be able to evaluate the representativeness and dispersion of values.
  - Furthermore, the heterogeneity of the natures of samples, sampling stations and detection limits are not sufficient to make comparisons between results from different laboratories, except for some data for ^{129}I in fucus that are consistent.
  - For milk, the impact of ^{131}I in the fallout from Chernobyl was observed in1986.
  - For fucus, an increase in the concentrations of ^{129}I has been observed since 1988.

- ^{90}Sr: results were supplied by EDF, COGEMA, LDA50, and OPRI; they concern milk, sea water, marine sediments, molluscs, fish, crustaceans and seaweed.

  - Results for milk are generally similar in different laboratories.
  - There are too few data to make comparisons for other types of samples.
  - Globally, a reduction of values has been observed from the 1980s to the 1990s.
  - The variation of annual averages does not demonstrate any repercussions on the ^{90}Sr level in milk (see 4.2.6.) following the silo incident on January 6 1981.

- ^{99}Tc: results mainly concern a long series of fucus measurements in Goury and a few data for limpets, lobsters and fish. These results were obtained by IPSN/LERFA.

  - The data were obtained from a single laboratory.
  - The ^{99}Tc is concentrated particularly by brown seaweed. There is a long series of results for fucus in Goury.
  - Concentrations increased from 1976 to 1985, and then reduced.

- Ambient Gamma: ambient gamma measurements as a dose rate were made by COGEMA in Vauville, Jobourg, Herqueville, Beaumont, Digulleville and Gréville, by EDF in Flamanville and Diélette, and by the OPRI.

  - Data supplied by laboratories are not always comparable due to the characteristics of measurement instruments that changed with time.
  - A map of dose rates in the Flamanville-La Hague region was made in 1981. Levels vary between 0.053 and 0.33 $\mu Gy.h^{-1}$.
  - Results supplied to GT2 by the OPRI in September 1998 are attached unchanged.

4.2.3. Third phase: other gamma radiations in limpets (^{54}Mn, ^{58}Co, ^{65}Zn, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{110m}Ag, ^{134}Cs, ^{144}CePr, ^{154}Eu)

More data are available for the limpet than for any other animal bio-indicator. The results of this series apply only to soft parts of this mollusk and are also presented by radionuclide.

- ^{54}Mn in limpets

  - Results were supplied by COGEMA, OPRI, GEA, EDF, IPSN/LERFA. The stations are: Barneville, Sciotot, Dielette, Moulinets Bay, Ecalgrain, Goury, Saint-Martin Bay, Querqueville, Brick Bay and Barfleur.
  - Good agreement is observed between values from different laboratories.
  - Globally, average concentrations reduced during the 1980-90s, however individual maximum values were observed in 1991.

- ^{58}Co in limpets

Results were supplied by COGEMA, OPRI, GEA, IPSN/LERFA, EDF. Stations used were: Barneville/Carteret, Sciotot, Dielette, Siouville, Herquemoulin, Moulinets Bay, Ecalgrain, Goury, Saint-Martin Bay, Querqueville, Brick Bay and Barfleur.
The concentrations exceeding LD values are applicable to the Flamanville region for the period from 1986 to 1991.

- ^{65}Zn in limpets

Results were supplied by COGEMA, GEA, OPRI, IPSN/LERFA. The stations were Barneville, Sciotot, Diélette, Siouville, Moulinets Bay, Ecalgrain, Herquemoulin, Goury, Saint-Martin Bay and Querqueville.

  - This radionuclide was detected during the 1978 - 1990 period.
  - Good agreement is observed between values obtained in different laboratories.

- ^{95}Zr in limpets

Results were supplied by COGEMA, GEA. The stations used were Barneville, Siouville, Moulinets Bay, Ecalgrain, Herquemoulin, Goury and Saint-Martin Bay.

  - This radionuclide was detected during the 1978 - 1987 period.
  - The number of data is relatively low.

- ^{103}Ru in limpets

Results were supplied by COGEMA, GEA. The stations were Sciotot, Moulinets Bay, Ecalgrain, Goury and Saint-Martin Bay.

The number of data is very low and applies to the years 1978 to 1986.

- ^{110m}Ag in limpets

Results were supplied by COGEMA, OPRI, GEA, IPSN, EDF. The stations were Barneville/Carteret, Sciotot, Flamanville, Dielette, Siouville, Herquemoulin, Moulinets Bay, Ecalgrain, Goury, Saint-Martin , Querqueville, Brick Bay and Barfleur.

  - Good agreement is observed between values obtained in different laboratories.
  - Concentrations in the North/North-East region of the Cotentin have been reducing during the period from 1978 to the present day.

- Concentrations around Flamanville reduced during the 1990s.

- ^{34}Cs in limpets

Results were supplied by COGEMA, GEA, OPRI, EDF. The stations used were Barneville, Sciotot, Flamanville, Diélette, Siouville, Moulinets Bay, Ecalgrain, Herquemoulin, Goury, Saint-Martin Bay, Querqueville, Brick Bay and Barfleur.

- This radionuclide was detected mainly during the 1978-1988 period.
- Apart from a few exceptions, good agreement is observed between values obtained in different laboratories.

- ^{144}CePr in limpets

Results were supplied by COGEMA, GEA, IPSN/LERFA. The stations used were Barneville, Sciotot, Diélette, Siouville, Moulinets Bay, Herquemoulin, Ecalgrain, Goury, Saint-Martin Bay and Querqueville.

- These radionuclides were detected only during the 1978 - 1988 period.
- Good agreement is observed between values obtained in different laboratories.

- ^{154}Eu in limpets

Results were supplied by COGEMA, GEA. The stations used were Sciotot, Siouville, Herquemoulin, Moulinets Bay, Ecalgrain, Goury and Saint-Martin.

The number of data is very small.

4.2.4. Fourth phase “Other gamma emitters at different indicators”

^{54}Mn, ^{58}Co, ^{65}Zn, ^{95}Zr, ^{95}Nb, ^{103}Ru, ^{110m}Ag, ^{134}Cs, ^{144}CePr, ^{154}Eu radionuclides have been detected more or less sporadically in different indicators in the marine environment and in the terrestrial environment. Usually, laboratories supplying data only reported values exceeding the LD. The number of data for each indicator and each radionuclide is very low, and is not enough to make a firm decision about the representativeness and dispersion of results.

The most abundant data are for ^{110m}Ag , ^{58}Co in Fucus seaweed and crustaceans.

Due to the release pipe break, the averages and maximum values in the Moulinets Bay in 1979-80 are different from levels recorded elsewhere for ^{144}CePr, ^{110m}Ag, ^{54}Mn, ^{65}Zn in Fucus, and for ^{144}CePr, ^{154}Eu, ^{134}Cs in sediments.

4.2.5. Fifth phase: Main γ emitters, total α, total β and tritium counts in rivers

This concerns water in rivers, springs leading into rivers and other resurgences supplying drinking troughs or wash houses, well water and ground water. This water is not consumed directly by man.

Results were supplied by ANDRA, COGEMA, OPRI, IPSN/LERFA, LDA50, CRII-RAD, and ACRO.
Data apply to the main gamma emitters, the total alpha count, the total beta count and tritium.

A very large number of periodic measurements are necessary to monitor levels precisely, due to the important influence of rainfall conditions on the results of measurements in the water in the Sainte-Hélène.

Most data are for tritium.

Globally, the results provided by the various organizations are similar, despite differences in how samples are processed.

The change in concentrations measured in the Sainte-Hélène reflects technical modifications made to the CM water collection networks. A global reduction of concentrations has been observed since the 1980s.

4.2.6. Sixth phase: gamma, ^{90}Sr, tritium, total β emitters during incidents in various indicators

GT1 listed five incidents. After reading data supplied by GT2, two of the incidents resulted in significantly higher annual average radioactivity levels than the averages for periods before and after the incident. These are:

- sea effluent release pipe break at COGEMA La Hague reprocessing plants between September and November 1979,

- the silo fire on January 06 1981 at COGEMA La Hague reprocessing plants.

An examination of individual data supplied by COGEMA, OPRI and EDF was carried out for the periods concerned. Measurement results supplied by COGEMA for grass sampling which was located on COGEMA site were included, contrary to the rule fixed by GT2 to consider only measurements outside the sites, considering the very localized aspect of the study on the consequences of the silo fire.

In general, it may be considered that the impact of the pipe break in September-November 1979 at the Moulinets Bay is geographically restricted to the area between Ecalgrain and Herquemoulin and was no longer observed in 1981.

The silo fire occurred on January 6 1981 and caused marking of the grass by several gamma emitters in the immediate surroundings of COGEMA La Hague reprocessing plants, that disappeared by the end of 1981. The most severely marked sectors were the North-West and South-East of the site. Grass marking at Diélette, Les Pieux and Vasteville stations was observed for several gamma emitters (Cs, CePr, RuRh, Nb, Zr), and for Sr. It is impossible to exclude marking of milk originating from farms in La Hague region, by isotopes of Cs and Sr. Note the special case of Herqueville (company S2454 located to the South-East of the site) in which significant marking by isotopes of Cs and Sr was observed. Concentrations in milk have dropped to levels similar to those preceding the fire at the end of 1981.

5. CONCLUSIONS

The work done by GT2 assembled and studied several thousand radionuclide concentration results within the framework of the Nord-Cotentin Radioecology Group (about **500 000** " **determinations of the concentration** of radionuclides or total alpha or beta activity " were identified). Nine laboratories provided these data. No **work on this scale had ever been done in the region** by representatives of operators, non governemental laboratories or public organizations**.**

This group did everything possible to be exhaustive in building up the inventory of samples and measurement types (computerized data). However, due to the large amount of the data to be collected and verified within a limited time, it was decided to give priority to measurement results and informations essential to GT3 (comparison between

models/measurements) and GT4 (estimate of doses to populations). Therefore, the following selection criteria were applied:

- give priority to processing results for which several organizations have taken samples from the same location and at the same time, in order to be able to compare them with each other;

- prefer to use indicators for which long series of measurements are available in order to monitor the variation of radioactivity with time, and for which existing sampling stations can give the best coverage of the Nord-Cotentin area;

- emphasize individual points that have a special interest such as some elements of food chain (milk), or the impact of an incident well defined in time and in space;

- give priority to results available in computer form so that they can be processed quickly;

- process data about the environment outside nuclear sites;

Only results obtained starting from 1978 were considered. Starting from the end of 1970s, a large amount of data was computerized, and the quality of the measurements also improved. Finally, the study covers measurements until 1997, contingent on the availability of measurements results for the year 1997.

This work enabled **GT3 to compare models and measured values**, particularly in the marine environment for which long series were carried out at the same location by several laboratories, for several indicators. The results used also provide useful information to GT4 for carrying out dose calculations starting from measured values.

The data collected by GT2 was presented in the form of:

- the publication of an inventory of samples and radioactivity measurement types. In the future, **it should be a very useful tool** to satisfy social demands about distribution and variation of artificial radioactivity in the Nord-Cotentin.

It applies to:

  - an area extending from the Gulf of Normandy-Brittany to the West as far as the East Coast to the South of Barfleur;
  - various types of samples (sea water, sediments, seaweed, molluscs, crustaceans, fish, drinking water, surface water, underground water, river sediments, grass, vegetables, milk, gas, etc.);
  - a large number of natural and artificial radionuclides, gamma emitters (natural ^{40}K, ^{137}Cs, ^{106}Ru, ^{60}Co, ^{125}Sb, ^{110m}Ag...), beta emitters (^{3}H, ^{90}Sr,^{99}Tc...), alpha emitters ($^{238,239,240}Pu$, ^{241}Am, natural ^{210}Po...).

- a critical review of the results. When the work started, a significant difficulty arose due to the lack of homogeneity between operating methods in different laboratories. This lack of homogeneity is due to the different **end purposes** of the measurements, which differ depending on the tasks of the different participants. In the end, the annual average was selected as the magnitude used to represent radioactivity levels in the environment, accompanied by the standard deviation, the maximum value of activity levels during the year, and the number of results for which the activity exceeded the detection limit as a fraction of the total number of measurements during the year. All these data have to be taken into account in order to make the best interpretation of the radioactivity results, and particularly:

- in cases in which detection limits vary from one laboratory to another, or vary with time in the same laboratory;
- as a function of the number of annual results for a radionuclide, an indicator, in a given location;
- when annual averages differ from the general trend, accompanied by a high standard deviation due to one or several " particular " results for which the explanation was not provided (sampling problems, processing problems, measurement problems, problems with inputting results, etc.).

Despite this lack of homogeneity and a sometimes difficult comparison of results (for example, particularly due to differences between detection limits in different laboratories), **GT2 found, all the assessment factors being taken into account, that results in general are consistent**, and a consensus was reached between participants about the analysis of the radioactivity levels supplied.

Considering the large amount of data to be processed within the allocated time, it was impossible to analyze all results (particularly results for radioactivity levels in seaweed and animal species, sediments in the near field, ambient gamma, gases, etc.). Data that were not processed but which are included in the inventory, or which were not collected as part of GT2's tasks, **can be requested by contacting the laboratories or organizations concerned.** GT2 mentioned weaknesses concerning the lack of measurements of some radionuclides in the environment. In the future, the hierarchization of radionuclides and environmental compartments to be studied will be defined by the Plenary Group when it receives the results of GT4. But it is obvious that **the objectives fixed for GT2 comply with the spirit of the government task note, and were achieved.**

PART B APPENDICES

APPENDIX 1 **Descriptions and inventory extracts**

APPENDIX 1-1 Description of sampling, processing and measurement methods for samples

APPENDIX 1-2 Inventory of samples and measurements types

APPENDIX 2 **Extract of critical review of the results including comments, tables, graphs and map.**

APPENDIX 1 - Descriptions and Inventory extracts

APPENDIX 1-1

Descriptions of methods of sampling, processing and measurement of samples are presented for each contributor (ACRO, ANDRA, COGEMA, CRII-RAD, EDF, GEA-MARINE NATIONALE, IPSN/LERFA, LDA 50 and OPRI).

As an illustration, the attached tables relate to information provided by the OPRI.

APPENDIX 1-2

The inventory of samples and measurement types is sorted by contributor (see previous list).

As an illustration, the attached table presents the first page of the inventory.

ment before analysis	Analysis method	Preparation before measurement	Equipment type	Unit	Detection limit	Comments
e filtration at 10 µm then tion of 100 ml sample at 55°C	Alpha radioactivity index in plutonium 239 equivalent	Deposition in thin layer on stainless steel dish	Mineral scintillator counter (ZnS/Ag)	$Bq.l^{-1}$	0.030 $Bq.l^{-1}$	
e filtration at 10 µm then tion of 100 ml sample at 55°C	Beta radioactivity index in strontium 90 and yttrium 90 equivalent	Deposition in thin layer on stainless steel dish	Geiger Müller counter with low background noise	$Bq.l^{-1}$	0.10 $Bq.l^{-1}$	
ble filtration at 10 µm	Emission spectrometry or flame photometry		Atomic absorption or flame photometer	$g.l^{-1}$	0.5 $mg.l^{-1}$	
n of scintillating liquid to ered water test sample	Liquid scintillation	Standardized flask	Liquid scintillator counter set	$Bq.l^{-1}$	10 $Bq.l^{-1}$	
then calcination of the 50°C - deposition of ash stainless steel dish	Alpha radioactivity index in plutonium 239 equivalent	Deposition in thin layer on stainless steel dish	Mineral scintillator counter (ZnS/Ag)	$Bq.g^{-1}$ of ash	Of the order of 1.0 $Bq.g^{-1}$ of ash	
then calcination of the 50°C - deposition of ash stainless steel dish	Beta radioactivity index in strontium 90 and yttrium 90 equivalent	Deposition in thin layer on stainless steel dish	Geiger Müller counter with low background noise	$Bq.g^{-1}$ of ash	Of the order of 3.0 $Bq.g^{-1}$ of ash	
ation of untreated water	Beta radioactivity index in potassium 40 equivalent	Deposition in thick layer on nylon dish	Geiger Müller counter with low background noise	$Bq.l^{-1}$	0.25 $Bq.l^{-1}$	
Untreated water		Direct count on standard flask (after or without concentration) or count on evaporation residue	Hyperpure germanium detector	$Bq.l^{-1}$	Of the order of 0.05 $Bq.l^{-1}$ for cesium 137 for a 5 liter test sample	
ation of untreated water		Count dw residue corresponding to the evaporation of 5 liters of water	Hyperpure germanium detector	$Bq.l^{-1}$	Of the order of 0.05 $Bq.l^{-1}$ for cesium 137	
Untreated water	nitric method: measurement of 90Sr from its descendant 90Y at equilibrium and precipitated in the oxalate state	Filter installed in nylon dish	Geiger Müller counter with low background noise	$Bq.l^{-1}$	Of the order of 0.010 $Bq.l^{-1}$ for a 5 liter test sample	
n of acid and possible iltration at 10 µm	Fluorescence of uranyl salts excited by U.V.	Chromatographic separation - fusion on sodium fluoride pellet	Fluorimeter	$g.l^{-1}$	0.5 $\mu g.l^{-1}$	Uranium is co-precipitated by methyl violet in strongly mineralized water
and calcination of the nitric recovery of ash	Fluorescence of uranyl salts excited by U.V.	Chromatographic separation - fusion on sodium fluoride pellet	Fluorimeter	$g.l^{-1}$	0.5 $\mu g.l^{-1}$	
ble filtration at 10 µm, oration until dw and recovery by HCl	Radon emanation method	Recovery of radon 222 in scintillating tank	Mineral scintillator counter (ZnS/Ag)	$Bq.l^{-1}$	0.040 $Bq.l^{-1}$	
Untreated water	Chemical separation followed by alpha spectrometry	Deposition in thin layer in the form of lanthanum fluoride	Grid chamber or silicon detector	$Bq.l^{-1}$	2 $mBq.l^{-1}$	
Untreated water	Chemical separation followed by alpha spectrometry	Deposition in a thin layer in the form of cerium fluoride	Grid chamber or silicon detector	$Bq.l^{-1}$	2 $mBq.l^{-1}$	
hen calcination at 450°C ition of ash on stainless steel dish	Alpha radioactivity index in plutonium 239 equivalent	Deposition of a thin layer in stainless steel dish	Mineral scintillator counter (ZnS/Ag)	Bq. dw or ww kg^{-1}	100 Bq. dw kg^{-1} (sediments); 10 Bq. dw kg^{-1} (plants); 5 Bq. ww kg^{-1} (fish); 2.5 Bq.ww kg^{-1} (plants)	Fish: complete gutted, molluscs: flesh + hepatopancreas (soft parts without the gills)
hen calcination at 450°C ition of ash on stainless steel dish	Beta radioactivity index in strontium 90 and yttrium 90 equivalent	Deposition of a thin layer in stainless steel dish	Geiger Müller counter with low background noise	Bq. dw or ww kg^{-1}	350 Bq. dw kg^{-1} (sediments); 35 Bq.dw kg^{-1} (plants); 20 Bq.ww kg^{-1} (fish); 10 Bq.ww kg^{-1} (plants)	
rement on ww sample		Count on standard flask	Hyperpure germanium detector	Bq. dw kg^{-1}	1 Bq.dw kg^{-1} for cesium 137	Sediments were analyzed dw before 1990
ement on dw and ground sample		Count on dw extract	Hyperpure germanium detector	Bq. ww kg^{-1}	0.2 Bq.ww kg^{-1} for cesium 137	Fish have been analyzed ww since 1997

and calcination, alkaline usion (sediments)	Nitric method: measurement of 90Sr from its descendant 90Y at equilibrium and precipitated in the oxalate state	Filter installed in nylon dish	Geiger Müller counter with low background noise	Bq. dw or ww kg^{-1}	2 Bq. dw kg^{-1} (sediments); 0.2 Bq.ww kg^{-1} (fish, plants)	
and calcination, nitric recovery of ash	Fluorescence of uranyl salts excited by U.V.	Chromatographic separation - fusion on sodium fluoride pellet	Fluorimeter	g. dw or ww kg^{-1}	100 µg. dw kg^{-1} (sediments); 10 µg.dw kg^{-1} (plants); 1 µg.ww kg^{-1} (fish, plants)	Fish: co-precipitation of uranium by methyl violet
and calcination, nitric recovery of ash	Radon emanation method	Recovery of radon 222 in scintillating tank	Mineral scintillator counter (ZnS/Ag)	Bq. dw or ww kg^{-1}	5 Bq. dw kg^{-1}; 0.1 Bq.ww kg^{-1} (fish)	
ing and calcination, neralization of ash	chemical separation followed by alpha spectrometry	Deposition in thin layer in the form of lanthanum fluoride	Grid chamber or silicon detector	Bq. dw or ww kg^{-1}	0.2 Bq. dw kg^{-1} (sediments); 0.02 Bq.dw kg^{-1} (plants); 0.05 Bq.ww kg^{-1} (fish,plants)	
ing and calcination, neralization of ash	Chemical separation followed by alpha spectrometry	Deposition in thin layer in the form of cerium fluoride	Grid chamber or silicon detector	Bq. dw or ww kg^{-1}	of the order of 0.2 Bq. dw kg^{-1} (sediments); 0.02 Bq.dw kg^{-1} (plants); 0.05 Bq.ww kg^{-1} (fish,plants)	
ement on the liquid milk		Count on 2-liter standard flask	Hyperpure germanium detector	Bq.l^{-1}	0.2 Bq.l^{-1} for cesium 137	Before 1987-1988, cesium was measured by gamma count of ammonium phosphomolyb-date, and iodine after passing on resin
ement on the liquid milk	chemical separation followed by gamma count	Deposition in thin layer in the form of palladium iodine	Hyperpure germanium detector	Bq.l^{-1}	0.01 Bq.l^{-1}	
ement on the liquid milk	Beta radioactivity index in strontium 90 and yttrium 90 equivalent (fixation on cationic resin, a precipitate of Ca oxalate obtained)	Deposition of calcium oxalate in thick layer on nylon dish	Geiger Müller counter with low background noise	Bq.l^{-1}	0.25 Bq.l^{-1}	The result possibly includes 90Sr+90Y+140Ba and other rare earths
ement on the liquid milk	Citric complexion. After passing over anionic resin, yttrium is precipitated in the form of oxalate	Filter installed in nylon dish	Geiger Müller counter with low background noise	Bq/l	0.05 Bq/l	

APPENDIX 1-2 - First page of the inventory of samples and measurement types

Sample identification (sorted by Responsible Organization)							Measurements made ...			499983	
	Nature	Type	Sampling method	Organ, Fraction, Processing, Packaging	Location(s)	Responsible organiz-ation	Element and/or Measure-ment type	Measure-ment	Frequency	Start year	End year
AC	WWW	River water	Polyethylene glass	F045	Moulin river: Mo	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-94	Dec-96
AC	WWW	Water not in river	Polyethylene glass	F045	Ste Hélène river: ST4D	ACRO	H3	ACRO	MONTHLY MONITORING	Dec-95	Dec-96
AC	WWW	River water	Polyethylene glass	F045	Ste Hélène river: STB0	ACRO	H3	ACRO	MONTHLY MONITORING	Mar-94	Dec-96
AC	WWW	River water	Polyethylene glass	F045	Ste Hélène river: ST4	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-94	Dec-95
AC	WWW	River water	Polyethylene glass	F045	Ste Hélène river: ST10	ACRO	H3	ACRO	MONTHLY MONITORING	Feb-94	Dec-96
AC	WWW	River water	Polyethylene glass	F045	Ste Hélène river: ST11	ACRO	H3	ACRO	MONTHLY MONITORING	Feb-94	Dec-96
AC	WWW	River water	Polyethylene glass	F045	Ste Hélène river: ST12	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-94	Dec-96
AC	WWW	River water	Polyethylene glass	F045	Grand Bel river: GB20	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-94	Dec-96
AC	WWW	River water	Polyethylene glass	F045	Grand Bel river: GB21	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-94	Dec-96
AC	SEDIM	River sediment	Manual	S0005:I2MN	Moulin river: Mo	ACRO	GAMMA	ACRO	QUATERLY MONITORING	Jan-94	Aug-96
AC	SEDIM	River sediment	Manual	S0005:I2MN	Ste Hélène river: ST10	ACRO	GAMMA	ACRO	QUATERLY MONITORING	Jan-94	Aug-96
AC	SEDIM	River sediment	Manual	S0005:I2MN	Ste Hélène river: ST11	ACRO	GAMMA	ACRO	QUATERLY MONITORING	Jan-94	Aug-96
AC	SEDIM	River sediment	Manual	S0005:I2MN	Ste Hélène river: ST12	ACRO	GAMMA	ACRO	QUATERLY MONITORING	Jan-94	Aug-96
AC	SEDIM	River sediment	Manual	S0005:I2MN	Grand Bel river: GB20	ACRO	GAMMA	ACRO	QUATERLY MONITORING	Jan-94	Aug-96
AC	SEDIM	River sediment	Manual	S0005:I2MN	Grand Bel river: GB21	ACRO	GAMMA	ACRO	QUATERLY MONITORING	Jan-94	Aug-96
AC	WWW	Well water	Polyethylene glass	F045	Grand Bel river: SGB	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-95	Dec-96
AC	WWW	Water not in river	Polyethylene glass	F045	Ste Hélène river: Ab	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-95	Dec-96
AC	WWW	Well water	Polyethylene glass	F045	Ste Hélène river: PPD	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-95	Dec-96
AC	WWW	Water not in river	Polyethylene glass	F045	Ste Hélène river: LPD	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-95	Dec-96
AC	WWW	Water not in river	Polyethylene glass	F045	Ste Hélène river: BPD	ACRO	H3	ACRO	MONTHLY MONITORING	Jan-96	Dec-96
AC	WWW	Water not in river	Polyethylene glass	F045	Ste Hélène river: R11'	ACRO	H3	ACRO	1 meas	Jan-95	Dec-95
AC	SEDIM	River sediment	Manual	S0005:I2MN	Ste Hélène river: ST4	ACRO	GAMMA	ACRO	1 meas	Oct-87	Dec-92
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Jobourg (village)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Jobourg (Hameau Ricard)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Omonville la petite (Hameau Henry)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Digulleville:Hameau les Clerges	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Digulleville:Hameau des Asselins	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Digulleville:Hamelin	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Digulleville:la Gouinerie	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Port Racine	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Hameau de Danneville/de Bas	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	St Germain des Vaux (les Bizeaux)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	St Germain de Vaux (village)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Auderville	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Hameau-Grainval (Maison Blanche)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Hameau d'Annery	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	on the D401 (to Jobourg)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	on the D901 (near COGEMA)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	on the D403 (La Vallée)	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
TER	LICHE	Xanthoria parietina	Manual	Parts in air	Herqueville	ACRO	Cs137	ACRO	1 meas	Dec-96	Dec-96
MAR	ARTHR	Macropipus puber	Manual diver	Flesh	End of COGEMA release pipe	GREEN-PEACE	GAMMA	ACRO	2 meas	Sept-97	Sept-97
MAR	ARTHR	Cancer pagurus	Manual diver	Flesh	End of COGEMA release pipe	GREEN-PEACE	GAMMA	ACRO	3 meas	Sept-97	Sept-97
MAR	ARTHR	Maia squinado	Manual diver	Flesh	End of COGEMA release pipe	GREEN-PEACE	GAMMA	ACRO	2 meas	Sept-97	Sept-97
AC	WWW	River water	PVC/MAN	FIL15	Grand Bel R.3	ANDRA	ALTOT	SPR COG	MONTHLY MONITORING	1985	1989
AC	WWW	River water	PVC/MAN	FIL15	Grand Bel R.3	ANDRA	BETOT	SPR COG	MONTHLY MONITORING	1985	1989
AC	WWW	River water	PVC/MAN	FIL15	Grand Bel R.3	ANDRA	H3	SPR COG	MONTHLY MONITORING	1985	1989
AC	WWW	River water	PVC/MAN	MES	Grand Bel R.3	ANDRA	BETOT	SPR COG	MONTHLY MONITORING	1986	1989
AC	WWW	River water	PVC/MAN	FIL15	Grand Bel R.3	ANDRA	ALTOT	SPR COG	WEEKLY MONITORING	1989	on going
AC	WWW	River water	PVC/MAN	FIL15	Grand Bel R.3	ANDRA	BETOT	SPR COG	WEEKLY MONITORING	1989	on going
AC	WWW	River water	PVC/MAN	FIL15	Grand Bel R.3	ANDRA	H3	SPR COG	WEEKLY MONITORING	1989	on going
AC	WWW	River water	PVC/MAN	MES	Grand Bel R.3	ANDRA	BETOT	SPR COG	WEEKLY MONITORING	1989	on going
AC	WWW	River water	PVC/MAN	FIL15	Roteures.R1	ANDRA	ALTOT	SPR COG	MONTHLY MONITORING	1972	1988
AC	WWW	River water	PVC/MAN	FIL15	Roteures.R1	ANDRA	BETOT	SPR COG	MONTHLY MONITORING	1970	1988
AC	WWW	River water	PVC/MAN	FIL15	Roteures.R1	ANDRA	H3	SPR COG	MONTHLY MONITORING	1977	1988
AC	WWW	River water	PVC/MAN	MES	Roteures.R1	ANDRA	BETOT	SPR COG	MONTHLY MONITORING	1986	1988
AC	WWW	River water	PVC/MAN	FIL15	Roteures.R1	ANDRA	ALTOT	SPR COG	WEEKLY MONITORING	1989	on going
AC	WWW	River water	PVC/MAN	FIL15	Roteures.R1	ANDRA	BETOT	SPR COG	WEEKLY MONITORING	1989	on going
AC	WWW	River water	PVC/MAN	FIL15	Roteures.R1	ANDRA	H3	SPR COG	WEEKLY MONITORING	1989	on going
AC	WWW	River water	PVC/MAN	MES	Roteures.R1	ANDRA	BETOT	SPR COG	WEEKLY MONITORING	1989	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Cs137	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Cs134	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Co60	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Sr90	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Ni63	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Tc99	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	C14	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	H3	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Ra226	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Th234	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Am241	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Pu	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	Cm244	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	U	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	F045	Sainte-Hélène river:Hameau Fosse	ANDRA	K40	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	RF045	Sainte-Hélène river:Hameau Fosse	ANDRA	K40	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	RF045	Sainte-Hélène river:Hameau Fosse	ANDRA	Co60	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	RF045	Sainte-Hélène river:Hameau Fosse	ANDRA	Cs134	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	RF045	Sainte-Hélène river:Hameau Fosse	ANDRA	Cs137	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going
AC	WWW	River water	PVC/MAN	RF045	Sainte-Hélène river:Hameau Fosse	ANDRA	Ra226	Nantes Ecole des Mines	ANNUAL MONITORING	1996	on going

APPENDIX 2

The critical review of the results includes a comments sheet, tables and graphs.

As an illustration, the critical analysis and presentation of results for the main gamma emitters (^{137}Cs, ^{125}Sb, ^{106}RuRh, ^{60}Co and ^{40}K) are attached for offshore water samples (see first phase - sea water indicator - offshore sampling).

Comment: As far as COGEMA results are concerned, LD stands for "detection limit".

Comments: Sea water (main Gamma emitters)

Offshore sea water (stations at Le Rozel, Cap de Jobourg, Cap La Hague, Cap de Jardeheu)

sampling / processing / measurement	COGEMA and OPRI: evaporation of 15 and 5 l respectively, gamma spectrometry for 8 to 15h. GEA: co-precipitation of 100 to 400 l, gamma spectrometry for 8 to 24h. The co-precipitation method excludes ^{40}K from the radioelements extracted from sea water. The results of the measurements supplied by GEA are unprocessed, in other words they do not take into account the extraction efficiency.
Representativeness (values < LD)	Many values of artificial radioelements obtained using the evaporation technique are less than detection limits, particularly for ^{106}RuRh and ^{60}Co (starting from the 1990s, this technique does not give any values greater than the LD for these two elements).
Dispersion (standard deviations, maximum)	Standard deviations reach 50 to 100% of the value of the average, which is particularly noticeable for cobalt. Maximum values for the various radionuclides are up to 3 times the average value.

Special comments:

When an annual average is only calculated with measurement results less than the LD, it is ignored in the comments although it appears in the table.

- ^{40}K: The concentration of this natural radioelement usually determined using the evaporation and gamma spectrometry method is stable at about 1200 mBq.l^{-1}.
- ^{137}Cs: levels are less than 300 mBq.l^{-1} offshore between Le Rozel and Cap de Jardeheu.
- ^{106}RuRh: since the 1980s, levels are below 1200 mBq.l^{-1} offshore between Le Rozel and la Cap de Jardeheu, except for the measurement made by COGEMA in 1987 offshore from Cap de Jobourg at 1600 mBq.l^{-1}.
- ^{125}Sb: since the 1980s, levels are less than 230 mBq.l $^{-1}$ offshore between Le Rozel and Cap de Jardeheu, except for one measurement made by COGEMA in 1987 offshore from Cap de Jobourg at 600 mBq.l^{-1}.
- ^{60}Co: levels are less than 40 mBq.l^{-1} offshore between Le Rozel and Cap de Jardeheu.

Conclusion:

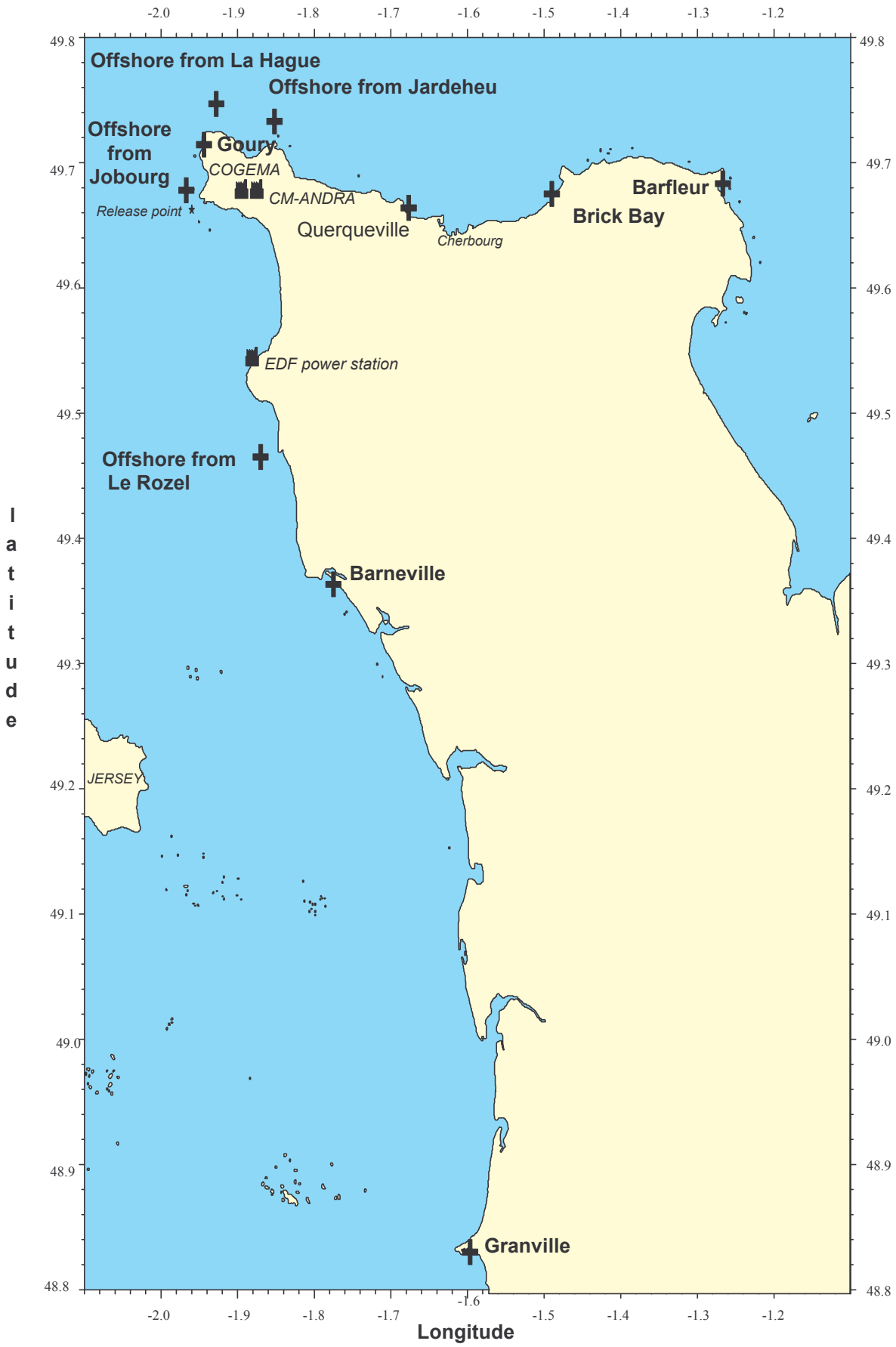
The distribution of radionuclides in the water mass close to the La Hague release point has not yet become uniform. Furthermore, the maximum number of samples per year is equal to 4. Different results are obtained depending on the releases, and depending on whether the sample was taken inside or outside the "plume" or at a time that is variable depending on the tide, which can explain much of the dispersion of the results. For ^{106}RuRh and ^{60}Co, the greater dispersion of measurements is related to the particularly complex nature of the physicochemical properties of these elements.

Some results originating from several laboratories show up large differences for the same location, for example such as ^{106}RuRh in 1987 offshore from Jobourg (COGEMA - average 1590 mBq/l, maximum 4400 mBq.l^{-1}; GEA - average 200 mBq.l^{-1}, maximum 227 mBq.l^{-1}, the results being greater than the detection limits in each case). In addition to the above comments, these differences can also be partly due to the principles used for sampling, processing and measurements.

Levels have been reducing since the 1980-1985 period, which is to be expected considering the variation in releases from COGEMA La Hague reprocessing plants.

Finally, it is obvious that the co-precipitation technique starting from large volumes of sea water with a long counting period, provides values exceeding detection limits for a larger number of measurements. Thus it is proposed to use the GEA's results for the purposes of GT3 and GT4, while considering the results obtained by other laboratories particularly for the period before 1982.

Sampling point map[22]



[22] GT2 organization team would particularly like to thank Mr. Jean-Michel Métivier of the IPSN/LMODE for his help in the production of land maps.

OGEMA offshore Jobourg						COGEMA offshore Le Rozel						COGEMA offshore La Hague						GEA offshore La Hague					
9°40.7N;1°58.0W)						**(49°27.9N;1°52.2W)**						**(49°44.8N;1°55.7W)**						**(49°44.8N;1°55.7W)**					
Cs 137 in sea water in mBq/l																							
COGEMA offshore Jobourg						COGEMA offshore Le Rozel						COGEMA offshore La Hague						GEA offshore La Hague					
	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N
	300,00		<	300,00	0/2							<	300,00		<	300,00	0/2	=	49,12	21,76	=	75,85	4/4
																		=	30,09	2,99	=	33,30	3/3
	224,75	370,22		780,00	3/4	<	278,50	341,53		520,00	1/2	<	60,75	39,07		110,00	3/4	=	36,78	20,43	=	72,89	5/5
	84,25	54,01		140,00	4/4	<	27,00	10,10		41,00	1/4	<	29,50	15,67		52,00	0/4	=	18,87	13,38	=	29,60	4/4
	29,25	1,50		30,00	2/4	<	25,00	7,87		35,00	1/4	<	23,75	2,50	<	27,00	0/4	=	27,66	11,55	=	43,29	4/4
	19,00	3,83	<	24,00	1/4	<	16,75	2,50	<	20,00	2/4	<	15,75	3,10	<	20,00	1/4	=	8,05	2,52	=	10,73	4/4
	18,25	7,09		27,00	2/4	<	15,00	2,16		17,00	0/4	<	18,75	6,90	<	29,00	1/4	=	16,56	6,88	=	25,90	4/4
	20,75	8,77		30,00	2/4	<	17,00	6,08	<	24,00	0/3	<	23,33	8,96	<	29,00	2/3	=	15,39	11,39	=	31,08	5/5
	14,25	6,55		24,00	1/4	<	15,25	6,85		25,00	1/4	<	51,50	72,36	<	160,00	3/4	=	13,32	3,66	=	17,02	4/4
	12,50	0,58		13,00	1/4	<	9,93	1,50	<	12,00	0/4	<	9,75	1,45	<	11,00	0/4	=	8,05	2,35	=	10,73	4/4
	7,93	0,49	<	8,50	0/4	<	7,73	0,50	<	8,10	0/4	<	8,73	0,76	<	9,60	0/3	=	6,10	1,01	=	7,40	4/4
	12,85	4,41		18,00	2/4	<	9,72	2,59	<	13,00	0/6	<	13,37	9,21	<	24,00	1/3	=	6,48	1,74	=	8,76	4/4
	7,50	0,44	<	8,00	0/4	<	9,53	1,50	<	11,00	0/3	<	8,20	1,22	<	10,00	0/4	=	19,98	16,44	=	40,10	4/4
	10,68	2,21		13,00	2/4	<	7,73	0,55	<	8,30	0/3	<	8,98	3,36	<	14,00	0/4	=	4,61	0,72	=	5,42	4/4
	7,73	0,65	<	8,60	0/4	<	7,30	0,73	<	8,10	0/4	<	8,60	0,91	<	9,30	0/4	=	3,72	1,01	=	4,97	4/4
	9,08	1,66	<	11,00	0/4	<	7,92	0,56	<	8,70	0/5												
Sb 125 in sea water in mBq/l																							
COGEMA offshore Jobourg						COGEMA offshore Le Rozel						COGEMA offshore La Hague						GEA offshore La Hague					
	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N
																		=	27,29	12,23	=	44,40	4/4
																		=	57,10	20,32	=	79,55	3/3
	231,50	195,87		370,00	2/2		100,00			100,00	1/1							=	52,54	17,29	=	82,88	5/5
	134,75	66,46		200,00	4/4		113,33	37,86		140,00	3/3		89,00			89,00	1/1	=	37,83	7,28	=	48,47	4/4
	105,50	34,65		130,00	2/2		83,50	13,44		93,00	2/2		55,67	3,51		59,00	3/3	=	60,40	18,67	=	79,55	4/4
	606,50	931,43		2000,0	4/4		89,67	27,02		110,00	3/3		100,00			100,00	2/2	=	57,73	7,59	=	62,90	4/4
	49,67	6,81		55,00	3/3		93,33	33,95		130,00	3/3		97,50	16,58		120,00	4/4	=	75,55	64,67	=	168,30	4/4
	90,75	61,50		180,00	3/4	<	58,33	17,79		74,00	2/3		101,67	59,20		170,00	3/3	=	26,64	14,73	=	38,50	5/5
	32,50	5,92		41,00	3/4	<	27,25	10,44		38,00	2/4		61,33	17,67		73,00	3/3	=	16,19	8,36	=	26,64	4/4
	27,50	6,24	<	34,00	1/4	<	26,75	18,21		54,00	1/4	<	28,00	2,16	<	31,00	2/4	=	9,44	3,80	=	14,43	4/4
	29,50	24,34		66,00	1/4	<	17,00	2,16	<	20,00	0/4	<	23,00	5,77	<	30,00	1/4	=	6,15	2,01	=	8,88	4/4
	16,25	1,50	<	17,00	0/4	<	16,67	1,03	<	18,00	0/6	<	17,33	2,08	<	19,00	0/3	=	3,39	1,86	=	5,80	4/4
	24,25	13,20	<	44,00	1/4	<	17,00	1,00	<	18,00	0/3	<	18,00	1,00	<	19,00	0/3	<	3,45	1,78	=	4,85	3/4
	17,25	1,26	<	19,00	0/4	<	17,00	2,00	<	19,00	0/3	<	16,50	2,08	<	19,00	0/4	<	1,15		=	2,01	1/4
	16,25	1,26	<	18,00	0/4	<	16,25	2,63	<	19,00	0/4	<	21,00	7,44	<	32,00	0/4	<			=		0/4
	21,00	4,55	<	27,00	0/4	<	18,80	2,17	<	22,00	0/5	<	20,50	2,38	<	23,00	0/4						

re Jobourg					GEA offshore Le Rozel						OPRI offshore Jardeheu					
1°58.0W)					**(49°27.9N;1°52.2W)**						**(49°44.0N;1°51.1W)**					
Cs 137 in sea water in mBq/l																
GEA offshore Jobourg					GEA offshore Le Rozel						OPRI offshore Jardeheu					
	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N
	13,86	=	72,52	6/6												
	77,97	=	132,46	2/2												
	2,06	=	32,19	4/4	=	37,59	17,08		54,76	5/5	=	9,93	1,47	=	12,00	3/3
	21,33	=	75,11	3/3	=	24,42	8,93		32,56	4/4	<	24,00	7,65	<	30,00	1/4
	5,51	=	26,64	4/4	=	16,10	9,16		22,57	2/2	<	36,33	8,81	<	44,00	0/3
	2,28	=	13,32	4/4	=	7,86	0,35		8,14	4/4	<	18,20	9,16	<	31,00	3/4
	4,28	=	15,54	4/4	=	11,66	2,21		14,06	4/4	=	14,50	8,41	=	29,00	4/4
	4,57	=	21,46	4/4	=	16,47	4,89		20,72	4/4	<	39,50	20,60	<	75,00	3/4
	6,26	=	22,57	3/3	=	12,21	4,18		18,13	4/4	<	43,75	44,89	<	120,00	3/4
	1,60	=	13,69	4/4	=	7,49	4,29		12,95	4/4	=	11,08	3,82	=	15,00	4/4
	1,71	=	8,21	4/4	=	5,16	0,61		5,76	4/4	=	38,08	47,31	=	120,00	4/4
	31,78	=	61,40	3/3	=	25,24	34,70		65,30	3/3	=	17,43	8,64	=	27,00	4/4
	6,30	=	18,60	4/4	=	8,24	4,21		12,50	4/4	<	22,25	8,38	<	36,00	3/4
	2,04	=	8,86	4/4	=	5,16	0,50		5,58	5/5	<	27,50	2,06	<	30,00	0/4
	1,34	=	5,08	4/4	=	4,09	1,18		5,76	4/4	<	25,50	3,04	<	29,00	0/4
											<	24,50	0,50	<	25,00	0/2
Sb 125 in sea water in mBq/l																
GEA offshore Jobourg					GEA offshore Le Rozel						OPRI offshore Jardeheu					
	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N
	13,79	=	36,63	4/6												
	114,33	=	202,76	2/2												
	27,43	=	99,16	4/4	=	57,79	21,01		80,29	5/5	<	91,67	11,09	<	100,00	0/3
	40,39	=	111,00	3/3	=	46,07	24,91		77,70	4/4	<	66,75	5,40	<	75,00	0/4
	21,86	=	81,03	4/4	=	30,53	3,92		33,30	2/2	<	62,33	2,62	<	66,00	0/3
	23,12	=	126,20	4/4	=	58,58	25,71		91,80	4/4	<	115,00	38,15	<	160,00	0/4
	21,15	=	59,20	4/4	=	54,40	32,56		103,20	4/4	<	170,00	39,37	<	220,00	0/4
	41,77	=	105,80	4/4	=	34,70	6,30		44,00	4/4	<	130,00	40,62	<	200,00	0/4
	10,57	=	27,75	3/3	=	17,76	14,73		37,74	4/4	<	130,50	59,92	<	200,00	0/4
	2,74	=	15,91	4/4	=	13,88	11,34		24,42	4/4	<	131,75	40,18	<	170,00	0/4
	4,50	=	11,39	4/4	<	3,46	3,31		8,31	3/4	<	152,50	38,97	<	190,00	0/4
	1,81	=	4,40	3/3	=	5,05	5,33		11,20	3/3	<	152,00	36,36	<	200,00	0/4
	5,24	=	12,60	4/4	=	5,47	7,89		17,30	4/4	<	165,00	58,95	<	230,00	0/4
	1,18	=	3,16	3/4	<	1,38	0,82		2,72	2/5	<	62,00	8,28	<	69,00	0/4
	0,13	=	1,00	2/4	<	0,94	0,17		1,19	2/4	<	62,00	8,57	<	71,00	0/4
											<	63,00	2,00	<	65,00	0/2

RuRh 106 in sea water in mBq/l

	COGEMA offshore Jobourg						COGEMA offshore Le Rozel						COGEMA offshore La Hague						GEA offshore La Hague					
	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N
<	746,67	265,58	<	900,00	1/3													=	354,92	182,40	=	606,80	4/4
																		=	244,82	77,53	=	310,06	3/3
<	672,50	823,79		1900,0	1/4	<	365,00	7,07	<	370,00	1/2							=	258,78	95,83	=	423,28	5/5
<	300,00		<	300,00	0/4	<	377,50	72,28	<	440,00	2/4	<	432,50	207,10		740,00	1/4	=	146,08	62,95	=	232,40	4/4
<	550,50	529,84		1300,0	2/4	<	585,00	417,33		1200,0	2/4	<	367,50	121,48		520,00	1/4	=	322,08	121,61	=	458,80	4/4
	1590,0	1889,6		4400,0	4/4	<	440,00	281,42		780,00	2/4	<	592,50	242,26		930,00	2/4	=	162,98	35,98	=	201,30	4/4
<	387,50	356,78		920,00	2/4	<	292,50	72,28		360,00	3/4	<	577,50	123,12		670,00	3/4	=	222,53	123,89	=	342,20	4/4
<	252,50	83,42		370,00	0/4	<	260,00	75,50	<	330,00	1/3		272,50	67,02		340,00	4/4	<	104,15	96,64	=	261,60	4/5
<	182,50	43,49		240,00	2/4	<	167,50	25,00	<	200,00	0/4	<	250,00	78,10		340,00	0/3	=	87,98	47,68	=	149,80	4/4
<	170,00	34,64	<	200,00	0/4	<	112,50	18,93	<	140,00	0/4	<	172,50	26,30		210,00	0/4	<	17,72	18,54	=	44,77	2/4
<	108,75	10,31	<	120,00	0/4	<	107,50	5,00	<	110,00	0/4	<	132,50	33,04	<	180,00	0/4	<	7,43	2,33	=	10,55	2/4
<	101,25	6,29	<	110,00	0/4	<	104,50	8,76	<	120,00	0/6	<	110,00	10,00	<	120,00	0/3	<	8,61	5,41	=	16,70	3/4
<	112,50	5,00	<	120,00	0/4	<	113,33	5,77	<	120,00	0/3	<	116,67	11,55	<	130,00	0/3	=	11,25	3,83	=	16,10	4/4
<	112,00	13,27	<	130,00	0/4	<	110,00	10,00	<	120,00	0/3	<	115,00	12,91	<	130,00	0/4	<	6,74	1,57	=	8,98	2/4
<	110,00	8,16	<	120,00	0/4	<	115,00	17,32	<	130,00	0/4	<	140,00	47,61	<	210,00	0/4	<	7,58		=	13,38	1/4
<	135,00	31,09	<	170,00	0/4	<	128,00	14,83	<	150,00	0/5	<	127,50	17,08	<	150,00	0/4						

Co 60 in sea water in mBq/l

	COGEMA offshore Jobourg						COGEMA offshore Le Rozel						COGEMA offshore La Hague						GEA offshore La Hague					
	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N
																		<	0,67	0,33	=	1,11	3/4
																		=	3,70	0,74	=	4,44	3/3
																		=	3,18	1,03	=	4,07	5/5
<	26,75	13,20		44,00	3/4		21,00	7,07		26,00	2/2							=	5,18	4,22	=	11,47	4/4
													27,00			27,00	1/1	=	14,25	14,17	=	34,78	4/4
	18,50	0,71		19,00	2/2													=	4,63	4,62	=	11,47	4/4
<	13,25	3,95	<	19,00	2/4	<	12,00	1,73		13,00	0/3		13,00			13,00	1/1	<	2,36	2,41	=	5,50	2/4
<	13,50	3,87	<	19,00	0/4	<	12,33	3,21	<	16,00	0/3	<	11,67	1,53	<	13,00	0/3	<	1,62	1,59	=	3,70	2/5
<	10,03	0,67	<	11,00	0/4	<	10,55	1,68	<	13,00	0/4	<	13,00	3,46	<	17,00	0/3	=	2,68	1,22	=	4,07	4/4
<	10,45	2,59	<	13,00	0/4	<	7,95	1,32	<	9,90	0/4	<	9,60	1,68	<	12,00	0/4	=	4,72	6,50	=	14,43	4/4
<	7,30	0,22	<	7,50	0/4	<	6,88	0,30	<	7,20	0/4	<	8,23	1,14	<	9,90	0/4	=	2,39	1,47	=	4,49	4/4
<	6,85	0,67	<	7,80	0/4	<	6,80	0,41	<	7,40	0/6	<	6,97	0,61	<	7,50	0/3	=	3,70	2,09	=	6,82	4/4
<	7,05	0,34	<	7,50	0/4	<	6,73	0,29	<	6,90	0/3	<	7,33	0,65	<	8,00	0/3	<	1,54	0,81	=	2,40	3/4
<	7,23	0,53	<	7,90	0/4	<	7,20	0,75	<	7,90	0/3	<	6,88	0,62	<	7,70	0/4	=	1,20	0,52	=	1,74	4/4
<	7,03	1,00	<	8,50	0/4	<	6,93	0,79	<	7,60	0/4	<	8,45	2,42	<	12,00	0/4	=	0,89	0,47	=	1,58	4/4
<	21,68	24,28	<	58,00	0/4	<	7,76	0,66	<	8,70	0/5	<	7,93	0,74	<	8,60	0/4						

RuRh 106 in sea water in mBq/l

GEA LargeJobourg					GEA Le Rozel					OPRI offshore Jardeheu				(106Ru x2)	
erage	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N
479,15	371,12	=	1198,8	6/6												
906,50	######	=	1628,0	2/2												
226,53	56,60	=	304,88	4/4	=	254,71	67,77		321,16	5/5	<	413,33	37,71	<	440,00	0/3
286,23	36,46	=	328,20	3/3	=	178,18	56,17		238,30	4/4	<	480,00	117,47	<	680,00	0/4
268,40	117,02	=	442,50	4/4	=	180,90	76,37		234,90	2/2	<	426,67	24,94	<	460,00	0/3
199,90	23,50	=	227,20	4/4	=	179,35	76,89		269,00	4/4	<	820,00	377,36	<	1420,0	1/4
191,75	120,11	=	303,40	4/4	=	143,08	47,63		179,80	4/4	<	940,00	169,71	<	1100,0	0/4
98,63	41,43	=	139,90	4/4	=	109,70	59,81		179,40	4/4	<	625,00	86,46	=	700,00	2/4
142,67	163,00	=	327,80	3/3	=	78,53	37,69		128,40	4/4	<	675,00	149,92	=	800,00	1/4
19,45	12,88	=	36,26	3/4	<	17,56			53,28	1/4	<	885,00	253,53	<	1100,0	0/4
6,53		=	9,18	1/4	<	8,70			17,84	1/4	<	905,00	210,42	<	1240,0	0/4
5,28	0,77	=	5,79	2/3	<	6,91	1,52		8,60	2/3	<	1045	372,93	<	1340,0	0/4
9,46	3,26	=	12,90	3/4	<	8,54	5,02		16,00	3/4	<	1030	383,28	<	1420,0	0/4
9,39		=	20,60	1/4	<	7,34	1,65		9,35	3/5	<	475,00	80,47	<	600,00	0/4
					<	7,70			13,85	1/4	<	410,00	41,23	<	460,00	0/4
											<	550,00	130,00	<	680,00	0/2

Co 60 in sea water in mBq/l

GEA offshore Jobourg					GEA Le Rozel					OPRI offshore Jardeheu					
erage	s	=	max	>LD/N	=	average	s	=	max	>LD/N	=	average	s	=	max	>LD/N
1,30	1,74	=	4,81	2/6												
7,77	6,80	=	12,58	2/2												
5,18	2,24	=	7,40	4/4	=	2,66	1,21		4,07	5/5	<	52,33	24,57	<	81,00	0/3
7,65	3,32	=	11,47	3/3	=	7,86	6,80		17,39	4/4	<	27,50	4,72	<	33,00	0/4
5,00	1,23	=	6,66	4/4	=	5,92	3,66		8,51	2/2	<	28,33	0,94	<	29,00	0/3
4,93	3,69	=	8,14	3/4	=	2,96	1,00		4,44	4/4	<	51,00	14,09	<	66,00	0/4
2,42	1,61	=	4,10	3/4	<	4,37	5,07		11,80	3/4	<	68,00	2,16	<	70,00	0/3
2,80	1,81	=	4,81	3/4	=	3,52	0,71		4,07	4/4	<	51,50	7,50	<	59,00	0/2
2,84	2,04	=	5,18	3/3	<	1,07	0,82		2,22	2/4	<	36,00	5,72	<	41,00	0/3
12,12	8,53	=	24,79	4/4	=	8,97	12,11		26,64	4/4	<	52,50	18,73	<	73,00	0/4
3,30	2,64	=	7,13	4/4	<	2,50	1,61		4,07	3/4	<	61,25	14,17	<	84,00	0/4
3,06	1,31	=	3,99	3/3	=	1,82	1,05		3,03	3/3	<	53,50	21,10	<	73,00	0/4
2,32	0,85	=	3,46	4/4	=	2,13	1,70		3,98	4/4	<	56,25	15,80	<	67,00	0/4
1,47	0,94	=	2,62	4/4	=	0,85	0,12		0,96	5/5	<	21,75	3,63	<	26,00	0/4
1,15	0,65	=	2,07	4/4	<	1,06	0,94		2,44	3/4	<	30,00	9,87	<	47,00	0/4
											<	25,50	0,50	<	26,00	0/2

PART C

TRANSFER MODELS FOR RADIONUCLIDES THROUGH THE ENVIRONMENT

1. OBJECTIVES

The main objective of GT3 was to propose the most suitable mathematical tools to evaluate radionuclide concentrations in the various components of the Nord-Cotentin environment. The procedure adopted by the Group consisted of validating models for transfers of radionuclides released by industry, by comparing calculation results with the results of measurements made on samples taken from the environment. The measurement results used by GT3 were those selected and adopted by GT2 for the 1978-1987 period[23].

A radioactive element may take various routes in the environment from source to man, referred to as exposure pathways or transfer pathways. The various steps in the transfer from the emitting source to the critical population group are modeled, with intermediate results in the environment (concentrations in living or mineral species) which may be compared with the results of measurements. Thus:

- The dispersion of radionuclides when the receiving environment is the sea and a river is modeled using an effluent release dilution factor, and in the atmosphere it is modeled using an atmospheric transfer coefficient (ATC).

- Radionuclide transfers in liquid compartments (sea and river) towards components of the environment that come into contact with man are modeled by radionuclide concentration factors for living species (FC), and by distribution coefficients for sediments (Kd). For terrestrial compartments and particularly food, modeling takes into account meteorology and the various possible transfer pathways (air, soil, crops, harvesting period, food processing transformations, etc.).

An assessment of the final impact on man requires a calculation of external and internal exposure of man in contact with radionuclides present in these compartments. Dose calculation uses parameters presented in GT4 report.

2. GENERAL PROCEDURE

The first task performed by the group was to draw up an inventory of existing models (models used by operators and the PC-CREAM European model) and their parameters.

The group then carried out a critical analysis of model results for similar release conditions, as they were supplied by the operators. This work was used to evaluate the divergence of calculation results obtained by the various models, with respect to each other.

In a third step, the group selected the models that it considered most appropriate for each environment and for each release type. When several models comprised different parameter values to describe identical phenomena, the group gave preference to choosing the values best representing the Nord-Cotentin ecosystem. When these values were not available, the group used values from the literature that appeared the most relevant, either as derived from the most complete possible bibliographic analyses, or as recommended by international organizations (IAEA or EEC). If no data were available for particular radionuclides, their characteristics were compared with the characteristics of a radionuclide with similar physical and chemical properties.

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[23] Measurement results, such as ^{14}C and ^{129}I on samples taken from the environment available from 1995 and 1997 respectively only, were not always sufficient to make detailed comparisons.

The final step was to identify measurement in the environment results that could be used to make a comparison with the results calculated by models, and then make this comparison. In doing this:

- environmental compartments for which this comparison was meaningful were selected (see Section 6);

- data selected by GT2 were used, making use of average annual values, maximum values, standard deviations of measured values, or even some significant individual values, wherever they were available. The critical analysis of these values made by GT2 was considered;

- For each compartment and for each radionuclide for which this comparison appeared possible, the values calculated by the model were systematically compared with measured values, at all sampling points and over the entire period for which significant values were available.

3. REVIEWED MODELS

Until 1998, Nord-Cotentin nuclear power station operators and the IPSN used the following models to estimate the impact of facilities:

- Dispersion of releases into the sea: COGEMA, ANDRA, EDF and the IPSN used the same type of models based on dilution factors, concentration factors and distribution coefficients (see section 5.2);

- Dispersion of atmospheric releases: three models were used, belonging to COGEMA [1], EDF (the BGAZDR software [2]), IPSN (the FOCON96 software [3]);

- River releases: three models are used, belonging to the ANDRA (the AQUABIOS software [4]), EDF (the software BLIQUID [5]), and the IPSN (the software AQUAREJ [6]).

The models used by operators for all releases from their facilities have been authorized for French and European regulatory procedures (particularly the EURATOM procedure, Art. 37, related to new nuclear facilities).

The European PC-CREAM [7] model was also tested by this project (see Section 4).

The purpose of these models is to provide evaluations of the exposure of some groups of population to different releases:

- For COGEMA releases, the exposures concerned are due to:

  - marine releases (COGEMA and ANDRA facilities) affecting adults and teenagers between ages 7 and 12 who are members of fishermen families located in Goury,

  - atmospheric releases affecting adults, teenagers and children less than one year old living in Digulleville;

- For EDF releases, the exposures concerned are due to:

  - liquid releases affecting theoretical populations consuming seafood caught within an area 500 meters from the release point;

  - atmospheric releases affecting inhabitants of the "La Berquerie" district, 800 meters from the installation.

- More specifically concerning ANDRA, the objective is to evaluate the impact of former releases and current activities in rivers.

The source term used for each installation is provided in the form of annual releases. Estimates of the health impact are expressed in effective annual doses received. Intermediate calculations provide radioactivity levels of some compartments of the environment expressed in average annual activities. These results can be presented as ranges of values that represent the variability of the most important parameters.

At this stage, it is worthwhile to emphasize the difficulty of comparing calculated values of concentrations with values obtained from measurements of environmental samples, which frequently have a temporary nature. The lack of knowledge of annual variations of the activity of radionuclides in the environment around the average annual value, or the failure to take them into account, prevents a direct comparison of the calculation results with most measurements made. Fluctuations to be considered are applicable particularly to quantities of radionuclides released during the year and natural phenomena such as seasons or the tide. Consequently, there are only two ways of comparing the results obtained from models with measurements in the environment:

- either by considering environmental indicators that concentrate some radionuclides (bio-indicators and sediments) in the more or less long term, thus eliminating the various fluctuations. In this case, the comparison is indirect and therefore only applies to some values of the model parameters;

- or by integrating the different variations mentioned above over a full year. Data available have to be supplemented with the widest possible variety of information about the characteristics of samples and the conditions under which they were taken. It is then possible to weight the results, compare the measurements with each other and define an average concentration over a year; or conversely, to use the model to evaluate a probable range within which the activities of samples from the environment are likely to be located. This variation can also be estimated afterwards, after a comparison between the results of models and in situ measurements.

This comparison is not possible in two cases:

- for the radioactivity of land eco-systems around EDF's Flamanville power station; the impact of gaseous releases from the power station cannot be distinguished from "atmospheric background noise". This point is discussed in the report for the 10-year radio-ecological statement of the environment surrounding the power station [8];

- the impact on the environment of releases from the ANDRA site; GT1 emphasized the fact that there is no simple relation between the radiological inventory of disposed waste and activities measured in rivers running close to the site, making it difficult to define a source term.

4. COMPARISON BETWEEN MODEL RESULTS

The first step was to make a comparison between models used by COGEMA, EDF and the IPSN. This step compared calculated activities in the environment and the dosimetric impact of releases, under practically similar release conditions, namely releases declared by operators for 1995. The European PC-CREAM model was also used for comparison.

However, this comparison has some general limitations:

- the compared models use different radionuclide libraries, adapted to releases specific to the facilities for which they are used. The assumptions for source terms used for the calculations are almost exactly the same for a given radionuclide, however estimate of total doses may be different due to the lack of certain radionuclides in some calculation programs;

- some radionuclides, for which the contribution to the dose appears to be negligible as a first approximation, were not included in the calculation. Therefore these calculations do not use clarifications made later by all the GT;

- this comparison does not prejudge the validity of the various models in any way; it simply provides information about the dispersion of their results.

In order to be able to estimate the dispersion of results supplied by the various models described in Section 3, each calculation tool was used for each site, with input data specific to each site (population groups, average diet, dilution factors, etc.).

The following sections describe the information obtained during this comparison.

4.1. Releases into the sea

- In general, it is found that the divergence of results obtained using COGEMA, EDF and IPSN models is low. This observation is not very surprising to the extent that these three organizations used the same dilution factors to make their calculations, and COGEMA and EDF used the same food rations for critical groups associated with each release. The main differences between the three models are water/sea species concentration factors or water/sediment distribution coefficients, and dose coefficients.

- However, the results provided by PC-CREAM were systematically higher for COGEMA releases by a ratio of 1 to 10, and were systematically lower for EDF releases by the same ratio. This is probably due to differences in the dilution factors. The ratio between dilution factors used by EDF and COGEMA is about 200; the dilution factor in COGEMA release is 200 times greater than the dilution factor for the EDF release. The PC-CREAM calculations are apparently based on a dilution factor intermediate between these two cases, a value that does not correspond to physically observable phenomena local to the study area in the canton of Beaumont-Hague, since the PC-CREAM value is averaged over a range that is too large to be representative of the examined area.

- The results of calculations of radioactivity values of sediments are generally highly dispersed. Activity levels evaluated using PC-CREAM appear to be significantly lower than levels calculated by COGEMA or the IPSN.

For these reasons, and despite European acceptance of this model, PC-CREAM parameters were not used for sea releases, except for concentration factors and distribution factors that are in keeping with EEC recommendations [7]. This is also the reason why the dispersion of results (max/min) were only calculated for COGEMA, EDF and IPSN values.

4.2. Atmospheric releases

- in terms of doses, the final results obtained by the various atmospheric models are less dispersed than results obtained for releases into the sea. The absence of some intermediate results[24] (atmospheric transfer coefficients for PC-CREAM, deposition rates for PC-CREAM and EDF, grass radioactivity for PC-CREAM) and the results of calculations made for different angular geographic sectors (firstly IPSN and PC-CREAM, and secondly EDF and COGEMA) make it difficult to compare results and to explain the dispersion of some of these results.

- in general, aerosol and iodine deposition rates calculated by COGEMA are greater (sometimes significantly greater) than values calculated by IPSN, regardless of the angular sector considered.

- results obtained by PC-CREAM are very often lower than the results calculated by other models, whereas the results of the IPSN model often appear higher than the results obtained from other models.

- a number of differences can be explained by the failure to take into account ground-plant transfers (EDF model) or by the lack of leaf transfer to root vegetables for some radionuclides (ruthenium and plutonium in the IPSN model).

- tritium activities of the various products calculated by the EDF model are systematically lower than values calculated by other models.

There are still a few differences:

- concerning EDF releases, calculated doses for cobalt 60 are different in the different models. The very variable levels of activity for beef are related to the dispersion of values obtained for plants.

- however for COGEMA releases, the calculations carried out by the various models for plutonium give different results for deposition rates, activities in root vegetables, etc.

5. CHOICE OF MODELS

5.1. Background noise

A comparison between the results of models for predicting the impact of radioactive releases on the environment and *in situ* measurements requires that previously existing natural and artificial radioactive background noise should be taken into account, particularly when industrial contributions are of the same order of magnitude or lower than this background noise. This background noise represents the level of radioactivity of sea water or the atmosphere, before it is influenced by releases from nuclear facilities in the Nord-Cotentin.

- Radionuclides from natural sources may:

  - be the result of original nucleosynthesis of earth materials - ^{40}K, the ^{232}Th, ^{235}U, ^{238}U families including radionuclides such as ^{210}Po.
  - be continuously produced by the interaction of cosmic radiation with components of the earth's upper atmosphere (^{3}H, ^{7}Be, ^{14}C).

[24] Definition of terms used: see section 5.3.1.

They have a relatively uniform distribution around the world, but some local variations may occur depending on their source or their chemical properties. Some human activities can locally increase concentrations of some radionuclides occurring naturally in the environment (manufacturing of fertilizers, mine tailings, etc.)

- Radionuclides from artificial sources are the result of:

  - fallout from atmospheric nuclear weapon tests (^{137}Cs, ^{90}Sr, Pu, ^{99}Tc, etc.) which may add to natural production (^{3}H, ^{14}C); they represent a well known, relatively stable and uniform contribution across Europe;
  - atmospheric fallout from the Chernobyl accident.
  - industrial discharges outside the Nord-Cotentin; possible influence of releases from the Sellafield reprocessing plant on the Irish Sea or previous releases of industrial waste that have escaped from the Arctic Ocean and returned through the North Atlantic; leaks from waste dumped into the English Channel and the Atlantic Ocean until 1982, etc.;

This background noise changes with time. The following order of priority was used to estimate marine background noise from available measurements for the purpose of comparing models and measurements:

- summaries made based on measurements over the entire English Channel for the years 1983, 1986, 1988 and 1994 [26].

- representative measurements of water flows entering the English Channel acquired by the IPSN (Irish Sea, Celtic Sea, Bay of Biscay);

- values of measurements available in the literature for the North Atlantic Ocean.

When no measurements were available, activities were interpolated making use of other radionuclides with the same sources and the same behavior. This background noise represents the activity of sea water before it is influenced by releases from power stations in the Nord-Cotentin region.

Much of the atmospheric background noise is the result of fallout from atmospheric nuclear weapon tests, and to a lesser extent fallout from the Chernobyl accident. This background noise was described in "Radio-ecological consequences of fallout from atmosphere nuclear weapon tests and the Chernobyl impact in the "La Manche" department" [9].

The contribution in ^{137}Cs and ^{90}Sr related to fallout from atmospheric nuclear weapon tests is considerably greater than the contribution of fallout from industrial atmospheric releases.

5.2. Modeling the impact of marine releases

5.2.1. Dilution factors that apply to marine releases

Movements of water masses are governed mainly by tidal phenomena in coastal areas. These movements may be relatively large over the period of a single tide, particularly in the case of a sea like the English Channel. However, when rising and falling tides are considered over several cycles, the resulting dynamics may be represented by a set of "residual" currents that are influenced by weather conditions. They can be considered as being constant over a year around the Nord-Cotentin. Thus, unlike the dynamics of air masses, the dynamics of water masses may be considered to act in a steady state over a year.

The dispersion of marine releases from the two facilities can then be modeled by release dilution factors, at each point along the Nord-Cotentin coast. These factors correspond to the average ratio (over a year) between the sea water activity from which the "background noise" is subtracted and the radioactivity flux released by the plant being considered. Dilution factors are representative of the transport of radionuclides by water masses, and

ignore any fixation of radionuclides on sediment particles between the release point and the area to which they are applied. The specific impact of each radionuclide is considered for each marine species, using the method described later.

5.2.1.1. Releases from COGEMA La Hague reprocessing plants

Dilution factors were calculated using the results of the sea water measurements made over long time periods at some sampling points (more than 400 measurements at a few points). For other points along the coast, the values used were obtained from occasional measurement campaigns, together with or confirmed by a hydrodynamic model of residual currents [26] (See section 6.1.1.).

For offshore areas, the available measurement results are also used to evaluate average dilution factors. Available data close to the release point (which is about 2 km offshore) are not sufficient to determine the characteristics of the average dilution over a year, and the variability of this dilution. Further away, specific dilution factors in the areas concerned were evaluated using models and measurements on some species fished offshore (See section 6.1.2).

5.2.1.2. Releases from the EDF plant

The method used for COGEMA La Hague reprocessing plants cannot be used for the EDF power station. Radionuclides released by the Flamanville power station have never been detected in sea water, except in the very close field and during releases. Therefore the ratio between the annual average measured concentration and the released annual flow cannot be calculated to estimate the dilution factor.

5.2.2. Transfers in the marine environment

If release dilution factors can be used to calculate the sea water activity in the various regions along the Nord-Cotentin shore, the activity of marine species (fish, crustaceans, molluscs, seaweed) and of sediments can be estimated assuming a steady state throughout the year. Under steady-state conditions, it can be assumed that the activity per unit mass of living species is proportional to the activity per unit volume of sea water at the location at which they were fished. For each radionuclide, the activity per unit volume is equal to the activity due to releases from facilities, plus the activity due to sea water radioactive "background noise". The corresponding proportionality factors are called concentration factors for marine species (FC) and distribution coefficients for sediments (Kd). The use of these factors to model radionuclide transfers in the environment appears suitable for concentrations corresponding to traces of radionuclides in the environment.

This proportionality assumption is based on a balance being reached between the various components of the environment (sea water, marine species and sediments). When this condition is not respected, the radioactivity of marine species, and even more the radioactivity of sediments, will not be the same as the radioactivity calculated with FC and Kd values. The analysis of the radioactivity of sediments was done separately from the analysis for living species, in order to take into account these phenomena.

5.2.2.1. Living marine species

The following formula is used to calculate concentrations in living marine species using the method described above and for a given radionuclide:

Concentration in the species = ((Annual Release x Dilution Factor) + Background noise in sea water) x Concentration Factor for this species

The values of concentration factors recommended by the IPSN for living species were used *a priori*, since these values are particularly applicable to the behavior of radionuclides in living species in the English Channel. IAEA values were used when no IPSN data were available. For carbon-14, the range of values used by COGEMA and the IAEA was kept initially. The list of concentration factors used in the comparison between models and measurements summarizes the factors used by the various models recommended factors. Note that concentration factors for species belonging to the same group (crustaceans, fish, molluscs, seaweed) may frequently vary by a factor of 1 to 10. This is the reason why comparisons were also made with extreme, minimum and maximum values of the factors in this list, whenever the variation between them rarely exceeds this order of magnitude.

There are no factors available in the literature for some radionuclides, and concentration factors of chemical analogs were used in these cases. Thus, beryllium is considered like cobalt 60, rubidium like cesium, rhodium like ruthenium, and praseodymium like cerium.

5.2.2.2. Sediments

Sediments can store medium to long-term radionuclide half-lives and gradually release particles, sometimes several years after their deposition and movement on the sea bed (mixing and resuspension phenomena).
Thus, radionuclides accumulated on sediments during the years when releases were highest will not be measured in quantities proportional to the more recent releases if the releases have significantly dropped. The sediment storage capacity is determined largely by the size grading and mineralogical composition of the sediments. Due to the variability of these characteristics, sediment samples taken on the same site can have very different radionuclide contents. The areas that are likely to have the highest marking are areas sheltered from the strongest currents in which the finest particles can settle (for example estuaries). In the Nord-Cotentin region, Cherbourg Bay is the area most concerned by these deposits.

Furthermore, the displacement of sediment particles according to dynamics different from the dynamics of the sea current restricts the use of dilution factors defined for sea water; over the period of a year, characteristic displacement speeds in the English Channel and the North Sea are of the order of a thousand kilometers for sea water compared with a few kilometers to a few tens of kilometers per year for sediments. At the present time there is no efficient modeling tool for simulating the displacement of sediments after they have been deposited on the English Channel sea bed. Although several studies [10] give orders of magnitude for displacements in some areas, they do not have sufficient spatial resolution for use for the purposes of the work done by GT3. Therefore, this parameter will not be used for the comparison between models and measurements, and general dilution factors will be applied.

Two methods have been selected *a priori* to take into account these uncertainties:

- The first method consists of applying Kd values using the same logic as that selected for living species. When these coefficients are not available in the literature, radionuclides were grouped using the same physicochemical analogies as for living species. Thus, in the special case of molybdenum for which there is no distribution coefficient, the distribution coefficient for technetium was used. Only two dilution zones were used (the environment close to the release point (between Cap de Flamanville and Cherbourg), and all other areas in the Nord-Cotentin, because it is impossible to take into account sediment transport phenomena. The following formula was used to calculate concentrations in sediments:

Concentration in sediment = ((Annual Release x Dilution Factor) + Background noise in sea water) x Kd

- The second method consists of extending the first method taking into account the sediment storage which integrates the influence of releases from N previous years. This integrated activity is calculated for a given year, by totalling the activities resulting from releases in each of the N years before that year. The influence of releases from previous years is corrected by the radioactive decay of the radionuclide and takes into account a sediment integration period which has to be defined for each chemical element considered:

Integrated activity over N years until year X =
(activity of sea water corresponding to releases in year X
+ activity of sea water corresponding to releases in year (X-1) having decayed for one year, based on the radioactive half-life of the radionuclide and a specific sediment integration period for the element
+ activity of sea water corresponding to releases in year (X-2) having decayed for two years, using the same half lives
…
+ activity of sea water corresponding to releases in year (X-N) having decayed for N years, using the same half lives)

/ sum of the contributions over N years to avoid overestimating releases.

The activity released in year (X-N) contributes to the measured activity on a sediment sampled in year X, proportional to $e^{-\lambda s.N}$, where N is the number of years during which sediments are being integrated and λ_s is equal to In(2)/P, where P is the sediment integration period characteristic of the element. The calculation result takes into account radioactive decay, the dilution factor and the distribution coefficient in calculating the integrated activity in the sediments. Measured activities in sediments are then compared with these calculated activities, taking into account the assumed sediment integration. The adjustment parameters selected are measurement dispersion and stability of the transfer factor of each radionuclide over time, in order to determine the most representative integration period for each radionuclide.

The value of P depends solely on the radionuclide considered; it takes into account its radioactive half-life and it is representative of the period during which it remains stored in sea bed sediments. However, transfer factors with integration determined in this way are closely dependent on the physicochemical characteristics of sediments (size grading, mineralogical composition). The Nord-Cotentin Radioecology Group does not have the information necessary for this characterization, since it was not included in the model. Defined transfer factors cannot be compared with Kd values since they take into account the fact that exchanges between sea water and sediments are variable with time, whereas Kd values represent a balanced situation. They appear in the results of model/measurement comparisons in the form of correction factors.

This empirical method is only a compromise due to the lack of a complete dynamic and physicochemical model of sediment radioactivity. However, note that the CEFAS at the British Ministry of Agriculture, Fisheries and Food has used a similar method for interpreting the radioactivity of living species due to releases from the Sellafield plant in the Irish Sea [11]. In the Irish Sea, where fine sediments predominate, the availability of radionuclides fixed on particles has an overriding influence on the radioactivity of living species, due to the magnitude of radionuclide retention and desorption phenomena on sediments and the strong reduction in flows discharged from this installation over time.

5.3. Modeling the impact of atmospheric releases

5.3.1. Dispersion of atmospheric releases

Dispersion depends on two sets of parameters, which needed to be known in priority:

- A detailed statistical analysis of meteorological conditions representative of the site;

- atmospheric transfer coefficients (ATC[25]) are representative of the dilution of atmospheric releases into air at a point and for given weather conditions close to an installation. The main difference between ATC values and marine release dilution factors is due to the timescale over which they can be used; dilution factors represent the average dispersion in sea water over a year, whereas ATC values are representative of a dilution corresponding to a given meteorological condition, which can vary considerably during a day. Models traditionally used consist of multiplying the annual release from an installation by an average annual ATC in order to obtain the average annual concentration of radionuclides in air at a given point affected by chronic releases from a nuclear installation, assuming the average annual weather conditions at this point. ATCs weighted for weather conditions were thus calculated for all villages surrounding installation output points.

5.3.1.1. Meteorology

The use of calculation models requires knowledge of at least the frequencies of weather situations corresponding to exhaustive ranges of wind speeds in dry weather or in wet weather, determined over a sufficient number of years to be representative of site conditions. These data can be used to evaluate weighted ATCs, and weighted dry or wet deposition rates. Two types of atmospheric dissemination conditions (normal and weak) are considered, in accordance with input parameters to dispersion models. Due to the lack of sufficient information about atmospheric dissemination conditions [26,27], it is assumed that weak dissemination conditions correspond to wind speeds of less than 5 m/s at an altitude of 100 meters. Dissemination conditions are considered to be normal for higher wind speeds. It is also found that particular weak dissemination appears particularly low for wind speeds greater than 5 m/s, although they are rare in this region, and are of the same order of magnitude as normal dissemination situations with wind speeds less than 5 m/s.

5.3.1.2. Calculation of atmospheric transfer coefficients

The IPSN's COTRAM2 model [12], [13] is a Gaussian model based on the Doury model [14] and was used assuming that releases from COGEMA installation are made at a height of 100 meters, and releases from the EDF power station are made at ground level.

Since radioactive rare gases do not deposit and do not accumulate in living organisms, the only external exposure of the population occurs while the releases are passing. Their radiological impact is estimated only using these weighted ATC coefficients.

For aerosols, this model takes into account depletion of the plume in dry and wet weather and the ATCs are adjusted accordingly.

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[25] Values of atmospheric transfer coefficients are expressed as an activity present in a volume of air, compared with the activity released by the plant per unit time ($Bq.m^{-3}$ per $Bq.s^{-1}$).

[26] Available elements are studies carried out during the 1980s for the purposes of article 37 in the EURATOM Treaty, vertical wind speed measurements made using the SODAR installed on the La Hague site since 1995, and temperature measurements at heights of 1.5 and 10 meters above the site.

[27] See also COGEMA note No. NT/008311/V/98.0347/Rev.0.

5.3.1.3. Calculation of deposition rates

Calculations of dry, wet and total deposition rates are made based on ATC values for radionuclides bonded to aerosols.

5.3.2. Carbon-14 transfers

According to the literature, it is accepted that carbon in man originates essentially (99.9%) from carbon ingested with food and not by inhalation. Therefore, ^{14}C reaches man through his consumption of vegetables, meat and milk from animals that have eaten contaminated plants. The proportion of assimilation by man and higher animals by breathing is considered to be insignificant compared with assimilation due to photosynthetic activity in plants. Concentrations of ^{14}C fixed in plant tissues at a given site is then considered as being equal to the value in air at this site. Therefore, in the case of a model at equilibrium, it must be assumed that exchanges of ^{14}C between plants - animals and the atmospheric environment are balanced, and therefore that the level of ^{14}C in the atmosphere is constant, which implies that the releases are themselves constant with time.

Most French and foreign models assumed that the content of ^{14}C in plants is proportional to the content in the atmosphere at the location at which these plants are growing. In order to model the radioactivity in plants, and then in animals and therefore in food, the ^{14}C activity in the atmosphere is calculated using the ATC and it is multiplied for the proportionality factor specific to each species:

- The ^{14}C activity in air is obtained by multiplying the release rate ($Bq.s^{-1}$) by the ATC for the location considered, determined using the so-called alternative method, corrected for the proportion of carbon in the form of carbon dioxide in the effluents[28] . This coefficient is assumed to be equal to 100% for COGEMA gaseous releases and 20% for EDF gaseous releases[29] .
- The proportionality factor is the ratio between the content of stable carbon in the food considered (expressed in kg of carbon per kg of total mass) and the concentration of stable carbon in air, namely 0.00019 $kg.m^{-3}$ of air which corresponds to 330 ppm of CO_2 by volume (Robert, 1996).
- The selected ^{14}C background noise in the atmosphere is 250 $Bq.kg^{-1}$ of stable carbon.

This method is officially used in Switzerland to evaluate the impact of carbon-14 released by Swiss nuclear power stations [15].

		Leaf vegetables			*Root vegetables*		*Fruit*	
Matrices	*Grass*	*Lettuce*	*Cabbage*	*Cauliflower*	*Potatoes*	*Carrot*	*Apples*	*Strawberries*
NCRP	0.16	0.020	0.032	0.035	0.095	0.049	0.07	0.044
GT3	0.16	0.035	0.035	0.035	0.095	0.095	0.057	0.057

	Meat				
Matrices	*Beef*	*Pork*	*Mutton*	*Poultry - Eggs*	*Milk from cows*
NCRP	0.228	0.402	0.289	0.156	0.067
GT3	0.228	0.402	0.289	0.156	0.067

Table 5.3.2: Relative proportions of total carbon in food expressed in $kgC.kg^{-1}$
Total fresh weight of food derived from NCRP values [33].

[28] Proportionality factor = $pm/[C^{12}]_{air}$, where pm = proportion of releases in mineral form and $[C^{12}]_{air}$ = concentration of stable carbon in the atmosphere.

[29] Proportions confirmed by GT1.

5.3.3. Tritium transfers

In the same way as for ^{14}C, most French models assume that the tritium content of vegetables or animal species is proportional to the tritium concentration present in the atmosphere at the location at which these species are present[30]. To model their radioactivity, the tritium content in the atmosphere is calculated at the location at which these species are located using ATCs and is multiplied by a proportionality factor that depends on their water content.

Thus, the tritium activity was modeled by multiplying the weighted ATC evaluated at the location at which the sample was taken, by the release flow and by a constant factor assumed equal to:

- 135 $m^3.kg^{-1}$ for leaf vegetables, milk and cheese;
- 130 $m^3.kg^{-1}$ for fruit vegetables;
- 115 $m^3.kg^{-1}$ for root vegetables, eggs and meat;
- 80 $m^3.kg^{-1}$ for cereals.

These factors are calculated based on the proportion of water in organisms derived from [16], and absolute and relative atmospheric humidity ratios for the Nord-Cotentin area supplied by COGEMA.

5.3.4. Other radionuclides: iodine, radionuclides bonded to aerosols

The model used by GT3 for transfers of iodine and radionuclides related to aerosols is based on the IPSN's FOCON 96 model [17], but it includes complementary phenomena such as the variability of releases in different years and resuspension of deposits.

Discussions were held within GT3 about the values of some of the parameters, and the following conclusions were reached:

- a factor of 10^{-8} m^2/m^3 was adopted for the resuspension of deposits, in order to calculate the average impact on the cohort in the canton of Beaumont-Hague. It may be assumed that this resuspension is greater for more specific "farmer" type scenarios, and the recommended factor is 10^{-6} m^2/m^3. These data are extracted from "Long-term behavior of a low and medium activity radioactive waste disposal facility" [18];
- two methods are used for the capture ratio in dry weather; the first approach gives a set of values derived from a recent bibliographic review [17] that relies on different types of plants, and the second method produces a single factor for all types of plants and all radionuclides, equal to 0.25; this factor was taken from the first European methodology [7];
- migration constants to be used for migration of radionuclides in soils are calculated using the EDF/CEA Guide [19], the values of K_d^{sol} to be used being the values given by IAEA in its publication 94/364. For radionuclides not mentioned in this publication, the decay constant due to migration in the soil is taken to be equal to 100 years by default, except for ^{36}Cl for which the value proposed by Sheppard *et al.* [31] is used.
- different values were used for ground/plant transfer factors for grass and for hay;

- Animal food rations: it was decided to use food rations adapted to the Nord-Cotentin based on values given in the CEA/EDF Radioecology Manual [19];

[30] Case in which animal drinking water is considered to be non-contaminated.

- for cows, this consists of considering a food ration consisting of pasture for two-thirds of the year (60 $kg.d^{-1}$ of grass and 10$l.d^{-1}$ of water), and stabling for one third of the year (35 $kg.d^{-1}$ of maize, 5 $kg.d^{-1}$ of hay, 10 $kg.d^{-1}$ of vegetable cake, or cereal waste[31] , 35 $l.d^{-1}$ of water). On average, this corresponds to 40 $kg.d^{-1}$ of grass, 18 $l.d^{-1}$ of water, 12 $kg.d^{-1}$ of silo corn, 2 $kg.d^{-1}$ of hay, 3 $kg.d^{-1}$ of cereal waste or vegetable cake;
- food rations for other animal species such as poultry were used as presented in the Radioecology Manual without change;
- two options were discussed for rabbits, which are not considered in the Radioecology Manual. The first was to assume the food ration used for factory-farm poultry as given in the Radioecology Manual, although it is accepted that rabbits eat more leaf vegetables than cereals. The second method would consist of considering rations more representative of a rabbit breeding center for home consumption, namely 100 $g.d^{-1}$ of grass or leaf vegetables, 35 $g.d^{-1}$ of maize, 0.1 $l.d^{-1}$ of water;
- the soil ingestion assumptions are as given by the IAEA [32], namely 4% of the solid food ration expressed as dry weight for cattle and 20% for sheep. The proportion used for poultry is also equal to 20%.

- Cider and jam transfer factors; it was decided to assume that the transfer factor to cider is the same as the transfer factor to fruit, since most of apples are processed into juice; furthermore, it was decided that the jam transfer factor to be used would be equal to 0.5 times the fruit transfer factor, considering firstly the proportion of fruit used in jam production, and secondly the effects of culinary preparation (evaporation during cooking);

- One method for dairy products would be to use transformation coefficients available in the literature. However not many values are available, and variability is very high depending on the radionuclides and products considered. GT3 also proposes multiplying the number of liters of milk necessary to make a kilogram of cheese or a kilogram of butter by the milk transfer factor, although it recognizes the limitations of the method which is conservative.

For some parameters, it appears better to take a sample of parameter in place of one. GT4 can use these samples to make a sensibility study.

5.3.5. Collective dose calculation principles

The models mentioned above are used to evaluate ATC values and transfers to different species for each commune in the canton. They depend on the distance and position of the village considered with respect to the release point. Furthermore, since meteorological data are only available for recent years, it appeared relevant to use average meteorological conditions for all years, calculated based on values available for the years 1992 to 1997. A simulation made using the FOCON model demonstrated that this simplifying assumption can result in annual variations of ATCs of 20% above and below the average. Finally, to avoid the need to carry out a systematic calculation for each of the 19 communes in the canton of Beaumont-Hague, it appeared simpler to use "average" values for the main parameters representative of dispersion and deposits for the entire canton, these averages being obtained by weighting the values of these parameters obtained for each village, by the populations of these villages. A simulation of ATCs also demonstrated that this simplifying calculation assumption can lead to variations of the order of 10% depending on the year considered, since the population structure in the canton changed with time. For the radioactivity of animal products and their feed (grass, fodder, etc.) the weighting factor was based on the area of fodder in each commune, rather than the population.

[31] Cereal waste used for animal feed

5.4. Transfers by seaweed and sea spray

Spreading of seaweed in fields was considered in calculating the radioactivity per unit mass in the soil and in garden vegetables. But only the soil/plant transfer was modeled.

For sea spray, the NRPB developed the TORIMA model [20] to model sea spray deposits on the ground and their inhalation. This is the only model available for the work done by the GT3. There is no working tool for calculating concentrations in air near the coast due to sea spray as a function of local conditions.

5.5. Transfers in waterways

This type of transfer only concerns the CM which is the source of observed marking. Since the source term for this installation cannot be precisely known, the only possible work in comparing models with measurements in the environment will concern validation of the "intermediate models" in other words water/river sediment distribution coefficients. In general, it was decided to adopt the factors recommended by the IAEA in its publication 94/364[32].

6. COMPARISON BETWEEN MODELS AND MEASUREMENTS

6.1. Releases into the sea

6.1.1. Sea water - Dilution factors

Graphs illustrating the results of this comparison are presented in the Appendices in the detailed report.

6.1.1.1. Release conditions

Dispersion studies of releases of liquid effluents made by the CEA prior to the construction of the outlet pipe, were designed to optimize the location and times of releases into the sea in order to provide maximum dilution in the near field and fast dispersion of releases in water masses flowing from the Atlantic to the North Sea through the English Channel from west to east. These studies, based on physical simulations in models and tracing experiments using colored markers on the future release site, were the reason why CEA proposed a release site 1.7 km offshore from Cap de Jobourg, in the South East part of the Blanchard tidal race along the Cap La Hague. From the beginning, times of releases of the most radioactive effluents were defined to be within the phase of the tide that maximizes their dispersion, with tidal currents towards the North (between 0h30 before and 2h30 after high tide at Dielette). The fraction of effluents justifying this precaution has gradually decreased, consequently the proportion of releases made outside optimum dilution periods has become greater.

6.1.1.2. Overview about prior work (1963 - 1997)

Many studies have been carried out in order to estimate the impact of releases of liquid effluents from the installation into the sea environment. They are based particularly on:

- experiments using colored markers;
- releases of floats and drift maps;
- regular measurements in coastal stations;
- sea campaigns;
- simulations made on hydrodynamic models.

Experiments using colored markers are used essentially to evaluate the short-term dilution of effluents, within 24 hours after the release. They give good characterization of the particularly intense local hydrodynamics that enables fast dilution of releases (greater than 10^6 in less than one hour). However, they cannot be used to obtain an estimate of their impact in the long term, even in the near field. Due to the intensity of local currents and the forward and backward motions caused by the tide, the hydrodynamics of the area causes homogenization of water masses over a period of several weeks. Colored markers cannot be used over these periods.

Measurements at coastal stations and sea campaigns are complementary and characterize firstly the variation of the radioactivity of water with time, and secondly their spatial distribution. In particular, ^{125}Sb released by the La Hague plant was measured reliably during a long period. ^{125}Sb is the reference radionuclide that was used to identify the dispersion of releases of other radionuclides in solution in the water of the English Channel. Thus, by comparing weekly measurements with daily releases from the plant, it was found that the average dilution rate at Goury for releases of ^{125}Sb from the La Hague plant were between 0.74 and 0.80 Bq.m^{-3} per TBq released annually between 1985 and 1989 [21] [22]. This latter value, confirmed by subsequent measurements (1989 - 1996) represents an average impact that includes a "short term" component (15 days) and a "long term" component (2 months and more) specific to the hydrodynamics in this region.

The use of the results of different sea campaigns carried out between 1984 and 1994 showed the average dispersion of effluents along the English Channel. It was possible to define the corresponding concentration in sea water over the entire English Channel to a given release from the La Hague plant [23].

The IFREMER hydrodynamical models allow to give observed dispersion, to calculate and to predict radionuclide dissemination in Manche and North Sea [24].

6.1.1.3. Comparison between models and measurements for sea water

6.1.1.3.1. Use of sea water measurements

Several organizations have regularly monitored the radioactivity of sea water in Nord-Cotentin coastal stations, for monitoring or research objectives. These organizations are COGEMA, OPRI, GEA and the IPSN. The monitored sites are Goury, Querqueville, Barneville, Barfleur, the Brick Bay on the shore, and Jobourg, the La Hague light house, Jardeheu, and Le Rozel offshore. The measurement frequency varies between weekly and quarterly.

The main measurement technique used is gamma radiation spectrometry. Note that differences between detection limits of the various organizations and the variation in released quantities mean that not all radionuclides were identified during each measurement. The most frequently measured radionuclides are ^{137}Cs, ^{106}Ru, ^{125}Sb and ^{60}Co. GT2 collected all measurements supplied by the various organizations in the form of annual averages, accompanied by the total number of measurements made during the year, the number of measurements significantly greater than the detection limit, the average, the standard deviation associated with this annual average and the maximum value.

In order to obtain representative values of radioactivity levels in the environment, it was decided that annual averages would only be used for comparisons between models and measurements described below, when at least 75% of the measurements were greater than the detection limit.

6.1.1.3.2. Comments on the Figures

- Sampling stations (IPSN - Goury and GEA - Querqueville) for which there is a large number of significant measurements provide the most uniform results throughout the entire period, for all radionuclides. This reflects the fact that the influence of variability

factors of individual measurements (sampling time with respect to the tide, variations in released quantities, release modes and weather conditions) are attenuated when the number of samples increases.

- COGEMA and OPRI measurements are more variable (standard deviation of up to 100%) and also involve a considerable degree of uncertainty. Furthermore, they are significantly higher than IPSN and GEA values. Values obtained by the IPSN and the GEA appear to be the most representative (see comments by GT2). Consequently, they are the only values used by GT3 to estimate dilution factors.

- If offshore measurements close to the release point within the tidal area (Jobourg, La Hague, Jardeheu) show greater variability than on the coast, the average dilution is similar to the Goury value. Furthermore, it is remarkable that there are no significantly higher values; this demonstrates very efficient dilution of releases in the near field.

- ^{125}Sb - Many studies have shown that this element, for which the only local source is releases from La Hague, is in soluble form and its behavior in sea water is conservative (it only fixes very slightly to living species and sediments). It can be used as a reference tracer to monitor the dispersion of radioactive elements in sea water in the short and long terms [25], [26]. The homogeneity of measurement results provided by GT2 for ^{125}Sb shows that the observed average dilution rate is remarkably stable with time. The variation of release conditions during the 1990 - 1995 period (greater releases outside the optimum dilution time slot) does not seem to have any significant influence on dilution in the near field.

- ^{137}Cs - Fluctuations of the annual average for this element are greater than for ^{125}Sb. However, the average of the value does not vary much with time, which results in a globally conservative behavior over this timescale and for these distances. However, it must be borne in mind that the background noise is not perfectly known, particularly before 1983, and this could distort the results.

- ^{106}Ru - Except at Goury, the dilution factor of this element is significantly lower than the dilution factor of ^{125}Sb. This reflects two characteristics specific to this element:

    - Chemical forms of the released ^{106}Ru varied with time [27], such that the precipitation protocol for this element in sea water samples was no longer appropriate.

    - ^{106}Ru has a significant affinity for sediment particles, which purify the sea water as they fall to the sea bed, as a function of the distance and the transit time. This phenomenon, combined with its short radioactive half-life (one year) can explain the value of the dilution factor observed at Querqueville.

- ^{60}Co - The results obtained for this element are atypical compared with values for other radionuclides, at all sampling stations. It shows a low dilution factor in 1983, which regularly increases with time until it reaches and even exceeds the value for ^{125}Sb in 1993 when it stabilized. As for ^{106}Ru, this apparent behavior may be due to the precipitation protocol during sampling which is not suitable. The different variation of the dilution factor can only be explained by two concomitant phenomena:

    - levels observed in water are the result of a non-negligible contribution of ^{60}Co previously fixed on sediments that influence sea water levels, either by renewed release or by simultaneous measurement of particles in suspension (sea water samples are not filtered), for which ^{60}Co has an affinity.
    - The radioactive half-life of ^{60}Co (5.3 years), which is longer than the half-life of ^{106}Ru (1 year), would make a remanence effect of ^{60}Co perceptible over a longer period.

6.1.1.3.3. Comments on the dilution factors

- All dilution factors for all sampling locations are within the range 0.04 - 4.88 $Bq.m^{-3}$ per $TBq.year^{-1}$. When the OPRI and COGEMA values are not used, the range drops to 0.04 - 1.64 $Bq.m^{-3}$ per $TBq.year^{-1}$.

- For ^{125}Sb, the range drops to 0.17 - 0.83, which is a ratio of 1 to 5 for distance scales from the release point ranging from 2 km (Jobourg) to 100 km (Granville). This represents the dilution efficiency in the near field which very quickly brings concentrations of radionuclides in the release plume to levels comparable with concentrations in surrounding sea water. In the longer term, the dispersion of releases in eddies in the Normandy - Brittany Gulf causes homogenization of water masses that return into the near field (Jobourg - Goury - La Hague - Jardeheu). The dilution factor is relatively weak outside the near field (see hydrodynamic modeling results [24]).

- The value obtained for Goury using this calculation mode is consistent with the previous results mentioned above.

- Although few measurements were made in Granville and Barfleur, the results conform with results obtained by other work ([23], [28]). Homogenization of medium scale releases into sea water makes individual measurements more representative.

6.1.1.3.4. Selection of dilution factors

Due to the number of available measurements and the constant ratio between released annual quantities and measured concentrations, it is proposed to use the dilution factor obtained by the IPSN in Goury as a reference (0.76 $Bq.m^{-3}$ per $TBq.year^{-1}$). Since the plume of individual releases cannot easily be identified in measurements listed by GT2, in practice this dilution factor represents an average value that can be used for a strictly soluble element in the Cap La Hague region.

A summary table of proposed dilution factors for the various sampling stations is based on results of the measurements for ^{125}Sb, taking into account the representativeness of each value (variability, significant number of measurements). Results acquired by the IPSN during offshore measurement campaigns are also used. The values thus chosen are consistent with results obtained from hydrodynamic models [24]. Dilution factors are also shown using a relative scale with respect to Goury, in order to facilitate comparisons.

These values reflect the current state of knowledge and express the average impact of a strictly soluble element on an annual scale. Considering the observed variability, it seems reasonable to assign an uncertainty of plus or minus 20% to these values. This uncertainty represents an average variation on annual averages of a large number of measurements. The results of measurements on isolated sea water samples are much more variable.

Differences from these values observed for other radionuclides reflect their lower conservativeness (reduction as a function of the distance for ^{106}Ru, long-term excess for ^{60}Co), or the possible impact of other sources (^{137}Cs). Transfers of radionuclides to living species and sediments take place through sea water, consequently these variations should be taken into consideration when comparing predictions made by models and measurement results in these constituents of the environment.

6.1.1.3.5. Mapping representations

Selected dilution factors are shown on the maps of the Cotentin. They are expressed as a relative value with respect to the dilution factor at Goury.

The ^{125}Sb measurements made during campaigns at sea during 1983, 1986, 1988 and 1994 were used to establish the average offshore impact due to releases from the La Hague plant [23]. When these results are plotted at the same scale, it is obvious that they are consistent with the selected results. Similar agreement is obtained with results obtained using hydrodynamic models.

6.1.1.3.6. Dilution of EDF releases

Dilution factors of releases from the EDF power station cannot be obtained directly by measurement. Annual quantities released from the power station are very much less than those released by COGEMA, for most radionuclides. Furthermore, the only radionuclides for which releases from the power station are similar to or greater than COGEMA releases (^{58}Co, ^{54}Mn, ^{110m}Ag) were not detected in sea water.

The only way of evaluating a dilution factor similar to that defined for COGEMA releases is to use an indirect method making use of comparisons between models and measurements in species on which this impact is detectable (limpets, seaweed). This point is discussed in section 6.1.2.2.

6.1.2. Marine species

6.1.2.1. Analysis of measurement results

The species for which radioactivity was regularly monitored in the various stations in Nord-Cotentin have been listed. The measurement frequency varies from one week to one year.

Only a few radionuclides could be detected during each measurement, due to detection limits for the various organizations and the variation in released quantities. GT2 has summarized all measurements supplied by the various organizations in the form of annual averages. The number of significant measurements as a proportion of the total number of measurements made during the year, and the average, standard deviation and the maximum value are also specified.

In order to provide representative values for the use of the results, a choice was made to only use annual averages when at least 75% of measurements were significantly higher than the detection limit, in the same way as for sea water.

6.1.2.2. Expression of results

Annual averages of measurements, and maximum measured values, are shown on graphs with a linear scale. Predictions made using the corresponding models are shown on the same graphs. The calculation is done as follows:

((Annual Release x Dilution Factor) + Background noise) x FC in the species = Model Prediction

When liquid releases from Flamanville nuclear power station were greater than one fiftieth of the releases from the La Hague plant, their contribution was included and the Flamanville area was considered separately from the La Hague area. This processing was only applicable for ^{54}Mn, ^{58}Co and ^{110m}Ag radionuclides to the extent that the impact of releases of other radionuclides from Flamanville power station is apparently not detectable.

In this case, the calculation is made as follows:

((COGEMA annual release x COGEMA dilution factor) + (EDF annual release x EDF dilution factor) + Background noise) x Concentration factor in the species = Model prediction

Data used for the model are as follows:

- annual releases: values supplied by GT1. GT1 estimated releases of ^{58}Co by using the ^{60}Co transfer factor in the plant. This first calculation gave estimated releases equal to 15 to 10^{12} times lower than the values that COGEMA had measured on effluents. However, measurements in the environment reveal values which are closer to those found in the effluents. The comparison between models and measurements was made using two sets of release data, and after seeing the results, GT1 decided to use the values obtained by the measurements of effluents as the source term (cf. paragraph 6.1.1.3.2.).

- dilution factors (FD): factors obtained using the method described in 6.1.1.

  For releases from Flamanville power station, the value given by EDF for the near field (137 $Bq.m^{-3}.TBq^{-1}$ released annually) is 180 times higher than the value for La Hague releases. It is the value of the impact simulated by hydrodynamic modeling under minimum dilution conditions; concentration calculated immediately after a release, at 500 m from the outlet at low tide and with a high tide coefficient. The purpose of this simulation is to evaluate maximum measurable concentrations in the environment and is not intended to represent an average impact. The comparison between the model and measurements for *Fucus* and limpets at Flamanville suggests a value of 3 $Bq.m^{-3}.TBq^{-1}.y^{-1}$ to represent the annual average of bio-available concentrations of sea water in the coast around Cap de Flamanville. This dilution factor is determined based on a small number of measurements and depends directly on cobalt concentration factors. This value will be used in the rest of the comparison. Consequently, four areas were defined to take into account the impact of Flamanville, namely the Carteret area (FD=0.2xFD for Flamanville), the Cherbourg area (FD=0.35xFD for Flamanville) and the La Hague area which was sub-divided into two areas, firstly the Flamanville area (FD=1xFD for Flamanville) and secondly the Cap La Hague area (FD=0.5xFD for Flamanville).

- Concentration factors (FC): these factors are listed. The FC values used for ^{14}C are 5000. Values expressed in Bq.ww kg^{-1} are deduced from values supplied by GT2 in $Bq.kg^{-1}$ of carbon assuming a carbon content of 45% of the dry weight and a ww / dw ratio of 4.6. These values represent the average of the contents measured by the IPSN in a marine environment.

- Measured values / Calculated values Ratio (MCR): this factor enables comparative measurements in the environment as the calculated results.

6.1.2.3. Comments and conclusions

Comments have been made on the graphs and figures prepared by GT3, and the comments are given in the following sections. In conclusion, these graphs were used to validate concentration factors, taking into account the following elements:

- *application of correction factors, independent of the sampling location, in order to take into account the characteristics of the various radionuclides, and particularly their affinity for particles, and also any special interactions that may exist between a radionuclide and a given species (for example some types of molluscs concentrate radionuclides better than others). Indirectly, these correction factors are sufficient to take into account the "lag effect" due to a secondary release of radionuclides by sediments. Thus, without having any real physical significance, there are means of globally taking into account a set of mechanisms and adjusting the model to match the radioactivity of the environment. The magnitude of these correction factors is usually consistent with the variability of concentration factors for the same species, which can vary within a ratio of 1 to 10. Correction factors of this type have been presented in a form in which average and maximum concentrations of the various marine products can be evaluated at each fishing location.*

The recommendation for different correction factors before and after 1990 is a direct result of the comparison between models and measurements. This differentiation is applicable mainly for ^{60}Co (all species), and to a lesser extent ^{106}Ru and ^{125}Sb (mussels and sediments). It can be explained by phenomena by which the radioactivity is integrated with time in various species; measures can then reflect the influence of releases that occurred several years before, at a time when released quantities were higher.

Sediments fix a non-negligible fraction of some released radionuclides. In the medium- or long-term, these radionuclides could enter into solution again in sea water (secondary release phenomenon) and then become bio-available to living species. Sediments can also mark species directly through particles in suspension.

These phenomena particularly concern ^{60}Co. For ^{106}Ru and ^{125}Sb, the significant reduction in releases starting from 1987 makes these sediment memory phenomena more noticeable in the years following this reduction.

Thus, for all species and radionuclides considered, the date of 1990 appears to be a good compromise to differentiate periods with different correction factors:

- *evaluation of average standard deviations, in order to get a good understanding of the distribution of radionuclides in the environment.*

- *identification of a very limited number of measurements (less than ten) made in the environment, which could not be explained by the model described above. Once it became clear that they could potentially represent an exceptional phenomenon - particularly when they cannot be explained by a sampling or analysis error, it was suggested that they should only be considered as part of an exceptional scenario.*

- *the pipe break at the end of 1979 increased marking of different species caught in Moulinets Bay for several months in 1979 and 1980. Comments are made on the relative impact in each sheet concerned. This event illustrates the importance of the location of the release point with respect to the impact on the coast in the near field; the anomaly did not concern other measurement stations for which there was time for "normal" dilution to take place. The variability of measurements reflects the momentary nature of the leak with respect to the annual average. This is why it seemed more appropriate that the dosimetric impact of this accident should be evaluated by reconstructing concentrations in sea water for these two years, based on measurements available in limpets and Fucus, by weighting them by their numbers, for all radionuclides for which measurements are available in these species. Concentrations of other radionuclides in sea water are reconstructed using multiplication factor equal to the average of the multiplication factors used for other radionuclides. Measurements available during the period after the accident are used for sediments in Moulinets Bay for which this impact was more long lasting.*

- *when the comparison did not appear significant, or when it was impossible due to the lack of a sufficient number of measurements in the environment, concentration factors were accepted for evaluating the average concentrations of species, since there were no better values. However in these cases, the Group recommended that measured values should be used to provide an estimate of the maximum possible values and the corresponding standard deviations.*

- *in cases for which concentration factors of their closest chemical analogs were used due to the lack of concentration factors given in the literature, it was decided to also use the corresponding correction factors whenever they could be determined.*

6.1.2.3.1. Mussels

- No measured value (average and maximum values) exceeds the calculated values by a factor greater than 9. There is a limited number of values available for ^{14}C, and there are very few significant values for ^{241}Am and ^{244}Cm.

- Measured annual averages are globally lower than calculated values (average MCR = 0.41), particularly for ^{137}Cs and ^{125}Sb which are more conservative, in other words which combine only slightly with particles (MCR = 0.48 and 0.47 respectively). These values appear reasonable since the selected concentration factor is valid for all molluscs and is not specific to mussels.

- ^{125}Sb: this radionuclide fixes only very slightly onto mussels (FC = 20); there are seven times less significant measurements for antimony than there are for other radionuclides; only the results for FD = 0.5 are useable. The measurement dispersion is low and the ratio between annual averages and calculated values is between 1 and 2. This uniformity may be assigned to the conservative behavior of antimony which only fixes very slightly to sediments during the transport of water masses, and furthermore the measurements are less disturbed by the particles contained in the mussels.

- ^{137}Cs: On average, measurements are comparable to antimony measurements, however with greater dispersion. This variability cannot be explained in the current state of knowledge. Some possible explanations would be the influence of particles measured at the same time as the mussels, and uncertainties about other sources (input from the Atlantic and fallout from Chernobyl). This comment is particularly applicable for the 1982 - 1989 period, in which maximum measured values significantly exceeded the values calculated at Saint Vaast and Barfleur.

- ^{106}Ru - Average measurements for ruthenium are five times lower than the calculated values. Observations made in sea water predicted this deficit. It is due to fixation of ^{106}Ru by sediment particles associated with its relatively short half-life (one year). Until 1989, no measured values exceeded one half of the calculated concentrations. The only measured values higher than calculated values were observed for 1991. One explanation could be the strong reduction of releases in 1991 compared with releases in previous years, compensated by input due to secondary releases from sediments.

- ^{60}Co - As for ^{106}Ru, the variation of cobalt measurements should be compared with the variation observed in sea water. The measured concentration was lower than the calculated concentration at first, and gradually increased with time to eventually exceed predicted values starting in 1991. As for sea water, these observations are probably the consequence of sediment storage and it is probable that sediment particles form a delayed source that traps a significant fraction of cobalt when releases increase or are stable, and then release it into the environment again in measurable quantities when releases decrease.

- ^{14}C - measured values (average and maximum values) are lower than values calculated by the model, both in the La Hague and the Barfleur area. A concentration factor of 5000 used in COGEMA's model appears close to reality, although still high. However, the number of measurements is far too small to provide a basis for a final decision on the selected FC. GT3 used this concentration factor, since there is no better value.

- ^{241}Am and ^{244}Cm - the measured values are less than or of the same order of magnitude as the calculated values; however, there are not enough values to form the basis for any conclusion about whether the chosen parameters are justified.

- The variability of measurements expressed by standard deviations should be used with caution, since the method of calculating annual averages (the use of detection limits when there are no measured values) and the small number of measurements concerned (for example standard deviation = 0 when there are only two measurements and they are identical) can alter their representativeness. However, comments made about multi-annual variability are also applicable to inter-annual variability: the variability of antimony (average standard deviation 27%) is significantly lower than the variability of other radionuclides (average standard deviations between 42 and 54%).

GT3 proposed the correction factors given in the following table. No other comparison appeared significant.

Radionuclide	Correction factor for averages	Correction factor for maxima	Standard deviation	Exceptional measurement (ratio with respect to the average)
Until 1990 Antimony 125 After 1990	0.5 0.5	2 6	 30% 	 -
Cesium 137	0.5	6	50%	-
Until 1990 Ruthenium 106 After 1990	0.2 1	0.8 3.5	 50% 	 -
Until 1990 Cobalt 60 After 1990	0.5 2	2 6	 50% 	 -

Table 6.1.2.3.1.: Correction factors applicable to estimated radioactivity in mussels.

6.1.2.3.2. Limpets

- The release pipe incident that occurred at the end of 1979 had a significant impact on measurements made at the Moulinets Bay in 1979 and 1980 for all radionuclides. The MCR is greater than the same ratio recorded on other measurement stations for which FD = 1 by a factor of between about 10 and 70.
- Two anomalies can be seen for ^{137}Cs measured in 1985 at Moulinets Bay, and in 1992 at Saint-Martin Bay. These anomalies are associated with large standard deviations (186 and 300%) respectively. They are both explained solely by the maximum measured, which is sufficiently high to modify the annual average (55 and 75 times higher respectively). These atypical values cannot be detected at the same time as other radionuclides, and are probably due to measurement errors, or added radioactivity from a source other than liquid releases from La Hague. For these reasons, the summary figures and tables produced without using the values from the Moulinets Bay also ignore these values.
- There is another anomaly for ^{60}Co measured at Sciotot by COGEMA in 1989, which only concerns COGEMA measurements in 1989 (4 measurements), but not measurements made by the IPSN at the same location and during the same year (10 measurements) or by other organizations in nearby stations in 1989. Since the IPSN and the OPRI have made a greater number of measurements of the same type that did not reveal the same anomaly and the same is true for other species measured in this area, it is suggested that these results should be ignored.

The following comments only concern the other results: values from the Moulinets station and the atypical value for ^{137}Cs measured in Saint-Martin Bay in 1992 are ignored.

- No measured value (average and maximum values) exceeds the calculated values by a factor greater than 7.

- Measured annual values are globally lower than calculated values (average MCR = 0.65). This is less true for ^{137}Cs and ^{125}Sb than for ^{106}Ru and ^{60}Co. In fact, ^{137}Cs and ^{125}Sb are the most conservative (MCR = 0.6 and 1.2 respectively). These values appear reasonable, since the selected concentration factor is valid for all molluscs and is not specific to limpets.
- ^{125}Sb - This radionuclide only fixes very slightly to limpets (FC = 20) and is measurable essentially for FD = 1. The measurement dispersion is low: all annual averages are within a ratio of 1 to 4 compared with calculated values, and the average value is close to this calculated value (average MCR = 1.2). This homogeneity may be assigned to the conservative behavior of antimony that only fixes very slightly to sediments during the transport of water masses, and furthermore measurements are only slightly disturbed by particles contained in limpets. It is not abnormal for the average MCR to exceed 1; it was already mentioned that the variability of concentration factors could be an order of magnitude. A correction factor of 1.2 would mean that the correction factor for antimony 125 in limpets is slightly greater than the average concentration factor used for molluscs and that this is even more true for mussels (correction factor 0.5).
- ^{137}Cs - On average, measurements are comparable to measurements for antimony, however with a slightly greater measurement dispersion and a slightly lower average MCR (0.6).
- ^{106}Ru - On average, measurements for ruthenium are three times lower than the calculated values. Observations made in sea water predicted this deficit that is probably due to fixation of ^{106}Ru by sediment particles, and its relatively short half-life (one year): the deficit is greater for increasing distance of the sampling location from the release point.
- ^{60}Co - As for ^{106}Ru, the variation of cobalt measurements should be compared with the variation observed in sea water. The measured concentration, firstly lower than the calculated concentration, increases gradually with time and eventually exceeds forecasts starting from 1992. These observations are probably the result of sediment storage; sediment particles form a delayed source that traps a significant fraction of cobalt when releases increase or are stable, and then releases measurable quantities into the environment again when releases decrease. These phenomena could explain the small reduction in observable measured levels during the 1990 - 1996 period, which does not correspond to the reduction in quantities released by the COGEMA La Hague reprocessing plants.
- ^{14}C[32] , ^{3}H, ^{99}Tc, ^{129}I, ^{241}Am, ^{244}Cm - the small number of measured samples (less than 12 for each radionuclide) makes it impossible to give a judgment about the validity of the model, and consequently to criticize the concentration factors chosen due to the lack of better values.
- ^{90}Sr - although on average measured values are lower than calculated values (by a factor of 2.4 on average), their dispersion is fairly low and they are consistent with the model.
- ^{238}Pu, $^{239+240}Pu$ - the behavior of these two radionuclides is similar: measured values are lower than calculated values by a factor of 2 on average, and this variation has been reducing since 1990. Two measurements are significantly different from the average for $^{239+240}Pu$ in 1987 in the La Hague area and in 1990 in Cherbourg.
- $^{144}Ce+Pr$ - the impact of the pipe break is obvious in 1979 (average MCR of 64 and maximum MCR of 127) and also to a lesser extent in 1980. Other measurements give higher values (by a factor of 3 on average) than calculated values, particularly for 1983

[32] The FC used for ^{14}C is 5000; the values expressed in Bq.ww kg^{-1} are deduced from the values supplied by GT2 in Bq.kg^{-1} of carbon, assuming a carbon content = 45% of the dw weight and a ww /dw ratio of 4.6. These values represent average values of contents measured by the IPSN in a marine environment.

and 1987. The particularly high average for 1987 (26) is probably related to an environment memory effect, combined with a reduction in releases between 1986 and 1987 by a factor of 10.

- ^{134}Cs - the pipe incident was significant for this element; MCR values are four times higher on average than for ^{137}Cs.

- ^{65}Zn - the pipe break had a measurable impact on this element. Since release data were not available before 1982, the comparison between models and measurements could only be made after this date; measured values are three times lower than calculated values on average. However, since a sufficient number of measurements was made between 1978 and 1982, the source term can be reconstructed using these measurements, using the concentration factor and correction factor calculated for the later period.

- ^{54}Mn - the dispersion of measured values is fairly high, and their order of magnitude is the same as calculated values.

- ^{110m}Ag - Measured values are 15 times higher than calculated values, on average. The comparison made with measurements in other species demonstrated that this difference between the model and measurements can be due to several reasons:

  - COGEMA source term may be underestimated when making analyses[33] on releases for the period before the EDF power station was put into operation. Changes in MCR values follow a similar pattern for all species, with calculated values being systematically underestimated;

  - very different correction factors may be applied depending on the species, to give good agreement between models and measurements, thus also casting doubt on some values of the concentration factors.

  For all these reasons, it was decided to reconstruct concentrations of ^{110m}Ag in sea water in all fishing areas making use of all available measurements, without reconstituting COGEMA and EDF source terms, and then determining correction factors independent of fishing areas for each species.

- ^{58}Co - although the model clearly describes the impact of Flamanville power station, the few measured values in the La Hague and Flamanville area before 1987 do not correspond to releases calculated by GT1 (average MCR 10 and maximum 67). Release values measured by COGEMA seem to be more realistic (average MCR 0.5 and maximum 7.3).

- The variability of measurements as expressed by standard deviations should be used with precaution, since the method of calculating annual averages (use of detection limits when there are no measured values) and the small number of measurements concerned (for example standard deviation equal to 0 when there are two measurements and they are identical) could modify their representativeness. The measurement dispersion is comparable for all radionuclides released by COGEMA La Hague reprocessing plants, except for ^{137}Cs for which standard deviations were higher before 1987.

Except for the results for the Moulinets Bay for which no mussel measurements are available, all comments for limpets are similar to comments for mussels; this similarity can be seen by comparing the corresponding figures, confirming the representativeness of the values obtained for these indicating species. However, the dispersion of results for limpets (globally less than for mussels) and the fact that more results are available (particularly in the environment close to the release point) makes them more useful for evaluating the impact of marine releases from COGEMA La Hague reprocessing plants. Limpets have a higher ^{125}Sb fixation capacity than mussels (average MCR 1.2 instead of 0.5).

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[33] ^{110m}Ag is more difficult to detect using direct gamma spectrometry when there is a significant activity of ^{137}Cs present in the releases.

The group proposed the correction factors given in the following table. No other comparison appeared significant. Furthermore, it is suggested that the conclusions of the comparison between models and measurement for mussels should be adopted for all filtering molluscs, and that the conclusions of the comparison between the models and measurements for limpets should be applied for all non-filtering molluscs, except for the specific problem of the pipe leak (1979-1980) described above.

Radionuclide	Correction factor for averages	Correction factor for maxima	Standard deviation	Exceptional measurement (ratio with respect to the average)
Antimony 125	1.2	7	35%	-
Cesium 137	0.6	5	50%	Moulinets Bay: 55 Saint-Martin Bay: 75
Ruthenium 106	0.4	5	35%	-
Until 1990 Cobalt 60 After 1990	0.5 1.2	7	35%	-
Strontium 90	0.4	2	40%	-
Plutonium 238, 239 + 240	0.6	7.6	35%	-
Cerium 144	3.1	67	70%	-
Cesium 134	3.4	38	50%	-
Zinc 65	0.35	1.7	35%	-
Manganese 54	1	7.6	45%	-
Cobalt 58 (with the measured COGEMA release)	0.5	7.3	30%	-
Silver 110m	15	140	30%	-

Table 6.1.2.3.2.: Correction factors applicable to estimated radioactivity in limpets.

6.1.2.3.3. Fish

The fish species most frequently sampled are the whiting (*Gadus Luscus*), conger eel (*Conger conger*), spotted dogfish (*Scylliorhinus canicula*), ray (*Raja clavata*), plaice (*Pleuronectes platessa*), wrasse (*Labrus bergylta*), and sea trout (*Salmo trutta*). COGEMA makes a distinction between two fish categories, namely round fish and flat fish, without identifying the species sampled.

- Unlike species living on marine substrates (seaweed, molluscs), fish move with respect to the water mass. The result is that the fishing position is not necessarily the location that will have had the maximum impact on the fish, from the point of view of its radioactive marking; a fish caught to the North of Cherbourg could have stayed close to the end of the COGEMA La Hague reprocessing plants release pipe, and its marking could be higher than would be expected in this area. This mobility is likely to increase the variability of measurements, particularly for results acquired near the Cap La Hague (FD=1), without fundamentally questioning the hierarchy of dilution factors between the various fishing areas.

- Values measured by the GEA at Les Huquets (shallow water 500 m to the South-East of the release point, within the area included in tidal ebb and flow around the release point) show significantly higher values than other measurements made in areas in which the dilution factor is equal to 1. These results are not surprising since the FD equal to 1 reflects an average impact on the coast which is not representative of dispersion in the near field around the release point. It appears that, except for ruthenium (a radionuclide for which even higher values were recorded), on average the measured values are 2.6 times higher than values calculated for an FD equal to 1 (range from 2.2 to 3.2).

- Values measured for ruthenium and the few values measured for Antimony show that the selected concentration factors appear to be underestimated on average by a factor of 4. Since measured values are usually very close to detection limits (5 and 27 measurements are available for ^{125}Sb and ^{106}Ru respectively, compared with 825 for ^{137}Cs), the measurements reflect clipping of peak concentrations actually present in fish. Therefore, this factor of 4 is probably not representative of real values, however the calculations were repeated using this multiplication factor.

- Three significantly higher values than the calculated impact are applicable to ^{106}Ru measured in whiting by the GEA at Les Huquets in 1993 (max MCR = 275), the measured value of ^{106}Ru in spotted dogfish by the GEA at Les Huquets in 1982 (max MCR = 64), and the measured value of ^{106}Ru in wrasse in Flamanville in 1996 (max MCR = 67). Each of these anomalies was found in a single significant measurement and they are probably not representative of the average marking.

Concerning the ^{106}Ru anomaly measured at Flamanville in 1996, since the same anomaly was not found in measurements of edible crabs and limpets made during the same year at the same location, it is suggested that the rest of GT4's work should ignore this measurement result.
Concerning the two abnormal values of ^{106}Ru measured at Les Huquets in 1982 and 1993, measurements on edible crabs made by the GEA at the same location between 1981 and 1996 do not show any significant increase in ^{106}Ru. Given the proximity to the release point, it is not impossible that the caught fish had stayed for a while in a zone significantly more severely marked than Les Huquets (see section 1 in the comments). It is proposed that they should only be used for a special approximate calculation to be defined by GT4, assuming that a fraction of fish caught in this area could have significantly higher concentrations of ^{106}Ru. Having seen the results, this fraction would be equivalent to two abnormal measurements out of 56 measurements made at Les Huquets, such that a proportion of 3.6% of all fish could have average concentrations 170 times higher.

The following comments are not applicable to the three atypical values of ^{106}Ru mentioned above, and assume a multiplication factor of 4 for Antimony and ruthenium concentration factors, and 2.6 for the dilution factor at Les Huquets.

- No measured value (average and maximum values) exceeds the calculated values by a factor greater than 10.

- Measured annual averages are globally lower than calculated values for ^{137}Cs and ^{60}Co (average MCR = 0.23 and 0.76 respectively).

- ^{125}Sb - This radionuclide fixes only very slightly on fish (FC = 20) and is rarely detected (5 measurements total). The result is a large dispersion of measurements that probably only represents a maximum impact (since lower values are ignored). The ratio between measured and calculated values varies from 1 to 8, and from 1 to 2 if a correction factor of 4 is applied to the concentration factor.

- ^{137}Cs - Apart from the near field, measurements of this radionuclide are fairly homogeneous and correspond to the variation in releases. The average MCR is fairly low (0.23). Two COGEMA measurements taken in 1987 and 1988 were slightly higher, and so are four GEA measurements in Flamanville in 1979 and 1980 (MCR of 2 to 3) which could be due to the release pipe break at the end of 1979.

- ^{106}Ru - There is a very large dispersion for ruthenium measurements, which on average are four times higher than the calculated values. The small value of concentration factors (2 or 8) make the influence of interferences more sensitive (particles measured at the same time as fish). Furthermore, the small number of significant measurements suggests that only maximum values are measured. Therefore, the acquired results should be used with care; however, the higher values measured at the Moulinets Bay by the OPRI in 1979 and by COGEMA in 1980 could be due to the release pipe break at the end of 1979.

- ^{60}Co - As for other species, the variation of cobalt measurements should be compared with the variation observed in sea water (see section 6.1.2.3.2.).
- ^{14}C - measured values in the La Hague area (average and maximum values) are significantly lower than values calculated by the model. The number of measurements is far too small to be able to give an opinion about the justification for the chosen FC.
- ^{90}Sr - most observed values are between values calculated using the recommended FC and values calculated with the minimum FC. The maximum observed values are close to the values calculated with the recommended FC. The contribution of background noise is negligible. The variation of MCRs tends to increase with time, in much the same way as ^{60}Co.
- ^{99}Tc - The only available value (in the La Hague area) is significantly greater than the value calculated by the model using the recommended FC; however, no conclusion can be made about the justification for the chosen parameters. The contribution of background noise is negligible.
- The variability of measurements expressed by standard deviations should be used with caution, since the method of calculating annual averages (use of detection limits when there is no measured value), and the small number of measurements involved (for example standard deviation equal to 0 when there are two measurements and they are identical) could affect their representativeness. In general, standard deviations are fairly similar, except for ^{106}Ru. Two values are distinctive for ^{60}Co in 1982 and ^{106}Ru in 1980, each due to one measurement being significantly higher than the others.

Except for ^{125}Sb and ^{106}Ru, for which the small number of measurements introduces a significant bias, all comments about fish are similar to comments for limpets and mussels.

The Group proposed the correction factors given in the above table. No other comparison appeared to be significant.

Radionuclide	Correction factor for averages	Correction factor for maxima	Standard deviation	Exceptional measurement (ratio with respect to the average)
Antimony 125	3.8	8	50%	
Cesium 137	0.2	3	50%	
Ruthenium 106	3.9	28	50%	Les Huquets: 275 Les Huquets: 64
Until 1990 Cobalt 60 After 1990	0.8 2	10	50%	
Until 1990 Strontium 90 After 1990	0.6 1.2	1.5 1.8	25%	

Table 6.1.2.3.3.: Correction factors applicable to estimates of radioactivity in fish (Les Huquets area: FD = dilution factor at Goury x 2.6)

6.1.2.3.4. Crustaceans

The species concerned are the edible crab (*Cancer pagurus*) and the spider-crab (*Maia squinado*). They are measured either whole, or in the form of shelled flesh samples.

- Unlike species that are fixed on the sea bed (seaweed, some bivalve molluscs), crustaceans are like fish in that they can move about. The result is that the location in which they are caught is not necessarily the location that will have had the maximum impact on the crustacean from the point of view of radioactive marking; a crustacean caught to the North of Cherbourg could have stayed close to the end of the La Hague plant release pipe, and its marking could be higher than would be expected in this area. Crustaceans move less quickly than fish, but their mobility can lead to a large variability of measurements, particularly for results acquired close to the Cap La Hague (FD=1).

- Values measured by the GEA at Les Huquets (shallow bed 500 m to the South East from the release point, within the ebb and flow tidal zone around this point) are significantly higher than other measurements made in areas in which the dilution factor is equal to 1. These results are not surprising, since an FD equal to 1 reflects an average impact at the coast which is not representative of dispersion in the field close to the release point. On average, measured values are 4.5 times higher than calculated values for an FD equal to 1 (range from 1.9 to 6.7). Note that this range encompasses the range obtained for fish. Therefore, the group used this range and the corresponding average to evaluate dilution in this area.

- Values of samples taken by Greenpeace at the end of the release pipe are significantly higher than the others (by a factor of 80 to 7000 depending on the radionuclide). These values are not surprising to the extent that the sampled crustaceans are living on the bed in an area in which the release which is close to the bed is practically undiluted. However, given the measured levels, the area concerned by markings in this range can only be very small (a few meters around the pipe aperture).

- Except at Les Huquets and close to the pipe, no measured value (average and maximum values) exceeds the calculated values by a factor of more than 12.

- The measured annual values are globally lower than values calculated for ^{137}Cs, ^{106}Ru and ^{60}Co (average MCR = 0.39, 0.48 and 0.56 respectively).

- ^{125}Sb - This radionuclide only fixes very slightly in crustaceans (FC = 10) and is not detected very much (105 measurements are available for ^{125}Sb compared with 630 for ^{60}Co). The result is a large dispersion of measurements that probably only represent a maximum impact (lower values not being included). The measured values include some isolated measurements higher than the average (Huquets - edible crab in 1979, MCR = 39, Cherbourg spider and edible crab in 1979 and 1992, max MCR = 11), which are not found for other radionuclides. One assumption that can explain these values is that the kinetics of antimony exchanges between crustaceans and sea water would be particularly fast, and in this case measured values would be very sensitive to concentration peaks in the water. There is no other data to confirm this mechanism at the moment, but if it is true, if could explain the significantly higher values obtained for antimony close to the release pipe.

- ^{137}Cs - Apart from in the near field, measurements of this radionuclide are fairly homogeneous and vary in the same way as releases. The average MCR is fairly low (0.39). A COGEMA measurement at Cosqueville in 1981 was higher.

- ^{106}Ru - Measurements for ruthenium are fairly homogeneous and on average are only half as high as calculated values, even though a significant increase was observed in 1990.

- ^{60}Co - As for other species, the variation of cobalt measurements can be compared with values observed in sea water (see paragraph 6.1.2.3.2.).

- ^{14}C - The four measured values in the La Hague area (average and maximum values) are significantly lower than the values calculated by the model (by a factor of 14). The number of measurements is insufficient to validate the selected FC values.
- ^{90}Sr - Calculated values agree very well with observed values; the contribution of background noise is negligible.
- ^{99}Tc - Measured values (La Hague area) are higher than values calculated by the model with the recommended FC which is equal to FC max. The measured number of samples is not sufficient to draw any conclusion about a justification for the parameters chosen. The contribution of background noise is negligible.
- ^{131}I - it was impossible to use the model to calculate environmental concentrations, due to the lack of data on releases.
- ^{238}Pu, $^{239, 240}Pu$ - the few values observed in the La Hague area, are intermediate between values calculated with FC min and values calculated with the recommended FC. The very few observed values in the Cherbourg area are less than values calculated by the model. Furthermore, the contribution of background noise becomes proportionally greater during the more recent period following the reduction in releases from the COGEMA La Hague reprocessing plants.
- ^{241}Am - the only value available in the La Hague area was obtained on edible crabs caught close to the La Hague plant release point. This explains why it is very much higher than values calculated by the model. The value measured in the Cherbourg area is close to values given by the model.
- The variability of measures expressed by standard deviations should be used with caution, the method of calculating annual averages (considering detection limits when there is no measured value) and the small number of measurements concerned (for example standard deviation equal to 0 when there are two measurements and they are identical) can modify their representativeness. In general, standard deviations are fairly consistent, except for the higher value of ^{137}Cs measured in Cosqueville in 1981.

Except for ^{125}Sb for which the variability is greater, all comments for crustaceans are similar to comments for fish, limpets and mussels. A comparison between the various figures illustrates this similarity for cobalt 60 results, for which the correlation of transfer factors during the 1991 - 1997 period is confirmed.

The Group suggested the correction factors given in the following table. No other comparison appeared significant (For the Les Huquets area, FD = dilution factor at Goury x 4.5 (from 1.9 to 6.7)).

Radionuclide	Correction factor for averages	Correction factor for maxima	Standard deviation	Exceptional measurement (ratio with respect to the average)
Antimony 125	1.4[34]	12	30%	Release pipe: 12460
Cesium 137	0.4	6	50%	Release pipe: 421
Ruthenium 106	0.5	4	40%	Release pipe: 359
Until 1990 Cobalt 60 After 1990	0.5 1.3	6	30%	Release pipe: 117
Strontium 90	1.3	1.6	10%	

Table 6.1.2.3.4: Correction factors applicable to estimates of radioactivity in crustaceans.

[34] This value is probably overestimated considering the small number of available measurements.

6.1.2.3.5. Seaweed (Fucus sp.)

Comments concerning *Fucus sp*. are similar to comments made for other species.

- The leak from the release pipe that occurred at the end of 1979 had a significant impact on measurements made at the Moulinets Bay in 1979 and 1980 for all radionuclides. The MCR is greater than the corresponding ratio measured on other measurement stations for which FD = 1, by a factor of between about 5 and 70. This event illustrates the importance of the position of the release point on the impact on the coast in the near field: the anomaly did not concern other measurement stations for which there was time for "normal" dilution to take place.

- An anomaly can be seen for ^{137}Cs measured in 1985 at the Moulinets Bay. This anomaly is associated with a large standard deviation (166%) and is explained by the only measurement of the maximum value which is 21 times higher than the average of the other values. This atypical value cannot be detected at the same time as the other radionuclides, but was also observed for limpets during the same year (probably for a sample taken at the same time); it could be due to radioactivity other than liquid releases from the COGEMA La Hague reprocessing plants.

The following comments are only applicable for the other results; values from the Moulinets station are ignored.

- No measured value (average and maximum values) exceeds calculated values by a factor of more than 6.

- All measured values are very consistent and confirm the advantages of using *Fucus* as an indicating species.

- Measured annual values are overall very similar to calculated values, although they are slightly lower (average MCR = 0.79).

- ^{125}Sb - This radionuclide fixes only slightly onto *Fucus* (FC=20). The measurement dispersion is low: all annual averages are within a ratio of 1 to 5 compared with calculated values, and the average of all values is close to this calculated value (average MCR = 0.85). This uniformity may be assigned to the conservative behavior of Antimony that fixes onto sediments only slightly during the transport of water masses, and furthermore the measurements are only slightly disturbed by particles contained in or on *Fucus*.

- ^{137}Cs - The measurements are very similar to calculated values, all annual values do not exceed calculated values by a factor of more than 2.3.

- ^{106}Ru - Measurements for ruthenium are very similar to values calculated close to the release point (MCR = 0.8), at greater distances the measured quantities are significantly lower (MCR from 0.6 to 0.3), probably translating the fixation of this element on sediment particles, and losses due to decay.

- ^{60}Co - As for ^{106}Ru, the variation of cobalt measurements should be compared with the variation observed in sea water (see paragraph 6.1.2.3.2.).

- ^{14}C - measured values are only applicable to the most recent years (1996 and 1997) and are globally lower than values calculated by the model (by a factor of 1.6 on average).

- ^{3}H - the three measured values are higher than the values calculated by the model (by a factor of 3.5), however they are not sufficient to cast doubt on the selected FC.

- ^{238}Pu, $^{239,240}Pu$ - the two radionuclides behave in a very similar way. After 1990, observed values agree well with calculated values. Measured values for the period before 1990 in the La Hague area tended to increase with time.

- ^{90}Sr - values calculated using the model are similar to, but slightly less than, measured values.

- ^{99}Tc - measured values (La Hague area) are higher by an average factor of 2.6 compared with values calculated by the model. The variation in transfers shows that this difference is not constant, and that it is correlated to the difference observed in sea water. This difference can be explained by an environmental memory effect associated with a strong reduction of releases during the 1990 - 1995 period; however, there could have been a poor evaluation of either background noise due to ^{99}Tc in the water in the English Channel, or industrial releases, during the 1979-1987 period. The IPSN made monthly aliquot measurements of the release from the La Hague plant during the 1983 - 1989 period [29], [30], which appear to agree better with the measurements in *Fucus*. GT1 has modified the transfer function used to calculate releases of ^{99}Tc taking into account these data. The average MCR then drops from 2.57 to 1.92.

- ^{129}I - values measured in the La Hague area agree very well with calculated values (average MCR of 1.1).

- ^{131}I - In the absence of any data on releases, it was impossible to use the model to make a comparison between the two available measurements.

- ^{241}Am - Two out of four available measurements are clearly associated with the pipe break in 1980 (MCR from 300 to 500), the other two values do not cast doubt on the validity of the model.

- ^{244}Cm - the single measurement agrees well with the calculated value.

- $^{144}Ce+Pr$ - the impact of the pipe break is clearly visible in 1980 (average MCR = 5, with a maximum of 66), the other measurements show values of the same order of magnitude as the calculated values.

- ^{134}Cs - the pipe break was significant for this element. The small number of measurements is not sufficient to cast doubt on the conclusions adopted for ^{137}Cs.

- ^{65}Zn - the pipe break was very significant for this element. Since GT1 did not supply the source term before 1982, the reconstructed source term based on measurements made in limpets between 1978 and 1982 was used for this period; measured values exceed calculated values by an average factor of 9.

- ^{54}Mn - the pipe break was significant for this element. However, in general, measured values are of the same order of magnitude as the calculated values.

- ^{58}Co - although the model gives a good description of the impact of Flamanville power station, values measured in the La Hague area before 1987 do not agree with releases calculated by GT1 (average MCR= 19.5 and maximum 665). Values of releases measured by COGEMA appear more realistic (average MCR = 0.7 and maximum of 5.2).

- ^{110m}Ag - On average, measured values are 30 times higher than the calculated values. This phenomenon is explained in the comments for limpets. The pipe break was clearly noticeable.

The Group suggested the correction factors given in the following table. No other comparison seemed significant.

Radionuclide	Correction factor for averages	Correction factor for maxima	Standard deviation	Exceptional measurement (ratio with respect to the average)
Antimony 125	0.9	5	40%	-
Cesium 137	0.7	2.3	30%	Moulinets Bay: 21
Ruthenium 106	0.7	6	40%	-
Until 1990 Cobalt 60 After 1990	0.6 1.1	3.6	30%	-
Strontium 90	0.4	0.8	30%	-
Plutonium 238, 239 +240	1	14	20%	
Technetium 99	1.9	9	130%	-
Iodine 129	1	4	25%	
Cerium 144	0.5	1.4	60%	-
Zinc 65	9	27	35%	-
Manganese 54	1.1	3.6	40%	-
Cobalt 58 (with the measured COGEMA release)	0.7	5.2	35%	-
Silver 110m	30	267	20%	-

Table 6.1.2.3.5 - Correction factors applicable to estimates of the radioactivity in seaweed (Fucus).

6.1.3. Sediments

The special behavior of sediments makes it impossible to apply dilution factors adopted for sea water. Examination of average values measured in sediments in each station compared with calculated values at Goury (released activity x dilution factor at Goury x Kd) as a function of the distance from the release point, shows that this parameter is not the predominant factor in the distribution of observed values.

In order to facilitate comparisons and graphic representations, stations were grouped into different classes based on average activities measured during the entire period considered at each station and for each radionuclide. It transpires that activity levels at some stations are higher than the average:

- either due to proximity to the release point (Cap Voidries, La Ronde);
- or due to the release pipe break in 1980 (Moulinets Bay);
- or due to the abundance of the fine fraction of sediments (Cherbourg Bay).

A reduction in specific activities weighted to the release flow was demonstrated for stations furthest away from the release pipe (Brick Bay, Sciotot, Barneville-Carteret). Other stations could not be differentiated based on their average specific activities. However, it appeared useful to draw a distinction between samples taken offshore and on the shore:

- Dilution factors with respect to Goury (FD) = 1:
  - Moulinets station and GEA point 2 in Cherbourg Bay;
  - stations located less than 1 km from the release point (La Ronde and Cap Voidries), and point W5 in Cherbourg Bay;

- stations located offshore Cap La Hague (Ecalgrain, Saint-Martin Bay, Querqueville);
- stations located along the shore of Cap La Hague; first series (Ecalgrain, Goury, Saint-Martin Bay); second series (Querqueville, Vauville, Flamanville).

- Dilution factors compared with Goury (FD) = 0.5:
  - stations furthest away for which average levels are only half as high as other stations; towards the East (Brick Bay), to the South (Sciotot, offshore and shore, Barneville-Carteret, offshore and shore).

The distribution coefficients originate from estimates made by the IPSN for Cherbourg Bay using measurements made by the GEA in sea water and surface sediments. Furthermore, transfer factors with integration were evaluated for some radionuclides using the method described in section 5.2.2.2. The results of the comparison are expressed in the same way as for living species and comprise a table of standard deviations on annual averages and the ratio between the maximum of the averages and the average of the averages for different radionuclides and integration periods.

6.1.3.1. Comments and conclusions for Sediments

- The nature, size and displacement of sediment particles for which measurements were made are not known and therefore their effect cannot be used to explain the large variability of the results.
- The integration of radionuclides over several years by a given sediment stock, its mix with unmarked particles and the variable depth at which it is buried, contribute to the large differences between measured activities and calculated activities. An attempt was made to take into account this integration to calculate activities in sediments. The global method used cannot reproduce the specific features for each station. However, it did efficiently reduce the variability of MCRs in time, particularly for ^{60}Co.
- Les Moulinets: the pipe incident is clearly visible at this station, particularly at the sampling station monitored by COGEMA. This influence is clearly perceptible for ^{125}Sb and ^{137}Cs (max MCR of 16 and 41), and to a lesser extent for ^{106}Ru and ^{60}Co (max MCR 1.7 and 4). The significantly shorter integration period that characterizes this incident may be the result of either a shorter contact time or mixing with less marked sediments in this area.
- Cherbourg Bay - due to the abundance of the fine fraction in sediments from this station, measured activities are significantly greater than activities reported for other stations (apart from Les Moulinets). The average MCR varies from 1.1 to 4.5, and the maximum MCR is as high as 27. Even considering sediment integration, average MCR values are higher than elsewhere, namely 0.8 to 2.7. Therefore it can be said that, on average, 10 times more ^{125}Sb, 20 to 25 times more ^{137}Cs and ^{106}Ru and 30 to 40 times more ^{60}Co are fixed on sediments in Cherbourg Bay than on sediments at other Nord-Cotentin stations. After taking into account sediment integration, there is still a residual variability in RMC values over time which has not yet been explained. These comments are also applicable for point W5 in Cherbourg Bay, but to a lesser extent.
- La Ronde and Cap Voidries: there is only one measurement from each of these stations, which shows higher results than in other Cap La Hague stations (except for Les Moulinets). Although not very representative, the values obtained can be explained by the proximity of the release point (less than 1 kilometer).
- Other stations: there is no significant difference between measurements made offshore and on the shore. Only the furthest stations have MCR values that are only half as high on average.

General comments

- Average MCRs vary with time for each radioelement. Concentrations of radionuclides are not globally correlated. Extreme values cannot be explained (1989 at the Brick Bay for all radionuclides; ^{125}Sb in 1980 in Goury; ^{106}Ru in 1982 in Vauville; ^{60}Co in 1990 in Vauville, etc.) due to the lack of size grading data.
- Except for the Moulinets, La Ronde, Cap Voidries and Cherbourg Bay stations, measured values are usually less than calculated values for all radionuclides, with or without taking into account sediment integration.
- ^{238}Pu - in the La Hague and the Moulinets areas and for remote stations, the observed values are usually between the values calculated with the recommended Kd and values calculated with the maximum Kd.
- ^{239,240}Pu - the same comments as were made for ^{238}Pu are valid for ^{239,240}Pu. Furthermore, the contribution of background noise becomes proportionately greater in the more recent period due to the reduction of releases from the COGEMA La Hague reprocessing plants. Note also that values observed at the Moulinets after 1990 are always greater than values calculated by the model. For remote stations, there is always good correlation between observed values and values calculated with the maximum Kd. However this does not mean that this Kd should be preferred for this group of stations (see sediment integration).
- ^{90}Sr: values calculated with the recommended Kd are generally underestimated with respect to observed average values. Maximum values remain below values calculated with the maximum Kd values. The contribution of background noise is negligible.
- ^{131}I: in the absence of any data about the release, it was impossible to use the model to calculate environmental concentrations.
- ^{241}Am: the few values available in the La Hague area agree with values calculated by the model. In the Cherbourg area, measured, average and maximum values are always greater than values calculated with the recommended Kd. For the 92-96 period, maximum values are always similar to values calculated with the maximum Kd. The specific characteristics of sampling point No. 2 in Cherbourg Bay can explain these results (high proportion of fine particles).

The selected Kd values are only a compromise; average values are conservative (by a factor of about 4 to 20) in most stations, and are low (by a factor of between 1 and 6) for Cherbourg Bay (point 2). It is not surprising that calculations and measurements should agree for point W5 in Cherbourg Bay since the distribution coefficients were compiled based on average values of activities measured in surface sediments in Cherbourg Bay.

Proposals

Based on all these data, it seemed best to use the method of modeling the impact on sediments with an integration period only for Cobalt 60. For other radionuclides, satisfactory results are obtained by using the distribution coefficient alone, provided that some adjustments are made for some of them (see following table).

Radionuclide	Correction factor for averages	Correction factor for maxima	Standard deviation
Antimony 125 Until 1990 After 1990	 0.2 0.6	3.3	50%
Cesium 137	0.2	1.8	50%
Ruthenium 106 Until 1990 After 1990	 0.05 0.2	0.8	50%
Strontium 90	3	25	50%

Table 6.1.3.1.: Correction factors applicable to estimates of radioactivity in sediments.

Furthermore

- sediments sampled at La Ronde and Cap Voidries are factored by an average correction factor of 4.3 for ^{137}Cs, which takes into account the proximity of the release point and observed measurements;

- sediments sampled at the Moulinets Bay, will be factored by average correction factors of 1.3 for ^{125}Sb, 1.8 for ^{137}Cs and 0.2 for ^{106}Ru;

- sediments sampled in Cherbourg Bay and in areas with fine sedimentation will be factored by average correction factors of 2.3 for ^{125}Sb, 4.5 for ^{137}Cs and 1.2 for ^{106}Ru.

Concerning actinides (^{238}Pu, ^{239,240}Pu, ^{241}Am), their sediment integration period is long and it is impossible to define it using available data. Consequently, for elements that fix strongly to sediments (Pu, Am, Cm, Zr, Eu) and which have a half-life exceeding 3 years, it is proposed to use a model in which a distribution factor is used starting when the plant was commissioned until the year of maximum release, and then for the later phase to assume constant radioactivity in the sediments equal to the average of values measured afterwards.

The modeling method used with the integration period for cobalt 60 is as follows:

$$A_n = \left(\sum_{t=n}^{t=n-x} \left[Q_t \times e^{-\lambda s.t} \times e^{-\lambda.t} \right] \times FC \times FD \times F_{cor.} \right) \Big/ \sum_{t=n}^{t=n-x} \left[e^{-\lambda s.t} \times e^{-\lambda.t} \right]$$

in which A_n is the activity in sediments during year n, Q_t is the flow of cobalt 60 released during year t, λ_s is equal to ln(2)/P where P is the sediment integration period (5 years for ^{60}Co), λ is equal to ln(2)/T where T is the half-life for radioactive decay, and $F_{cor.}$ are the correction factors given in the following table.

Radionuclide	Correction factor for averages	Correction factor for maxima	Standard deviation	Exceptional measurement (ratio with respect to the average)
Cobalt 60	0.04	1.4	50%	-

Table 6.1.3.1.b: Correction factors applicable to estimates of the radioactivity of ^{60}Co in sediments.

Furthermore

- sediments taken at La Ronde and Cap Voidries are factored by an average correction factor equal to 0.12 for ^{60}Co which takes into account the proximity of the release point and observed measurements;

- sediments taken at Moulinets Bay are factored by a specific correction factor equal to 0.4 for ^{60}Co, in addition to the average correction factor;

- sediments sampled in Cherbourg Bay (point 2) or in areas with fine sedimentation will be factored by an average correction factor equal to 1.1 for ^{60}Co.

6.2. Atmospheric releases[35]

6.2.1. Atmospheric dispersion

6.2.1.1. Critical analysis of the model

Some "krypton 85 campaigns" were carried out between June 1997 and March 1998 by the IPSN in association with GEA and COGEMA. Despite their limited number and difficulties in carrying them out (sampling and analysis of krypton 85 in air, delimitation of the plume), these campaigns may eventually provide some information about the dispersion of releases from COGEMA La Hague reprocessing plants, by comparison with the results calculated by the chosen model.

As described in section 5.3.1.2., the calculations were carried out using the COTRAM2 model, based on the Doury model. It provides ATC values in s.m^{-3}. These ATC values can be used either for short-term releases, or for releases assumed to be constant throughout the year by the use of statistical processing taking into account weather conditions.

In the case of releases from COGEMA La Hague reprocessing plants, the group questioned the validity range of the model (Gaussian type model) as a result of the "krypton 85 campaigns" carried out under very specific weather conditions (normal diffusion, high wind speeds) for a high point source; for villages closest to the release point and with maximum wind speeds, estimates produced by the model applied without caution are several orders of magnitudes lower than values obtained from measurement results.

Consequently, in this special case, it was decided that the COTRAM2 program, based on the Doury model, should only be used within its validity range. An alternative method was proposed outside this range. The definition of the selected validity range, and the recommended alternative methods, are described below.

6.2.1.2. Proposed method of evaluating ATCs

6.2.1.2.1. Model validity range

In general, Gaussian models must not be used at perpendicular distances from the center line of the wind exceeding 2 or 3 times the value of the diffusion standard deviation in the vertical plane [14]. For example, if the release takes place at a height of 100 meters, these models cannot be applied to evaluate the ATC at ground level in areas in which σ_z is less than 50 meters. The reason for this application restriction is that the Gaussian equation is only a solution for the pollutants transport-diffusion equation when the environment is

[35] This Section is mostly concerned with releases from COGEMA La Hague reprocessing plants, since it was impossible to make any comparison in the environment around Flamanville power station. However, a number of conclusions are applicable to both sites.

homogeneous (in the fluid mechanics sense). However, the atmosphere is not a homogeneous medium, particularly in the vertical direction, simply due to the presence of the ground.

More specifically, under strong wind conditions the Doury model underestimates diffusion of the plume and predicts very tight plumes. Consequently, at short distances and for high releases, it underestimates concentrations at ground level along the line of the plume and overestimates concentrations at ground level at greater distances.

	Weak diffusion Wind ≤ 5 m/s	Normal diffusion 5 m/s <≤ 8 m/s	Normal diffusion 8 m/s <≤ 11 m/s	Normal diffusion Wind > 11 m/s
D ≤1500 meters				
1500m <≤ 2000 m				
2000m <≤ 2500 m				
2500m <≤ 3000 m				
D > 3000 m				

: valid
: not valid

Table 6.2.1.2.1.: Validity and non validity ranges for use of the Doury model.

The use of the criterion described above can define various validity ranges depending on whether normal diffusion or weak diffusion conditions are considered. Having seen the available elements (See 5.3.1.1.), it appears appropriate to apply the Doury model in the canton of Beaumont-Hague within the validity range shown in the form of a diagram in the following table, defined based on the standard deviation criterion (100 meters < $2\sigma z$), and to find an alternative method of evaluating ATC values outside the validity range thus defined.

The COTRAM calculation program used by GT4 based on the Doury model considers the reflection of the plume by the ground, and takes into account gradual depletion of the plume by deposition for the radionuclides concerned in aerosol form.

6.2.1.2.2. Definition of an "alternative method"

The proposed method consists of:

- for normal diffusion situations:
  - for each wind range considered, for communes outside the validity range defined above, using a ATC value equal to the maximum value calculated at the ground level using the model, for the average wind speed within the wind range considered under normal diffusion conditions; the corresponding value will be called the "alternative method value" throughout the rest of this report.
  - considering that the result obtained can underestimate the real result by a factor of between 1 and 4, a value which is compatible with ATC results evaluated approximately using the results of "krypton campaigns" and uncertainties inherent to the Doury model. The value obtained by multiplying the alternative method value by a factor of 4 is called the "alternative method upper bound".
- For low diffusion situations:
  - No results from "krypton campaigns" can provide information in this type of situation.

Based on a tracing experiment carried out in Germany in a weak diffusion situation with a high release (60 meters), it appears that the "alternative method" proposed in the previous situation could produce similar results under weak diffusion situations (similar results with the real ATC being underestimated by a similar factor). This method appears to give results closer to measured values than a calculation assuming a release at ground level, but should be compared with the results to be obtained from future "krypton campaigns" in this type of situation.

Unprocessed ATC values obtained firstly by applying the model directly, and secondly using the maximum method described above, can be compared. This comparison shows that the difference between the model and the maximum method is less than 20% in most cases, within the validity range defined above. However, this difference is much greater outside the defined validity range, justifying the subsequent use of the maximum method outside this range.

6.2.1.3. Conclusion

It has been accepted that the maximum method can only be used temporarily. Thus, a more scientific method should be developed for situations outside the validity range of the Doury model.

This method could be based on three-dimensional finite element models and on meteorological measurement campaigns and ^{85}Kr concentrations to improve knowledge of transfer mechanisms in the atmosphere in the near field around COGEMA La Hague reprocessing plants. Considering the magnitude of this task, it cannot be done before the Nord-Cotentin radio-ecology group has given its conclusions. If the conditions for some measurements are within the validity range of the Doury model, the results could also be used to confirm this validity.

A note was drafted for summarizing the calculations necessary to apply the adopted method and the results obtained for the various years for which meteorological conditions are available.

6.2.2. Transfer of Carbon-14

The results of measurements made by the OPRI and by COGEMA in 1996, 1997 and 1998[36] enabled an initial comparison between models and measurements. Table 6.2.2. presents the results of this comparison based on data for gaseous releases of carbon-14 from COGEMA reprocessing center provided by GT1 for 1996, and by COGEMA for 1997 and 1998.

Globally, the results obtained by modeling are similar to measured results regardless of the distance, sector and food considered. There is a slight tendency for the model to produce overestimates as the distance from the industrial site increases. However, measured values at a distance of 2 km in the Jobourg sector south-west from the release point exceed values predicted using the model by a factor of 2.2.

It is observed that the modelisation of the impact of releases from COGEMA La Hague reprocessing plants for samples taken to the south of COGEMA La Hague reprocessing plants towards Flamanville power station, gives concentrations similar to values measured in the environment and cannot identify any effect due to EDF releases.

However, care should be taken in interpreting this comparison, considering the small number of measurements available. Consequently, it is proposed that the transfer factors selected in

[36] Release data for the year 1998 were supplied to GT3 directly by COGEMA without any prior analysis by GT2.

the beginning based on the literature should not be modified. In fact, this analysis would confirm the necessity to take into account a range of uncertainties for evaluations made in the near field.

Under these conditions, it is recommended that GT4 should use the following method for calculations of transfers to plants:

^{14}C concentration expressed in Bq.kg^{-1} of stable C in plants =

annual release flow
X ATC evaluated using the alternative method
X NCRP concentration factor (§ 5.3.2.)
X factor representing the variability and uncertainty of the result[37]

The latter factor did not exceed 2.3 in the comparison between the model and measurements, but it is suggested that a factor of 4 should be used considering the small number of measurement results available.

Location	Matrix	Year	Measured 14C activity		ATC	release flow	activity of air	Food	Measurement / Calculation
			Bq.kg^{-1}.C	Bq.l^{-1} or Bq.kg^{-1}	s.m^{-3}	Bq.s^{-1}	Bq.m^{-3}	Bq.kg^{-1} mass	
Herqueville									
1.1km	Grass OPRI	1997		100.0	3.95E-08	6.70E+05	0.026	62.3	1.61
170° - 190°	milk 2213	1997	220	14.7	3.95E-08	6.70E+05	0.026	26.1	0.57
	milk 2027	1998		24.5	4.66E-08	6.70E+05	0.031	27.8	0.88
	parsley-grass	1998		28.3	4.66E-08	6.70E+05	0.031	26.3	1.08
Jobourg									
2km	grass A12	1996	886	141.8	4.66E-08	6.00E+05	0.028	63.5	2.23
270° - 290°		1997	914	146.2	4.66E-08	6.60E+05	0.031	65.9	2.22
	alternative	1997		97.8	4.66E-08	6.60E+05	0.031	65.9	1.48
		1998		85.1	4.66E-08	6.70E+05	0.031	66.3	1.28
Omonville-petite									
2.5km		1998		18.3	1.00E-07	6.70E+05	0.067	40.4	0.45
350° - 10°	carrots	1996	834	40.9	1.00E-07	6.00E+05	0.060	27.7	1.47
		1997	403	19.7	1.00E-07	6.60E+05	0.066	17.0	1.16
		1998		15.0	1.00E-07	6.70E+05	0.067	17.3	0.87
	cabbage	1996	628	20.1	1.00E-07	6.00E+05	0.060	18.1	1.11
	cauliflower	1997	989	34.6	1.00E-07	6.60E+05	0.066	20.2	1.72
	leeks	1996	681	23.8	1.00E-07	6.00E+05	0.060	19.8	1.20
		1997	501	17.5	1.00E-07	6.60E+05	0.066	20.9	0.84
		1998		14.0	1.00E-07	6.70E+05	0.067	21.1	0.66
	milk 2176	1997	205	13.7	1.00E-07	6.60E+05	0.066	40.0	0.34
Digulleville									
2.6km	beans	1997	475	9.5	8.50E-08	6.60E+05	0.056	19.1	0.50
30° - 50°	lettuce	1997	500	10.0	8.50E-08	6.60E+05	0.056	10.9	0.92
	parsley-grass	1997	629	30.8	8.50E-08	6.70E+05	0.057	48.0	0.64
	grass A3	1996	752	120.3	8.50E-08	6.00E+05	0.051	82.9	1.45
		1998		73.4	8.50E-08	6.60E+05	0.056	87.2	0.84
	milk 2083	1997	433	13.7	8.50E-08	6.60E+05	0.056	36.5	0.38
		1998		37.0	8.50E-08	6.70E+05	0.057	36.8	1.00
Saint Germain des Vaux									
4.5km	meat	1996	364	24.5	1.88E-08	6.00E+05	0.011	70.5	0.35
310° - 330°									

Table 6.2.2.: Results of a comparison between models/measurements for ^{14}C in different food and biological indicators calculated using the method in § 5.3.2. Results are presented by geographic sector, distance and year.

It is proposed that the same formula be used to evaluate concentrations in animal products. However, considering the small number of measurements used for comparison between the model and measurements, it is proposed that more systematic measurements of ^{14}C be made in the environment around both facilities, in order to refine the calculations for this radionuclide, which makes one of the largest contributions to the effective dose caused by atmospheric releases.

[37] Only applicable in the case of COGEMA releases.

6.2.3. Transfer of tritium

According to GT1, tritium releases from COGEMA were equal to 75 TBq in 1997, 10 TBq in 1981, and 9.2 TBq in 1980, which is equivalent to release flows of $2.4.10^6$, $0.3.10^6$ and $0.29.10^6$ $Bq.s^{-1}$ respectively assuming a constant release throughout the year.

Location Year	Distance from release point (m)	Sector considered	ATC used	Sample type	Calculated value $Bq.kg^{-1}$	Measured value $Bq.kg^{-1}$ or $Bq.l^{-1}$
Greville 97	6,000	90°-110°	$5.1 - 5.6x10^{-8}$	lettuce	16.5 - 18	1.69
Beaumont 97	3,000	110°-130°	$3.8 - 4.2x10^{-8}$	lettuce	12.3 - 13.6	2.02
Vauville 97	5,000	150°-170°	$2.1 - 2.5x10^{-8}$	chives	6.8 - 8.1	3.66
Branville 97	7,000	110°-130°	$3 - 3.3x10^{-8}$	lettuce	9.7 - 10.7	2.06
Branville 97	7,000	110°-130°	$3 - 3.3x10^{-8}$	chives	9.7 - 10.7	0.92
Sottevast 80/81	25,000	130°-150°	$6.3x10^{-9}$	cheese	0.27	7.4 - 13
Vasteville 80/81	12,000	130°-150°	$1.5x10^{-8}$	cider	0.65	15.8
Surtainville 80/81	22,000	70°-90°	$1.5x10^{-8}$	carrot	0.65	15

Table 6.2.3.: Tritium values in various biological indicators. The calculations used in the model do not include any background noise.

ATCs were calculated using the method described above. For nearer points (< 10 km), two values are supplied in the above table, firstly the value obtained using the alternative method, and secondly the value obtained using the alternative method's upper bound (the contribution to the weighted ATC outside the validity range of the model used multiplied by 4). For 1980 and 1981, the ATC was calculated using average meteorological conditions for the 92-97 period. The comparison was simplified by using a single transfer factor in all cases (135 $m^3.kg^{-1}$, the value proposed in section 5.3.3. for leaf vegetables and milk).

For 1997, calculated values are generally an order of magnitude greater than values actually measured, without taking into account background noise. Based on available measurements, the value supplied by the model appears to exceed values measured in the environment. Some explanations of this could be as follows:

- the sample may have been taken at a time at which the activity of tritium in air was low. Since the balance between air and the plant is achieved extremely quickly, this could explain the low measured value compared with the value predicted by the model which is an annual average and therefore includes periods of the year in which the tritium activity in air could be much higher;
- another explanation is that the only tritium vector considered in the model is rainwater or moisture in the air; however the contribution of ground water is ignored, although it could be predominant; yet inclusion of this contribution, probably less concentrated, could play a major role in diluting tritium and consequently reducing concentrations in plants.

For 1981, calculated values are less than measured values, reflecting the influence of background noise due to fallout from atmospheric nuclear weapons tests. Tritium levels in rainwater in 1981, the date of the last atmospheric nuclear weapons test, were twice as high as values measured in 1997.

However, due to the lack of additional relevant information, it is proposed to use the transfer factors suggested in § 5.3.3., while noting that the results obtained will probably be higher than the true value for this radionuclide.

As for ^{14}C, it is recommended that measurements should be made more systematically in the environment around the two facilities, taking special care that when these measurements are made, they should apply to the tritium content in plants, and also the content in rainwater and the ground water at the time of taking the sample.

6.2.4. Deposition and transfer of iodine and radionuclides bonded to aerosols

The comparison between models and measurements for other radionuclides was unsuccessful:

- there are very few significant measurements in the environment, in other words for which levels exceed detection limits;
- for radionuclides for which there are significant measurements (cesium in grass and milk, and strontium in milk), the comparison was not sufficient to validate the model because, as for ^{137}Cs, atmospheric background noise is very much higher than the activity induced by releases from the plant, by the order of a factor of 1000.
- it was impossible to define predominant transfer pathways through the environment for each radionuclide, which could have made it possible to restrict calculations to these pathways in the models.

Although releases of radionuclides bound to aerosols are generally low and do not exceed values due to atmospheric background noise, this is not necessarily true for iodine 129 for which the source term is greater. However, there are few measurements of iodine 129 in compartments of the terrestrial environment. As for ^{14}C and tritium, it is recommended that more systematic iodine 129 measurements should continue to be made in the environment around COGEMA La Hague reprocessing plants.

6.3. Special case of sea spray

This point deserves special attention in a region in which radionuclides present in sea water can be blown onto land. Measurement campaigns on lichens have shown that these bio-indicators located within a 300-meter-wide shore strip are more marked by some radionuclides (^{60}Co, Pu) than bio-indicators sampled further inland.

This is why a comparison of models and measurements was made using the TORIMA model [20], based on a few measurements that can be used in lichens (^{60}Co, ^{137}Cs, ^{144}Ce, Pu) and in a grass sample (^{125}Sb, ^{134}Cs, ^{137}Cs, ^{106}Ru, ^{144}Ce, $^{239+240}$Pu).

It shows that:

- the reduction with distance predicted by the TORIMA model appears to correspond to the reduction found by measurements made on lichens in the Nord-Cotentin, except for ^{60}Co for which the reduction measured on lichens appears to be much faster;
- based on a single grass measurement made 500 meters from the shore, levels calculated by the model and measured levels are relatively close, except for a few radionuclides; the calculated value for ruthenium is nearly 15 times higher, whereas for cerium it is nearly 30 times lower. However, it is difficult to justify adapting the model based on this single measurement;
- calculations show that for some radionuclides, atmospheric activity due to liquid effluents released into the sea and then carried onto a shore strip by sea spray can be proportionally greater in air than the value due to gaseous releases into the atmosphere.

Consequently, it is impossible to make a decision about the relevance of the model applied to the canton of Beaumont Hague without calculating the contribution to the total dose of the input from sea spray modeled in this way. Thus, the model should be integrated into the dose calculation and two calculations should be made; the first using exactly the same parameters as are used in TORIMA, even if there are limitations to them and there is no proof that they can be applied to the Nord-Cotentin; and the second "canceling" this contribution to transfers to land species.

6.4. Releases into waterways

The only points for which sufficient simultaneous measurements are available in water and sediments for the same years are "Pont-Durand", "La Brasserie" and the mouth of the Sainte-Hélène river. Thus, the calculation of ratios between radioactivity levels in river water

and sediments was only possible at a very small number of sampling points and only for one radionuclide, ^{137}Cs.

The Kd model appears to be relevant for ^{137}Cs. The recommended value for this Kd would be 10 000 l.dw kg^{-1} ($Bq.l^{-1}/Bq.kg^{-1}$).

Based on the list of Kd values used by other organizations, it was decided that the Kd values recommended by the IAEA in its publication 94/364 would be used for other radionuclides, namely 0 for tritium, 50 for uranium, 5 000 for cobalt and americium and 100 000 for plutonium.

The values of parameters in the IAEA publication [32] were also used for fish transfer factors.

7. CONCLUSIONS

GT3 has carried out an analysis of models used for calculating estimates of the radio-ecological impact of slightly radioactive gaseous and liquid effluents authorized for release into the environment by the different facilities located in Nord-Cotentin. It compared the results of activity levels in the various environmental components obtained by modeling with measurement results on samples taken from the environment. As a result of this work, the Group reached the following general conclusions:

- *Marine and continental aquatic ecosystems: the selected models used by operators and the IPSN to simulate transfers of radionuclides in this domain are relevant (concentration factors in biological species, distribution factors in sediments, etc.). The addition of correction factors derived from measurement results supplied by GT2 enabled GT3 to more precisely adjust calculation results to correspond to values measured locally in the environment or to take into account uncertainties inherent to their use. In the marine environment, the comparison between models/measurements is based on 16 000 useable measurement results.*

- *Terrestrial ecosystems: generic models derived from literature can be used. In carrying out its comparisons, GT3 used values of parameters derived from the literature, and which are therefore not specific to local site characteristics. The comparison between the model and measurements was limited to estimate of transfers into the environment through COGEMA's releases of tritium, ^{14}C and iodine 129 during the most recent period (1998-1999), due to the small number of measurements exceeding detection limits or very close to the background noise caused by fallout from atmospheric nuclear weapons tests (^{137}Cs).*

The limitations to this exercise of comparing models and measurements carried out by GT3 are as follows:

- the use of some studied models is not relevant, for example for modeling the near field dispersion of effluents from liquid and gaseous effluent release outlets,
- the validation of the proposed models may be incomplete, for example for modeling the impact of sea spray,
- it is not always possible to compare results obtained by calculations with results obtained by sample measurements in the Nord-Cotentin environment, due to the lack of significant field measurement results.

Radioecological knowledge of the Nord-Cotentin area could be improved in these cases by:

- preparing special models representative of local transfer processes by which radionuclides are transferred into the environment,
- carrying out sample-taking campaigns using sampling strategies adapted to the space-time dynamics of the processes concerned,
- measurements adapted both to radionuclides and to the activity levels likely to be present in the environment around nuclear sites.

These general conclusions are described in detail in the following sections.

7.1. The sea

COGEMA, ANDRA, EDF and IPSN use the same type of model to estimate transfers and radioactivity levels of radionuclides initially present in slightly radioactive liquid effluents authorized to be released into the sea, in the various components of the marine environment. These models are based on use of release dilution factors for each radionuclide, concentration factors for living organisms and distribution coefficients for sediments.

A comparison between results given by models and results given by measurements on samples from the environment (GT2) was used to adjust the values of the dilution factors, concentration factors and distribution coefficients used in the models, to satisfy environmental conditions in the Nord-Cotentin. When this comparison was possible, it was used to evaluate the precision of estimates made using these models:

- by estimating the amplitude of fluctuations of values of dilution factors;
- by adjusting the parameters used for transfer models to suit real site conditions, by introducing correction factors;
- by establishing the statistical data, averages, standard deviations, maximum values, etc., necessary to validate models, and by evaluating activities in the case of exceptional situations.

At the end of its collective work, the Group selected parameters to be used to model transfers of radionuclides in release sources into the various components of the environment. These values, which are most representative of local conditions, are described in the summary tables provided at the end of this conclusion and were forwarded to GT4. Tables 7.1a to 7.1h contain the following values (see Part C Appendices):

- dilution factors for liquid releases,
- concentration factors in the various marine organisms,
- distribution coefficients in sediments,
- correction factors to be applied, if any, and
- the results of exceptional measurements.

The concentration factors and correction factors given in these tables are unrelated to fishing areas. Therefore, they can be used in most cases. However, this general approach has been adapted for:

- the evaluation of the impact of the sea release pipe break in 1979 which was studied more specifically in the Moulinets Bay. Considering the lack of field data, concentrations of the various radionuclides in sea water were calculated retroactively based on the results of measurements available for the various species. Thus, multiplication factors to be applied

to dilution factors were calculated for this period and for each released radionuclide, to make the dilution factors more representative of the changed dilution conditions. It was impossible to evaluate concentrations in sediments in the Moulinets Bay throughout the entire influenced period, therefore available measurements were used to infer activity levels in sea water.

- It was impossible to evaluate the impact of releases from the EDF power station using results of measurements in the environment, since all measurement results were below detection limits. Therefore, dilution factors to evaluate concentrations in species had to be estimated for the main areas under the influence of these releases.
- ^{110m}Ag concentrations in living species was evaluated from available measurements in the environment, since the recommended model could not be validated by the comparison between model and measurements.
- The results of measurements on sediments at La Ronde and Cap Voidries were used to correct activities by an average correction factor equal to 4.3 for ^{137}Cs, to take into account the proximity of the release point;
- Samples taken in Cherbourg Bay or in areas with fine sedimentation were multiplied by an average correction factor of 2.3 for ^{125}Sb, 4.5 for ^{137}Cs and 1.2 for ^{106}Ru.
- Sediment integration periods for actinides are long, and it is impossible to define them using available data. Consequently, it is proposed to calculate the activity of sediments for elements that fix strongly and that have a half-life greater than 3 years (Pu, Am, Cm, Zr, Eu) by using the distribution coefficient for the period between when the plant was commissioned and the year during which releases were maximum, and then for the later period by assuming a constant contamination in sediments equal to the average value of subsequent measurements.

For some cases, it was impossible to compare the models and measurements due to the lack of any measurement results that exceeded detection limits. In these cases, the models could not be validated based on available measurement results and the conclusions given in the above paragraphs are then used to carry out a calculation using the best available information. However, some items deserve further discussion:

- comparisons between models and measurements for ^{14}C were not very conclusive because the reference background noise along the shoreline is not well known. Therefore, there is a significant uncertainty about the selected concentration factor. So, it would be desirable to improve knowledge of the ^{14}C background noise away from the influence of the facilities, in order to characterize ambient levels of ^{14}C and their variability as a function of the sample type, the substrate type, the season, etc. Sampling and measurement campaigns should be organized with a sampling and analysis strategy adapted to this radionuclide to subsequently facilitate the evaluation of measurement results, in order to evaluate the impact of nuclear facilities.

- For the same reasons as for ^{14}C, the number of tritium measurements, and particularly bound tritium, should also be increased in marine species.

- It was possible to determine dilution factors for the entire coast, and for a few offshore areas. However, some samples taken in the very near field close to the release point demonstrated poor knowledge of the variability of the dilution of liquid releases in this area. Models and validation methods do exist to evaluate dilution in the very near field in the short term. They are not easy to apply for releases into the open sea. However, it would be possible to define a method of evaluating the annual average dilution factor in the near field, based on these tools and on concentration measurement campaigns for the most conservative radionuclides in appropriate matrices.

- Modeling to evaluate the activities of radionuclides in sediments using the same value of Kd regardless of the nature of the sediments, does not take into account the properties of

sediments. Therefore, the study on empirical transfer functions to sediments should be continued, for example by examining the use of different Kd values for each sediment class (shore sand, pebbles, port mud, etc.). This approach would require series of simultaneous measurement results on radionuclide concentrations and the physicochemical and size grading characteristics of the same samples.

In the future, precise procedures must be respected when taking samples and measuring the radioactivity associated with sediments, in order to obtain consistent long-term series.

- Specific concentration factors should be prepared for environmental conditions at the Nord-Cotentin site for radionuclides for which insufficient information is available (^{110m}Ag, Pa, etc.).

7.2. The atmosphere

Generic models derived from the literature can be used. However, the comparison between models and measurements was not carried out to the same extent as for the marine environment, due to the small number of available measurements that exceed detection limits, or which are very close to the background noise due to fallout from atmosphere tests of nuclear weapons (^{137}Cs). In carrying out its comparisons, GT3 used values of parameters derived from the literature, and which are therefore not specific to local site characteristics. The comparison between models and measurements was limited to estimates of transfers into the environment of COGEMA releases of ^{14}C and ^{129}I for the most recent period (1998-1999).
The following conclusions drawn from calculations of models and comparisons with results of measurements in the environment are limited and will have to be confirmed based on new measurement results specifically selected for the validation of models:

- Simplifying assumptions were made in models to evaluate dispersion conditions for gaseous releases. In the future, site weather conditions (wind directions at the height of the release, wind speeds at the height of the release, diffusion conditions) should be used to define a criterion for determining realistic atmospheric diffusion conditions, if necessary making use of measurements additional to existing measurements, and to determine the occurrence frequencies of various weather situations.

- Rare gases: the COTRAM2 model was used for rare gas radionuclides in the comparison, at ground level for EDF releases and for all weather configurations, and at a height of 100 meters for COGEMA releases. The Group determined the validity ranges of the Doury model (table 6.2.1.2.1.). The "maximum" method can be used outside the validity range, knowing that the values thus calculated could be underestimated by a factor of 4. Therefore, diffusion models that can be used for the near field should be improved, as demonstrated by available krypton 85 measurements. More comprehensive krypton 85 measurement campaigns should be carried out considering the various weather conditions, to validate an alternative method outside the validity range of the Doury model, which could be based on three-dimensional finite element models.

- Carbon-14: the proposed method of evaluating ^{14}C concentrations in vegetable and animal species consists of using ATC values and a transfer factor that depends on the CO_2 content of releases calculated using assumptions usually selected by other countries (Switzerland, USA).

- Tritium: the principle for modeling the impact of tritium releases is identical to the principle for modeling the impact of ^{14}C releases. It was impossible to compare models and measurements for EDF releases. The only available model for determining the impact of releases from COGEMA La Hague reprocessing plants for radionuclides for which this comparison is possible, gave concentrations exceeding values measured in the environment. More systematic measurements of tritium in the environment around the

two plants should be made, taking special care to ensure that they are applicable to the tritium content bound to plants, and also to the tritium content of rainwater and ground water.

- Iodine and radionuclides bound to aerosols; since it was impossible to validate specific models to evaluate the impact of these radionuclides, it was decided to use the values of parameters given by the FOCON 96 model (IPSN) (with a few exceptions and additions). A sensitivity analysis on the dose calculation should be carried out for the values of some parameters, for which a range of values has to be chosen.

- Since the lack of any measurement in the past made it difficult to compare values observed in the field with the results of chosen models, it appeared necessary for systematic measurements to be carried out for ^{14}C and iodine 129 in the environment around COGEMA La Hague reprocessing plants, in order to refine calculations for these radionuclides, which are among those that now make the greatest contribution to the dose assignable to atmospheric releases. This monitoring should also be applied to ^{14}C released by Flamanville power station.

- Even if specific food rations were proposed, it would be desirable to carry out a dietary survey on rations of farm animals in the Nord-Cotentin in order to obtain values more representative of local conditions.

7.3. Sea spray

For sea spray, the only available model for the work done by GT3 was the TORIMA model [20] developed by the NRPB to model deposition and inhalation of sea spray. There is no tool for calculating concentrations in air due to sea spray in the coastal area.

It was decided to use the TORIMA model when sea spray had to be taken into account, since there was no other available model.

Few studies and measurements were carried out in order to model the transfer by sea spray. More complete studies should be carried out in this field in order to obtain a specific model for the processes concerned, taking into account the local topography and weather conditions.

7.4. Waterways

GT3 did not examine transfer models to waterways and ground water, but the principle adopted by default is to use parameters given in IAEA publication 94/364, except for the Kd factor for ^{137}Cs for which models and measurements could be compared.

Studies specific to transfers of radionuclides in ground water and their transport to discharges into rivers should be continued.

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PART C APPENDICES

Table 7.1a: Dilution factors proposed for COGEMA releases:

	$Bq.m^{-3}/TBq.year^{-1}$	Dilution factor compared with Goury
Dilution factor for living species		
Beaumont-La Hague shore (except for Querqueville)	0.76	1
Querqueville	0.53	0.7
Offshore La Hague	0.76	1
Les Huquets	3.4 $\subset$ [1.5;5.3]	Average: 4.5 $\subset$[1.9;6.7]
Dielette/Flamanville/Vauville	0.76	1
Le Rozel	0.61	0.8
Sciotot	0.53	0.7
Urville	0.53	0.7
Cherbourg Bay	0.53	0.7
Brick	0.46	0.6
Cotentin East	0.38	0.5
Barneville	0.31	0.4
Pirou => Hauteville/sea	0.23	0.3
Granville	0.15	0.2
Dilution factor for sediments		
Shore area around Cap La Hague, from Cap Flamanville to Cherbourg	0.76	1
Other areas in Nord-Cotentin	0.38	0.5

Table 7.1b: Dilution factors proposed for EDF releases:

	$Bq.m^{-3}/TBq.year^{-1}$	Dilution factor compared with Flamanville
Cap Flamanville area	3	1
Cap La Hague area	1.5	0.5
Cherbourg area	1.05	0.35
Carteret area	0.6	0.2

Table 7.1c: Concentration factors (l.ww kg^{-1}) for filtering molluscs (mussels):

Symbol	Element	Recommended value	Correction factors for averages	Correction factors for maxima	Standard deviations
H	Tritium	1	-	-	-
C	Carbon	5000	-	-	-
I	Iodine	100	-	-	-
Ru	Ruthenium	600	0.2 - 1 [38]	0.8 - 3.5	50%
Sb	Antimony	20	0.5	2 - 6	30%
Sr	Strontium	10	-	-	-
Cs	Cesium	50	0.5	6	50%
Co	Cobalt	2000	0.5 - 2	2 - 6	50%
Tc	Technetium	400	-	-	-
Pu	Plutonium	3000	-	-	-
Am	Americium	1000	-	-	-
Cm	Curium	1000	-	-	-
Mn	Manganese	10000	-	-	-
Ag	Silver	40000	measurements	51	-
Fe	Iron	20000	-	-	-
Mo	Molybdenum	100	-	-	-
Ce	Cerium	1500	-	-	-
Zn	Zinc	80000	-	-	-
Zr	Zirconium	1000	-	-	-
Cl	Chlorine	0.05	-	-	-
Ca	Calcium	1	-	-	-
Ni	Nickel	2000	-	-	-
Eu	Europium	7000	-	-	-
Se	Selenium	6000	-	-	-
Np	Neptunium	400	-	-	-
Y	Yttrium	1000	-	-	-
Nb	Niobium	1000	-	-	-
Pa	Palladium	500	-	-	-
Cd	Cadmium	20000	-	-	-
Sn	Tin	50000	-	-	-
Te	Tellurium	1000	-	-	-
Pm	Promethium	5000	-	-	-
U	Uranium	30	-	-	-
Be	Beryllium	2000	*0.5-2*	*2-6*	*50%*
Rh	Rhodium	600	*0.2-1*	*0.8 - 3.5*	*50%*
Rb	Rubidium	50	*0.5*	*6*	*50%*
Sa	Samarium	5000	-	-	-
Pr	Praseodymium	1500	-	-	-
Tb	Terbium	3000	-	-	-

[38] First value: until 1990. Second value: after 1990

Table 7.1d: Concentration factors (l.ww kg^{-1}) for non-filtering molluscs (limpets):

Symbol	Element	Recommended value	Correction factors for averages	Correction factors for maxima	Standard deviations
H	Tritium	1	-	-	-
C	Carbon	5000	-	-	-
I	Iodine	100	-	-	-
Ru	Ruthenium	600	0.4	5	35%
Sb	Antimony	20	1.2	7	35%
Sr	Strontium	10	0.4	2	-
Cs	Cesium 134	50	3.4	38	50%
	Cesium 137	50	0.6	5	50%
Co	Cobalt 60	2000	0.5 - 1.2	7	35%
	Cobalt 58	2000	0.5	7.3	-
Tc	Technetium	400	-	-	-
	Plutonium	3000	0.6	7.6	35%
Am	Americium	1000	-	-	-
Cm	Curium	1000	-	-	-
Mn	Manganese	10000	1	7.6	-
Ag	Silver	40000	measurements	140	-
Fe	Iron	20000	-	-	-
Mo	Molybdenum	100	-	-	-
Ce	Cerium	1500	3.1	67	-
Zn	Zinc	80000	0.35	1.7	-
Zr	Zirconium	1000	-	-	-
Cl	Chlorine	0.05	-	-	-
Ca	Calcium	1	-	-	-
Ni	Nickel	2000	-	-	-
Eu	Europium	7000	-	-	-
Se	Selenium	6000	-	-	-
Np	Neptunium	400	-	-	-
Y	Yttrium	1000	-	-	-
Nb	Niobium	1000	-	-	-
Pa	Palladium	500	-	-	-
Cd	Cadmium	20000	-	-	-
Sn	Tin	50000	-	-	-
Te	Tellurium	1000	-	-	-
Pm	Promethium	5000	-	-	-
U	Uranium	30	-	-	-
Be	Beryllium	*2000*	*0.5 - 1.2*	*7*	*35%*
Rh	Rhodium	*600*	*0.4*	*0.5*	*35%*
Rb	Rubidium	*50*	*0.6*	*5*	*50%*
Sa	Samarium	5000	-	-	-
Pr	Praseodymium	*1500*	*3.1*	*67*	-
Tb	Terbium	3000	-	-	-

Exceptional measurements: Moulinets Bay (correction factor 55 for ^{137}Cs), Saint-Martin Bay (correction factor 75 for ^{137}Cs).

Table 7.1e: Concentration factors (l.ww kg^{-1}) for fish:

Symbol	Element	Recommended value	Correction factors for average	Correction factors for maxima	Standard deviations
H	Tritium	1	-	-	-
C	Carbon	5000	-	-	-
I	Iodine	15	-	-	-
Ru	Ruthenium	2	3.9	28	50%
Sb	Antimony	20	3.8	8	50%
Sr	Strontium	5	0.6 - 1.2[39]	1.5 - 1.8[38]	25%
Cs	Cesium	400	0.2	3	50%
Co	Cobalt	200	0.8 - 2[38]	10	50%
Tc	Technetium	80	-	-	-
Pu	Plutonium	100	-	-	-
Am	Americium	100	-	-	-
Cm	Curium	100	-	-	-
Mn	Manganese	1000	-	-	-
Ag	Silver	4000	measurements	27	-
Fe	Iron	1000	-	-	-
Mo	Molybdenum	20	-	-	-
Ce	Cerium	100	-	-	-
Zn	Zinc	5000	-	-	-
Zr	Zirconium	30	-	-	-
Cl	Chlorine	0.05	-	-	-
Ca	Calcium	2	-	-	-
Ni	Nickel	1000	-	-	-
Eu	Europium	300	-	-	-
Se	Selenium	6000	-	-	-
Np	Neptunium	10	-	-	-
Y	Yttrium	20	-	-	-
Nb	Niobium	30	-	-	-
Pa	Palladium	50	-	-	-
Cd	Cadmium	1000	-	-	-
Sn	Tin	500	-	-	-
Te	Tellurium	1	-	-	-
Pm	Promethium	5000	-	-	-
U	Uranium	1	-	-	-
Be	Beryllium	200	*0.8 - 2[38]*	*10*	*50%*
Rh	Rhodium	2	*3.9*	*28*	*50%*
Rb	Rubidium	400	*0.2*	*3*	*50%*
Sa	Samarium	500	-	-	-
Pr	Praseodymium	100	-	-	-
Tb	Terbium	60	-	-	-

Exceptional measurements at the Huquets: 275, 64 for ^{106}Ru.

[39] First value: until 1990. Second value: after 1990

Table 7.1f: Concentration factors (l.ww kg^{-1}) for crustaceans:

Symbol	Element	Recommended value	Correction factors for average	Correction factors for maxima	Standard deviations
H	Tritium	1	-	-	-
C	Carbon	5000	-	-	-
I	Iodine	100	-	-	-
Ru	Ruthenium	300	0.5	4	40%
Sb	Antimony	10	1.4	12	30%
Sr	Strontium	5	1.3	1.6	10%
Cs	Cesium	100	0.4	6	50%
Co	Cobalt	5000	0.5 - 1.3 [40]	6	30%
Tc	Technetium	1300	-	-	-
Pu	Plutonium	500	-	-	-
Am	Americium	1000	-	-	-
Cm	Curium	1000	-	-	-
Mn	Manganese	5000	-	-	-
Ag	Silver	3000	measurements	724	-
Fe	Iron	5000	-	-	-
Mo	Molybdenum	100	-	-	-
Ce	Cerium	1500	-	-	-
Zn	Zinc	4000	-	-	-
Zr	Zirconium	500	-	-	-
Cl	Chlorine	0.05	-	-	-
Ca	Calcium	5	-	-	-
Ni	Nickel	1000	-	-	-
Eu	Europium	1000	-	-	-
Se	Selenium	5000	-	-	-
Np	Neptunium	100	-	-	-
Y	Yttrium	1000	-	-	-
Nb	Niobium	200	-	-	-
Pa	Palladium	10	-	-	-
Cd	Cadmium	10000	-	-	-
Sn	Tin	50000	-	-	-
Te	Tellurium	1000	-	-	-
Pm	Promethium	1000	-	-	-
U	Uranium	10	-	-	-
Be	Beryllium	*5000*	*0.5 - 1.3*	*6*	*50%*
Rh	Rhodium	*300*	*0.5*	*4*	*40%*
Rb	Rubidium	*100*	*0.4*	*6*	*30%*
Sa	Samarium	1000	-	-	-
Pr	Praseodymium	*1500*	-	-	-
Tb	Terbium	1000	-	-	-

Exceptional measurements at the end of the release pipe: correction factors of 12460 for ^{125}Sb, 421 for ^{137}Cs, 359 for ^{106}Ru, 117 for ^{60}Co.

[40] First value: until 1990. Second value: after 1990

Table 7.1g: Concentration factors (l.ww kg^{-1}) for seaweed:

Symbol	Element	Recommended value	Correction factors for averages	Correction factors for maxima	Standard deviations
H	Tritium	1	-	-	-
C	Carbon	5000	-	-	-
I	Iodine	10000	1	4	25%
Ru	Ruthenium	300	0.7	6	40%
Sb	Antimony	20	0.9	5	40%
Sr	Strontium	40	0.4	0.8	30%
Cs	Cesium	50	0.7	2.3	30%
Co	Cobalt 60	6000	0.6 - 1.1[41]	3.6	30%
Tc	Cobalt 58 (with measured COGEMA release)	6000	0.7	5.2	35%
Tc	Technetium	30000	1.9	9	130%
Pu	Plutonium	4000	1	14	20%
Am	Americium	400	-	-	-
Cm	Curium	400	-	-	-
Mn	Manganese	5000	1.1	3.6	40%
Ag	Silver	5000	measurements	267	20%
Fe	Iron	20000	-	-	-
Mo	Molybdenum	100	-	-	-
Ce	Cerium	5000	0.5	1.4	60%
Zn	Zinc	2000	9	27	35%
Zr	Zirconium	2000	-	-	-
Cl	Chlorine	0.05	-	-	-
Ca	Calcium	6	-	-	-
Ni	Nickel	2000	-	-	-
Eu	Europium	3000	-	-	-
Se	Selenium	1000	-	-	-
Np	Neptunium	50	-	-	-
Y	Yttrium	1000	-	-	-
Nb	Niobium	3000	-	-	-
Pa	Palladium	100	-	-	-
Cd	Cadmium	5000	-	-	-
Sn	Tin	20000	-	-	-
Te	Tellurium	10000	-	-	-
Pm	Promethium	3000	-	-	-
U	Uranium	100	-	-	-
Be	Beryllium	*6000*	*0.6 - 1.1*	*3.6*	*35%*
Rh	Rhodium	*300*	*0.7*	*6*	*40%*
Rb	Rubidium	*50*	*0.7*	*2.3*	*30%*
Sa	Samarium	3000	-	-	-
Pr	Praseodymium	*5000*	*0.5*	*1.4*	*60%*
Tb	Terbium	2000	-	-	-

Exceptional measurements at Moulinets Bay: correction factor of 21 for ^{137}Cs.

[41] First value: until 1990. Second value: after 1990

Table 7.1h: Kd (l.dw kg^{-1}) for sediments:

Symbol	Element	Recommended value	Correction factors for averages	Correction factors for maxima	Standard deviations
H	Tritium	1	-	-	-
C	Carbon	2000	-	-	-
I	Iodine	500	-	-	-
Ru	Ruthenium	5000	0.05 - 0.2[42]	0.8	50%
Sb	Antimony	400	0.2 - 0.6[41]	3.3	50%
Sr	Strontium	30	3	25	50%
Cs	Cesium	1000	0.2	1.8	50%
Co	Cobalt	40000[43]	0.04	1.4	50%
Tc	Technetium	100	-	-	-
Pu	Plutonium	10000[44]	-	-	-
Am	Americium	30000	-	-	-
Cm	Curium	2000000	-	-	-
Mn	Manganese	1000	-	-	-
Ag	Silver	1000	-	-	-
Fe	Iron	50000	-	-	-
Mo	Molybdenum	100	-	-	-
Ce	Cerium	20000	-	-	-
Zn	Zinc	2000	-	-	-
Zr	Zirconium	3000	-	-	-
Cl	Chlorine	0.03	-	-	-
Ca	Calcium	500	-	-	-
Ni	Nickel	100000	-	-	-
Eu	Europium	500000	-	-	-
Se	Selenium	100000	-	-	-
Np	Neptunium	1000	-	-	-
Y	Yttrium	1000000	-	-	-
Nb	Niobium	500000	-	-	-
Pa	Palladium	5000000	-	-	-
Cd	Cadmium	2000	-	-	-
Sn	Tin	1000	-	-	-
Te	Tellurium	1000	-	-	-
Pm	Promethium	2000000	-	-	-
U	Uranium	1000	-	-	-
Be	Beryllium	*40000*[13]	*0.04*	*1.4*	*50%*
Rh	Rhodium	*5000*	*0.05 - 0.2*[41]	*0.8*	*50%*
Rb	Rubidium	*1000*	*0.2*	*1.8*	*50%*
Sa	Samarium	2000000	-	-	-
Pr	Praseodymium	*20000*	-	-	-
Tb	Terbium	1000000	-	-	-

[42] First value: until 1990. Second value: after 1990

[43] Transfer factor with integration; integration period 5 years.

[44] Until the year of the maximum release. Afterwards, constant contamination equal to the average of values measured in the environment during this period.

PART D

ESTIMATE OF DOSES AND ASSOCIATED LEUKEMIA RISKS

1. OBJECTIVES

The objective of GT4 is to estimate doses and the associated risk of leukemia. These estimates are provided within the framework of the twofold task of the Nord-Cotentin Radioecology Group.

- Task 1: to provide information to complement the epidemiological studies carried out or being carried out in the Nord-Cotentin, by estimating the exposure from the various sources of ionizing radiation (nuclear industry, medical examinations, natural radiation) and hence the risk of leukemia to young people (0-24 year old) living in the Beaumont-Hague canton during the period from 1978 to 1996.

- Task 2: to provide background information for the decisions to be made regarding the revisions of the regulatory texts governing the operation of COGEMA La Hague reprocessing plants by determining the exposures of the groups of population likely to be the most exposed.

The Group has defined two methods of making the dosimetric calculation and estimating the risk, in order to fulfill these two tasks:

- Task 1: the estimate of the risk of leukemia for the 0-24 year old cohort living in the Beaumont-Hague canton for the period from 1978 to 1996, based on reconstructed doses to the red bone marrow since birth.

- Task 2: estimate of individual effective doses for particular scenarios that could lead to exposures greater than the average

All calculations carried out by GT4 are based on the results of work done by the other three working groups, and particularly work done by GT1 for the source term for releases from local nuclear facilities, and work done by GT3 to model radionuclide transfers through the environment until they reach man.

GT4 brief report presents the main results of these GT4 studies, namely:

- Task 1:

    - the demographic reconstruction of the 0 to 24 year old cohort in the Beaumont-Hague canton,
    - modeling of doses to the red bone marrow for the cohort,
    - the choice of characteristic habit parameters for the cohort,
    - risk estimating models,
    - the estimate of individual and collective doses to the red bone marrow and the estimate of the risk of leukemia associated with all sources of exposure (natural, medical, fallout from atmospheric testing of nuclear weapons and the Chernobyl accident, the nuclear facilities in the Nord-Cotentin) for the 0 to 24 year old cohort living in the Beaumont-Hague canton,
    - the estimate of individual doses to the red bone marrow and the estimate of the individual risk of leukemia associated with cohort scenarios corresponding to habits that could lead to above-average exposures.

- Task 2:

  - modeling of effective doses,
  - the definition of particular scenarios and associated habit parameters,
  - the estimate of individual effective doses for particular scenarios that could lead to above-average exposures.

GT4 detailed report contains all results obtained by GT4, and in particular the appendices describe details of various technical points.

2. EPIDEMIOLOGICAL CONTEXT

2.1. Overview of epidemiological results

A total of eight epidemiological studies have been published concerning the risk of cancer in the Nord-Cotentin or close to the La Hague plant [Laurier 1999] from 1989. The results or conclusions of two of these studies raised points that could justify the estimate of doses.

In 1995, JF Viel's team published the result of a study on the incidence of leukemia in the 0 to 24 year old population within a radius of 35 km around the La Hague plant [Viel et al 1995]. This study suggested excess leukemia in the 10 km area (Beaumont-Hague canton), at the limit of statistical significance (four cases observed between 1978 and 1992 compared with 1.4 expected).

In 1997, the same team published the result of a case-control study attempting to determine the factors (medical history, exposure, habits, dose-relevant habits) associated with the risk of leukemia in the young of the Nord-Cotentin region [Pobel and Viel 1997]. This study compared the retrospective reconstruction of exposure factors of a group of 27 children suffering from leukemia with a group of 192 children without leukemia with the same characteristics. A total of more than 170 factors were studied. Three types of habit among the results obtained were thus statistically associated with an increase in the risk of leukemia:

- visits to local beaches by mothers during their pregnancy, or by children during their childhood,

- consumption of local fish and seafood at least once per week,

- the time spent living in a house made of granite or built on a granite subsoil.

GT4 carried out a review of previous radioecological studies performed in the United Kingdom, as part of its task of developing a working method of providing further information for the two epidemiological studies mentioned above.

2.2. Summary of radioecological studies carried out in the United Kingdom

The NRPB carried out radioecological studies in the United Kingdom, to investigate the excess number of cases of leukemia in children observed close to nuclear sites in the town of Thurso (10 km from the Dounreay reprocessing plant) in 1986 [Dionan 1986, NRPB report R196], in the neighbourhood of the Aldermaston and Burghfield weapon factories (close to the town of Reading in the Oxford region) in 1987 [Dionan 1987, NRPB report R202], and in the village of Seascale (3 km from the Sellafield reprocessing plant) in 1995 [Simmonds 1995, NRPB report R276]. A study of the dose to the Guernsey population due to releases from La Hague and Flamanville installations was also carried out in 1997 [Haywood 1997, NRPB report R294].

These four examples provide basic information for setting up a radioecological study in the Nord-Cotentin. GT4 analyzed them and they were used as a basis for the study on the methodology to be used by GT4. In each case, the authors attempted to estimate doses as realistically as possible, based on a reconstruction of exposures and the most "representative" possible habits of the population. The methods and results are described in the reference [Laurier and Rommens 1998].

2.3. Application to the Nord-Cotentin

The objective of the radioecological evaluation is to estimate the dose associated with exposure to ionizing radiation as realistically and completely as possible.

In the two epidemiological studies [Viel *et al* 1995] and [Pobel and Viel 1997], the results are related to the risk of leukemia. Therefore, a useful radioecological estimate should involve the estimate of the dose to the red bone marrow.

The radioecological answer to the results of the first study [Viel *et al* 1995] corresponds to the estimate of the number of cases of leukemia associated with this dose. The objective is to compare the number of cases actually observed in individuals between 0 and 24 year old in the Beaumont-Hague canton between 1978 and 1992, with the number of cases expected in the same population as a function of exposure to radiation and what is known about the effect of ionizing radiation. This type of estimate requires a calculation of the collective dose of this population (its reconstruction described in section 3.1 will be called the "cohort") based on estimates reflecting the average habit and exposure of individuals within the cohort.

The radioecological answer to the results of the second study [Pobel and Viel 1997] may be limited to the estimate of the dose associated with specific habits or dose-relevant habits in the form of scenarios (subsequently called "cohort scenarios" - see section 3.6):

- frequent visits to local beaches by children during their childhood,
- frequent visits to local beaches by mothers during their pregnancy,
- high levels of consumption of local fish and seafood,
- living in a house made of granite.

Different methods should be used to deal with these two types of answers. The methodology proposed to answer the first question is described in section 3 of this report. The method used to answer the second question is described in section 3.6.

3. METHODOLOGY SELECTED TO ESTIMATE THE DOSE AND THE RISK OF LEUKEMIA FOR THE 0-24 YEAR OLD COHORT

The excess risk of leukemia suggested by epidemiological results is related to individuals between 0 and 24 year old who lived in the Beaumont-Hague canton (see figure 3.a) between 1978 and 1992 inclusive. Therefore, the study deals with the estimate of the history of the dose to the red bone marrow and the risk of radiation-induced leukemia in this population, extended until 1996 to benefit from the most recent records available from the Manche department register. With this approach, the number of cases observed in 0-24 year old individuals in the Beaumont-Hague canton between 1978 and 1996 can be compared with the number of cases that would be expected in the same population as a function of exposure to radiation and what is known about the effects of ionizing radiation.

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Figure 3.a: Geographic location of the Beaumont-Hague canton

3.1. Composition of the 0-24 year old cohort

Purpose

The Beaumont-Hague canton is composed of 19 villages. The size of the population has changed considerably with time, with a slight reduction between 1968 and 1975, followed by a large increase until 1990 (data from INSEE censuses). The number of inhabitants was 6046 during the 1968 census, and 10783 during the 1990 census. The number of individuals in the 0-24 year old cohort living in the canton varied from 2734 in 1968 to 4247 in 1990.

The objective is to reconstruct the 0-24 year old cohort who had lived in the Beaumont-Hague canton between 1978 and 1996 inclusive, as precisely as possible, based on existing data [Laurier *et al* 1998]. The estimated dose and the risk associated with this dose should be assessed for each individual, in order to take into account the fact that the dose is engaged and that the risk of radiation induced leukemia varies with age. Therefore, it is not enough to simply estimate the number of individuals in residence each year, it is also necessary to reconstruct the fictitious population that had lived in the area (reconstruction of generations). Nor is the objective to search for real individual data (a task which would have

been required by a prospective epidemiological approach) but to reconstruct the variation of a population in time, based on the demographic data (risk evaluation approach).

This reconstruction of the population of 0 to 24 year old individuals who had resided in the Beaumont-Hague canton between 1978 and 1996 inclusive is called the "cohort" in this report. This reconstruction makes it necessary to consider all generations from 1954 (who would be 24 year old in 1978) to 1996, namely 43 generations. Figure 3.1.1.a diagrammatically shows the principle on which the cohort is built up.

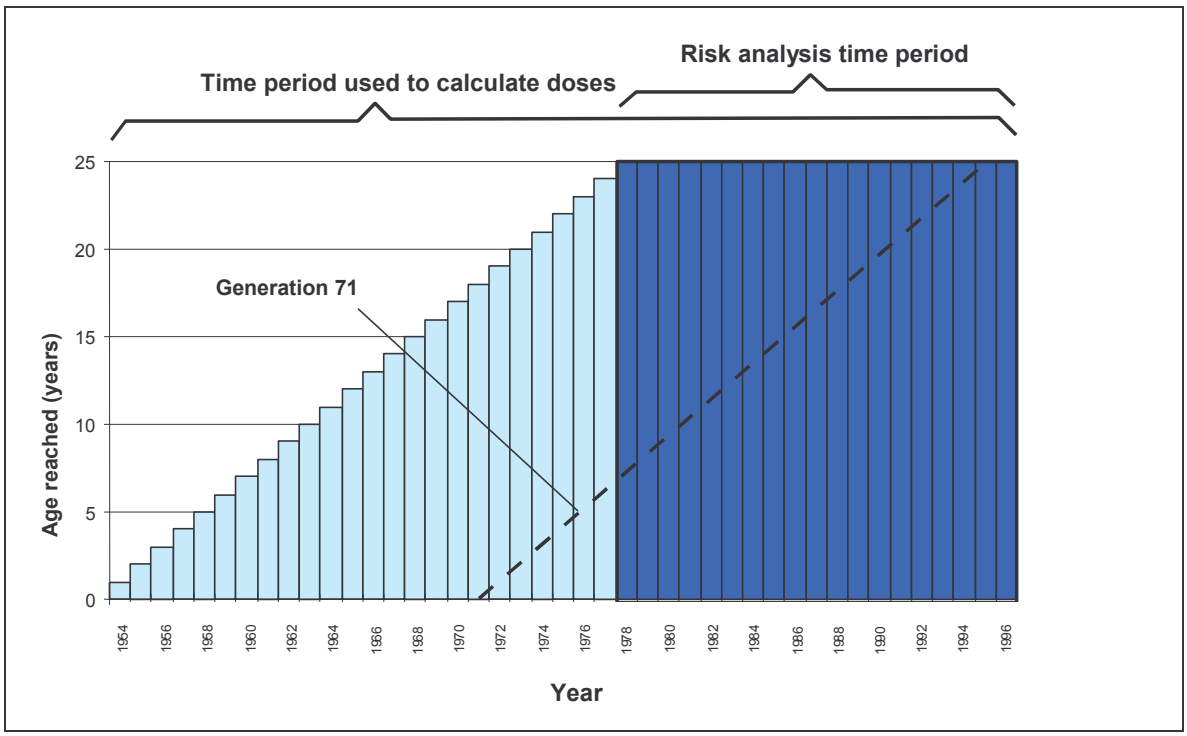


Figure 3.1.1.a: Diagram showing reconstruction of the 0-24 year old cohort to estimate the risk of radiation-induced leukemia in the Beaumont-Hague canton between 1978 and 1996

3.1.2. Reconstruction based on births

The method used in English radioecological studies carried out by the NRPB [Dionan 1986, Simmonds 1995, Laurier and Rommens 1998] is based on the construction of a "fictitious cohort", in other words a reconstruction of the population of 0-24 year old individuals who have lived within the study area. In order to recreate the individual dimension necessary to estimate the risk, it was assumed that a number of individuals were born each year in the study area and remained in this area until their 25th birthday or until the end of the study period. The size of each generation was either considered as being fixed (as at Dounreay [Dionan 1986]) or based on the annual birth rate (as at Sellafield [Simmonds 1995]). No corrections were made to reflect migrations of these individuals into the study area (arrival of individuals not born in the study area) or outside the study area (individuals born in the area and then leaving).

The method proposed here is as follows:

- The population of 0-24 year old individuals who lived in the Beaumont-Hague canton between 1978 and 1996 is reconstructed based on generations of individuals estimated using annual birth rates. All individuals born between 1954 and 1996 have to be considered, in order to include all individuals who were between the ages of 0 and 25 year

old during the period from 1978 up to 1996. The number of births per village and per year was obtained from the INSEE (figure 3.1.2.a).

- Due to the lack of any information about outgoing migrations from the canton, it is assumed that any person born within the study area remains in it until his or her 25th birthday or until the end of December 1996. Therefore each person is exposed throughout the period in the study area. The estimated population of 0-24 year old individuals in the canton is equal to the sum of the 43 generations. However, the death rate within each generation is simulated by applying national death rates due to all causes.

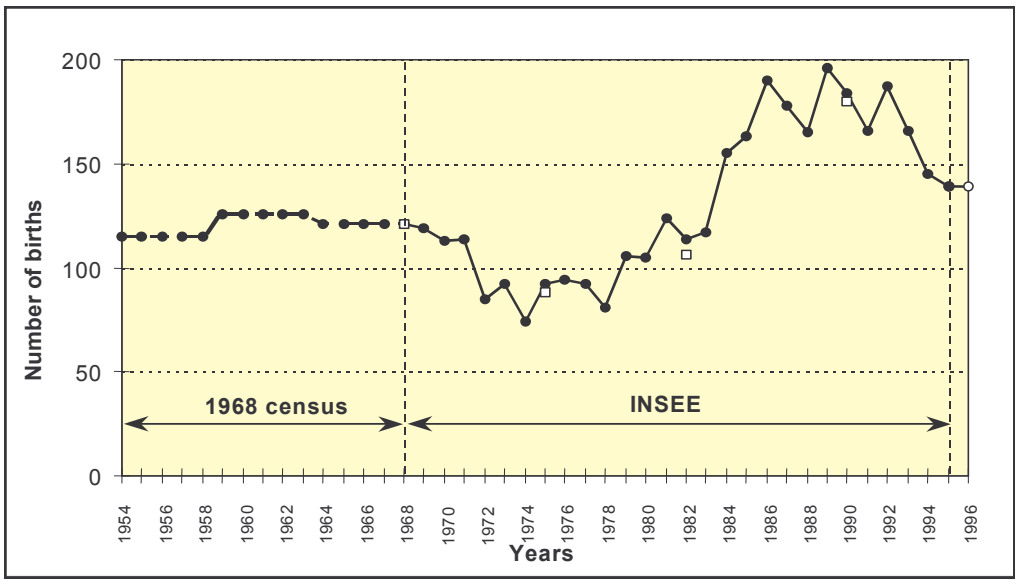


Figure 3.1.2.a: Births with domicile in the Beaumont-Hague canton

N.B.: The squares represent the results of INSEE censuses

The cohort thus defined includes 5506 individuals (sum of births during 43 years). Each of these individuals is present for at least 1 year during the period from 1978 to 1996. The total number of years present between 1978 and 1996 (number of person-years) for the whole cohort is 56761.

3.1.3. Including school attendance data

There was a large influx of workers during the "La Hague Major Construction Site" between 1982 and 1989. This influx resulted in an increase in the population of the Beaumont-Hague canton, but this influx is difficult to quantify from available demographic data, since the major construction site took place between two censuses.

School attendance records at State schools in the Beaumont-Hague canton provided by the Manche department Academic Inspection records were used to determine population variations. These data translate an increase in the population of the canton between 1983 and 1986 (figure 3.1.3.a). This is reflected in birth data (figure 3.1.2.a). This increase is observed in a more or less marked manner in all age groups. It can apparently be assigned to two distinct phenomena; firstly the fast expansion of the village of Urville-Nacqueville, and secondly the influx of population at the time of the La Hague Major Construction Site.

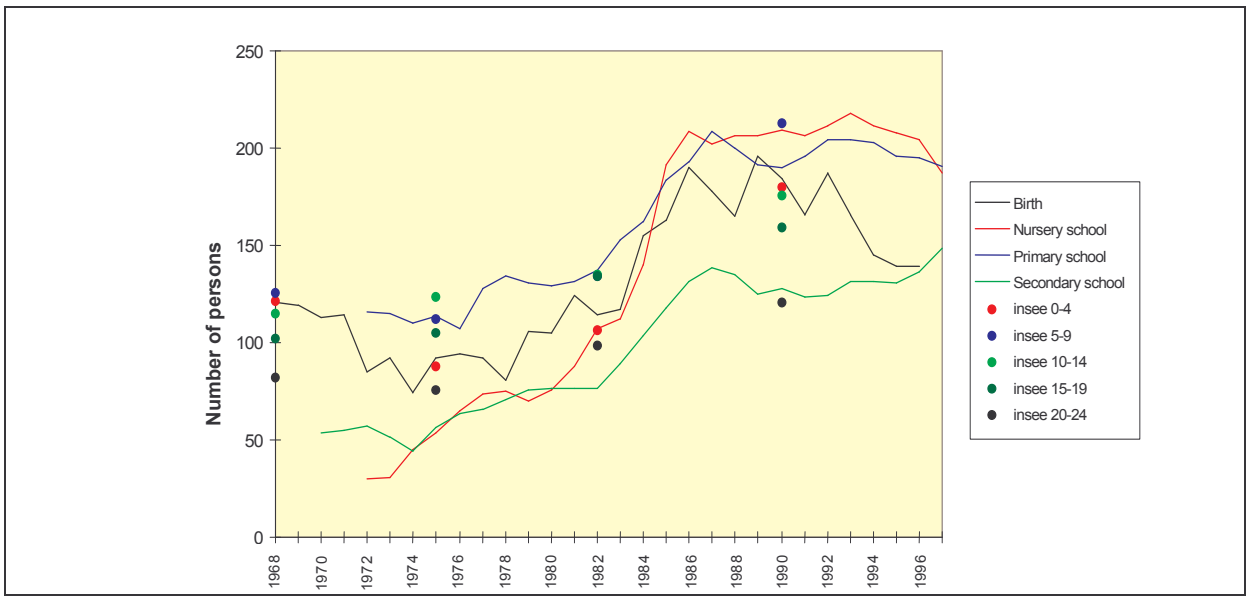


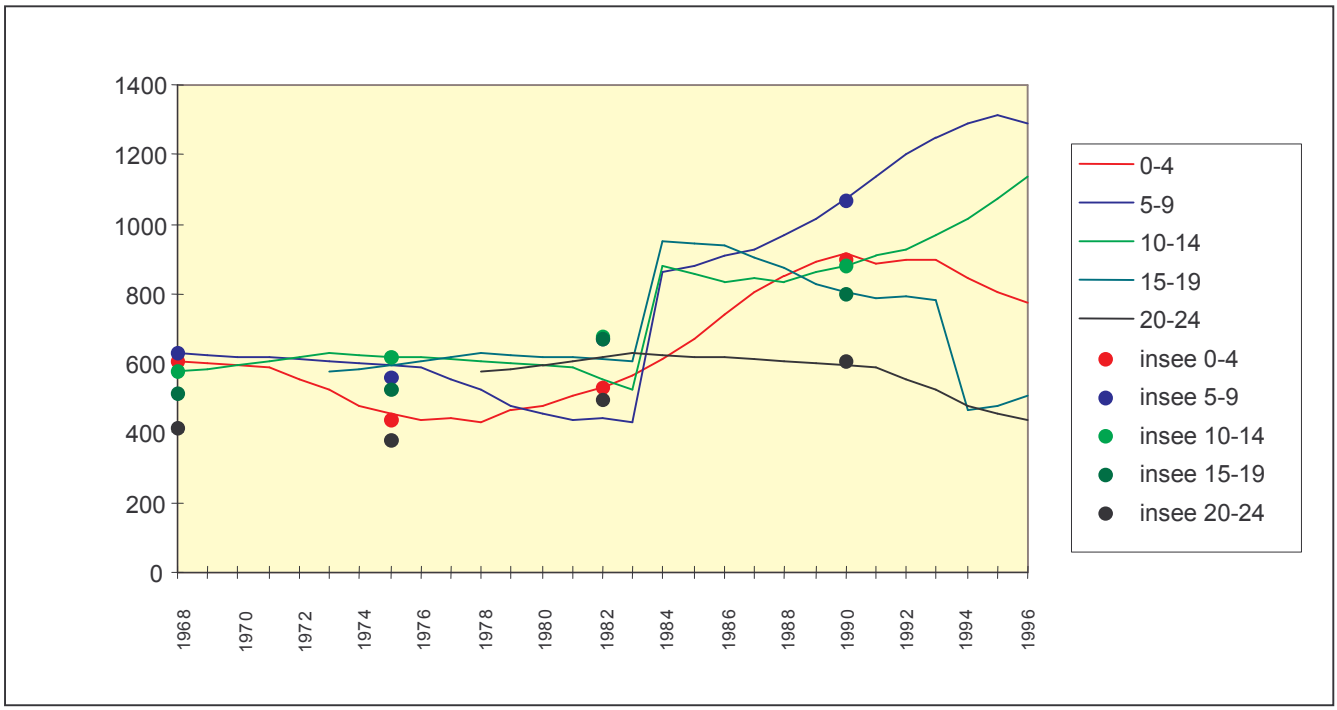
Figure 3.1.3.a: School attendance data in the Beaumont-Hague canton

This increase in the population is not reflected in the estimate of our study population, if the study is based on birth data only. Failure to take into account this influx would cause an underestimate of the population being studied, and therefore the collective dose and the risk that can be assigned to exposure to ionizing radiation. A correction is proposed to add individuals not born in the area and who arrived between 1983 and 1986. A fixed number of individuals will be added in each age group, this number being determined to give the best match with the number of individuals in the study population according to the 1990 census data. It is assumed that a sudden increase occurs in 1984[45], the proposed numbers are as follows:

- no new arrival between 0 and 4 year old,
- 400 new arrivals at the age of 5 years,
- 400 new arrivals at the age of 10 years,
- 350 new arrivals at the age of 15 years,
- no new arrivals within the 20-24 year old cohort.

The result of this correction is shown in figure 3.1.3.b for each age group. It shows good agreement between the numbers and the data derived from the 1990 census (represented by dots) for the five cohorts. This correction adds 1150 individuals to our study population. These individuals increase the total number of person-years present by 13900. The total number of person-years in our study population between 1978 and 1996 is 70661.

[45] This assumption was made to limit the number of calculations. However, the choice of the year 1984 undoubtedly slightly overestimates the doses and the risk, because the influx of new arrivals took place before the year in which releases from the reprocessing plant had the highest dosimetric impact (1985).



Note : The curves correspond to the number of individuals in the reconstructed cohorts. Dots correspond to data provided by INSEE censuses.

Figure 3.1.3.b: Number of individuals in the cohort by age group after correction for the influx of new arrivals in 1984

The influx of workers for the Major Construction site was temporary between 1982 and 1989. However, it was decided not to consider an output migration of individuals from the study population. Neither birth data nor school attendance data clearly indicate a reduction in numbers after 1989. Although there was a significant population departure after the end of the major construction site, it was probably offset by an increase in the population in some villages, and particularly in Urville-Nacqueville.

3.1.4. Including death due to all causes

The death rate due to all causes combined corresponding to each generation was applied to the cohort, in order to take into account the probability of death of an individual between 0 and 24 year old. Death rates were taken from WHO death statistics [WHO 1998] and were transformed so that they could be applicable longitudinally to each generation from 1954 to 1996. Death rates are highest for the early years of life (infant mortality) and for the oldest generations.
The impact of taking into account death due to all causes on the entire cohort is to reduce the total number of person-years by 1.9%. The numbers are summarized in table 3.1.4.A.

Table 3.1.4.A: Size of the reconstructed 0-24 year old cohort in the Beaumont-Hague canton between 1978 and 1996

	Individuals born in the canton *	"Major construction site" **	Total
Number of individuals	5506	1150	6656
Years of presence (person-years) between 1978 and 1996	56761	13900	70661
Person-years after including deaths	55437	13871	69308

* births in the 1954 to 1996 generations
** including new arrivals in 1984

Figure 3.1.4.a shows the size of the cohort reconstructed as a function of time. The reduction in numbers in 1994 is due to the fact that new 15-year-old arrivals in 1984 reached the age of 25 in 1994. The figure illustrates the large underestimate that would have been made by considering birth data only. Although this method was used in previous radioecological studies, it is obvious that failure to take into account an influx of new arrivals would have significantly underestimated the size of the cohort in the case of this study. The numbers agree fairly well with the actual numbers found in the 1990 census, although the number of individuals is still slightly underestimated compared with the 1982 census. The final size of the reconstructed cohort is 69308 person-years. The order of magnitude of this population appears to be realistic. Interpolation between censuses for the 0-24 year old cohort over the period from 1978 to 1996 gives a total number of 69702 person-years.

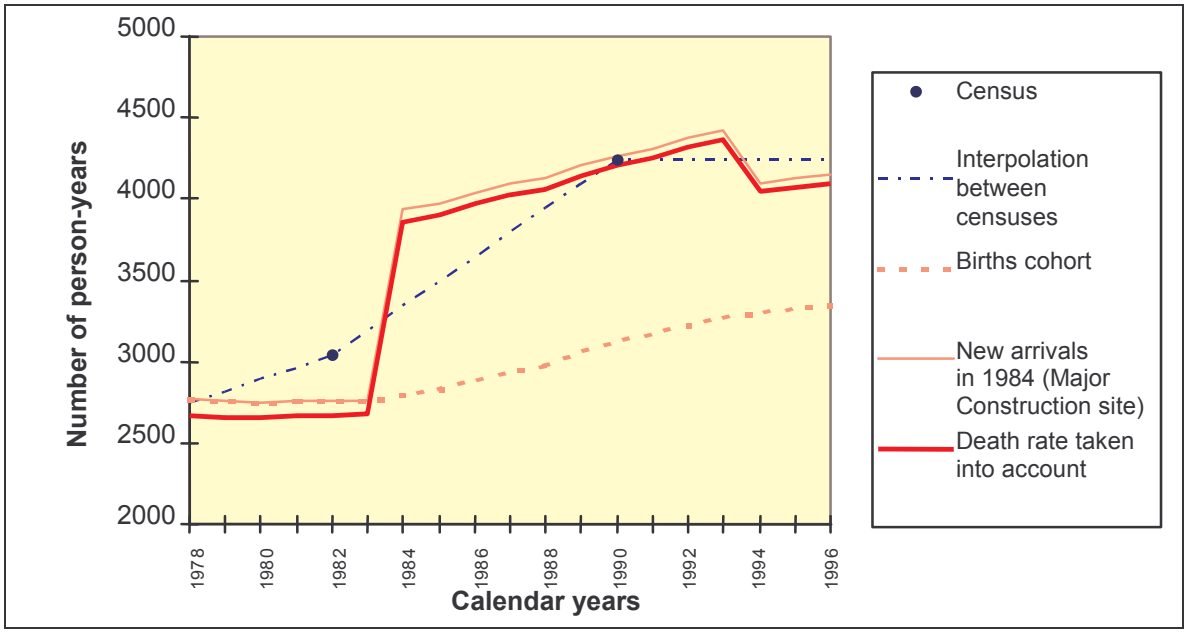


Figure 3.1.4.a: Total number in the cohort after correction for an influx of new arrivals in 1984 and taking into account the death rate

As can be seen in figure 3.1.1.a, the cohort is broken down into two windows: from 1954 to 1996 for the calculation of the dose from different sources of exposure, and from 1978 to 1996 for the calculation of the risk from doses received since birth (therefore for the period from 1954 to 1996). Table 3.1.4.B presents the number of person-years associated with each of these windows.

Table 3.1.4.B: Distribution of the number of person-years within the cohort for different periods

Period	Person-Years	Application
1954-96	103215	Calculation of the dose from all sources of exposure
1966-96	94296	Calculation of the dose from local nuclear facilities
1978-96	69308	Calculation of the radiation-induced risk

3.2. Modeling sources of exposure for the cohort

3.2.1. Exposure pathways due to Nord-Cotentin nuclear facilities

A list of exposure pathways sufficiently frequent to be considered as being realistic for the 0-24 year old cohort in the Beaumont-Hague canton was drawn up. Those used by GT4 for exposure of the cohort are as follows:

- External exposure:
  - by the plume,
  - by deposition on the ground,
  - by sand on the beaches,
  - by bathing in the sea.
- Internal exposure:
  - by inhalation of the plume,
  - by inhalation of resuspended deposits,
  - by inhalation of sea spray,
  - by ingestion of food from terrestrial and marine environments,
  - by accidental ingestion of sea water while bathing,
  - by accidental ingestion of soil,
  - by accidental ingestion of sand during time spent on the beach.

Food grown on land considered in the model of exposure by ingestion includes cereals, leaf vegetables (lettuce, spinach, etc.), root vegetables (potatoes, carrots, etc.), fruit vegetables (beans, tomatoes, apples, pears, etc.), jam, cider, cow's milk and various derived dairy products (cheese, butter, etc.), beef, mutton, pork, poultry, rabbits and eggs.

Seafood includes fish, crustaceans and molluscs. Since seaweed is not normally consumed in this region, it does not need to be considered as being realistic for the cohort; therefore it was not included in this study.

Land food can be contaminated by the plume and deposits related to atmospheric releases, but also by sea spray. Spreading of seaweed in gardens is an old practice but is still widespread since the study made by CREDOC for COGEMA shows that 7% of the population sampled in the Nord-Cotentin spreads seaweed in their garden (13% for retired individuals) [CREDOC 1998]. Therefore, this exposure method will be included and applied to 25% of the cohort[46].

Considering the low flow in contaminated rivers, and particularly in the Sainte-Hélène river, the use of water from rivers for irrigation of crops and vegetable gardens and for drinking water for animals was ignored for the cohort.

Seafood can be contaminated through liquid releases into the sea.

Fishing in local rivers (the Sainte-Hélène, Combes, Moulinets rivers, etc.) is rare and therefore cannot be considered as being realistic for the entire cohort. Similarly, bathing in these rivers is not realistic considering the low flows in them. Since water supply pipes were installed over the entire Beaumont-Hague canton in the 1950s, consumption of water from the rivers is very unlikely. Therefore, these exposure pathways are not considered for the cohort.

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[46] It is not easy to apply an exposure pathway to only part of the cohort using GT4 dosimetric calculation program. Therefore in practice, this exposure pathway was considered for the entire cohort, assuming that the amount of seaweed spread is equal to 25% of the selected value.

However, some exposure pathways not considered for the cohort may be considered for a small fraction of the population. Inhabitants of the canton have mentioned that children sometimes paddle at the mouth of the Sainte-Hélène river. Electrical fishing in local rivers have identified eel populations (Sainte-Hélène, Grand Bel, Rivière du Moulin, Linet, etc.) and trout populations (to a lesser extent and only in the Herquemoulin river). These exposure pathways will then be treated later within particular scenarios (section 4).

It should be noted that exposure pathways associated with individuals being present close to the La Hague site or in the Moulinets Bay during low tides in which the release pipe is emerged, will be considered later within the framework of particular scenarios (section 4).

In utero exposure is considered for the cohort. *In utero* exposure includes the main exposure pathways that could reach the fetus during its prenatal development[47], namely:

- external exposure of the fetus to the deposit, plume, outlet river or immersion in water,
- internal exposure due to inhalation or ingestion by the mother; transfers of radionuclides from the mother to the fetus take place through the placenta;
- external exposure of the fetus to radionuclides incorporated by the mother and deposited in maternal tissues.

These exposure pathways are modeled within the framework of normal operation of installations in the Nord-Cotentin, and also for incident/accidents listed by GT1 (except for *in utero* exposure).

3.2.2. Concentrations in the environment used for calculations of doses to the red bone marrow and risk of leukemia

The area considered in this study is much more extensive (19 villages) than the areas covered by English studies carried out in Thurso [Dionan 1986] and Seascale [Simmonds 1995], in which the areas considered are restricted to a single municipality. There was an ongoing discussion about the need to consider the geographic variation of exposure over the 19 villages. In order to avoid carrying out a large number of dose estimates on small areas and small populations, which would considerably increase calculation times without providing any particular benefit in an overall risk estimate, it was decided to use best estimates for contamination of the environment, the values of which were supplied by GT3.

For external exposure to the plume and inhalation of the plume and resuspended deposits, the average concentration in air in the Beaumont-Hague canton is the average of activities in air calculated in each of the 19 villages of the canton weighted by the number of inhabitants aged between 0 and 24 year old in each of these villages. An annual average concentration is calculated for each year of the study, and for each radionuclide.

For *external exposure to deposits on the ground*, the average concentration per unit area on the ground in the canton is calculated in the same way as above, for each year of the study and for each radionuclide.

For *exposure pathways related to sand on beaches* (external exposure, accidental ingestion), four main beaches were identified in the Beaumont-Hague canton (Vauville, Ecalgrain, Saint-Martin, Querqueville). A comparison made by GT3 between estimates produced by the models and the results of measurements made on these beaches shows that concentrations in marine sediments are relatively uniform over the entire canton (except in 1979-80 for the Moulinets Bay due to the pipe break). An annual average concentration per unit volume is used for the canton for each year and for each radionuclide, on the basis

[47] Radionuclide transfers from the mother to the child when nursing are not considered.

of the model recommended by GT3 to calculate the concentration of radionuclides per unit volume in the sediments (except for europium).

For exposure by inhalation of sea spray, the NRPB's TORIMA (Transfer Of Radionuclides through the Marine Aerosol) model was used to estimate the contribution of this type of exposure. This model is described in GT3's final detailed report. However, the TORIMA model is not applicable in all situations and particularly for calculating the activity of sea spray on the beach or at sea. Therefore, sea spray was included for exposure by ingestion of land products contaminated by sea spray deposits, but inhalation of sea spray is underestimated due to the lack of a model for inhalation of sea spray by an individual on the beach or at sea.

For exposure pathways related to sea water (bathing and accidental ingestion of water), the comparison between estimates produced by models and the results of measurements made on sea water at the shore shows that there is little difference between radionuclide concentrations in sea water in the various beaches in the canton. GT4 estimated the average concentration of radionuclides in sea water in the canton using the average dilution factors on each of these beaches, namely 0.53 $Bq.m^{-3}$ per TBq released per year for Querqueville and 0.76 $Bq.m^{-3}$ per TBq released per year for the other three beaches, which gives an average dilution factor for the cohort of 0.7 $Bq.m^{-3}$ per TBq released per year, in accordance with proposals made by GT3. The average annual concentration in sea water is calculated for each year of the study and for each radionuclide.

Concerning sea fish, an analysis of measurements made in the environment by GT2 cannot confirm whether or not there is an important difference in concentrations between different fish species, between the results of measurements on gutted fish or on consumable parts, and between different fishing areas in the Nord-Cotentin. Therefore, GT4 estimated concentration in fish based on the average concentration in fish in different fishing areas in the Nord-Cotentin (estimated by GT3 using an average dilution factor for the cohort equal to 0.7 $Bq.m^{-3}$ per TBq released per year). These fishing areas are distributed over the entire Nord-Cotentin coast, consequently the average concentration in fish consumed by inhabitants of the Beaumont-Hague canton can be determined using a model for the Nord-Cotentin region as a whole. The average annual concentration in fish is calculated for each year of the study and for each radionuclide.

In the case of molluscs, two categories were identified: filtering molluscs represented by the mussels and oysters, and gastropod molluscs represented by limpets. Laboratories participating in GT2 made fewer measurements in oysters than in mussels. Very few individuals eat limpets. Therefore, mussels were considered as being the mollusk that best represents this food category for the cohort. Even if it is possible that a small fraction of all mussels eaten are not farmed, most local mussels originate from the two closest mussel growing beds (Blainville and Barfleur) which are outside the Beaumont-Hague canton. The original location of mussels used by GT4 is the bed closest to the canton, namely Barfleur. The average annual concentration in molluscs is calculated for each year of the study and for each radionuclide based on recommendations made by GT3 for mussels and for Barfleur (dilution factor of 0.38 $Bq.m^{-3}$ per TBq released per year)[48].

For crustaceans, the analysis of measurements in the environment made by GT2 does not demonstrate any important differences in concentration between different species of crustaceans (edible crab, spider-crab), between the results of measurements on the whole

[48] P. Barbey and M. Sené believe that molluscs forming part of the food ration for the cohort could originate from shore areas of the Beaumont-Hague canton (scallops, abalones, etc.) and therefore that the dilution factor should be 0.76 $Bq.m^{-3}$ per TBq released per year. The majority of GT4 did not agree with this assumption since quantities of molluscs that could potentially be fished in the Beaumont-Hague canton are apparently too small to feed the entire cohort. Since there were about 4000 person in this cohort each year, about 5700 $kg.year^{-1}$ of mollusk flesh would be necessary just to feed 0-24 year old individuals living in the Beaumont-Hague canton, considering the self-consumption ratio of molluscs (75% - see Table 3.3.2.D).

animal and on the flesh only, and between different fishing areas distributed along the entire Nord-Cotentin coast. Consumption of local crustaceans is based essentially on coastal fishing, fishing areas considered for this study being areas located offshore the Beaumont-Hague canton only. The average annual concentration in crustaceans is calculated for each year in the study period and for each radionuclide (using an average dilution factor for the cohort equal to 0.7 $Bq.m^{-3}$ per TBq released per year).

In the case of *terrestrial food*, the deposit for *cultivated products* is calculated in the same way as for external exposure to the deposit (average of deposits in each village weighted by the population of individuals between 0 and 24 year old). This deposit is homogenized by ploughing and can be used to estimate the average concentration in the ground. The concentration added by sea spray and by spreading seaweed needs to be added to this concentration. For spread seaweed, the activity contained in the seaweed is considered to be transferred entirely to the soil. This conservative assumption is used because there is no more precise model. It at least partly explains the relative importance of this transfer pathway for some radionuclides (for example ^{99}Tc - see section 4.1.2.). For animal products and animal derivatives, the weighting uses the total animal fodder area in each village, rather than the population. After homogenization by ploughing, the average concentration in soils, then in the fodder used to feed animals, and finally in animal products or animal derivatives, can be determined using this deposit. The average annual concentration in land food is calculated for each year in the study period and for each radionuclide. Modifications of the activities per unit weight of food due to preparation (peeling, cooking, etc.) are ignored.
GT3 provides all concentrations in the environment in the form of an average annual value estimated by modeling and possibly a correction factor derived from the comparison between the model and local measurements to be applied to this average. The use of these synthetic indicators gives a best estimate of the dose within the cohort. This same method had been used in previous studies carried out by the NRPB, including in the radioecological study around the Aldermaston and Burghfield sites which covered a very wide area (with a radius of up to 20 km) [Dionan 1987]. Elements concerning the impact of geographic variations of exposure levels on the dose estimate are presented in section 4 (dose calculated for the Huquets fishing area or in the hamlet of Pont-Durand).

3.2.3. Modeling of accidents/incidents

The three most significant accidents/incidents identified by GT1 were studied in terms of dosimetric impact. These were releases of ^{3}H in 1976 into the Sainte-Hélène river and into the atmosphere from the CM, the rupture of COGEMA La Hague reprocessing plants release pipe in 1979-1980 and the fire in an irradiated graphite liners storage silo at COGEMA La Hague reprocessing plants in 1981.

- Releases of ^{3}H from the CM

  - Releases of tritium into Sainte-Hélène river in 1976.

During an inspection operation, the French Central Protection against Ionizing Radiation Service (SCPRI) identified abnormal tritium contents in the water in Sainte-Hélène river in the vicinity of the CM disposal facility, managed at the time by the INFRATOME company. A sampling campaign was then carried out by the La Hague Radiation Shielding Service, on the site and in the environment. This campaign identified the cause of this release, which was concrete trench TB2 in which tritiated waste had been disposed.

This incident was not considered in the study of the 0 to 24 year old cohort since GT4 considered that exposure pathways associated with the Sainte-Hélène river (consumption of river water, irrigation of crops, drinking for animals, fishing in the river) were rare, and therefore unlikely over the scale of the entire cohort. However, this incident is treated later in the particular "Sainte-Hélène farmers" and "Sainte-Hélène fishermen" scenarios (see section 4) for which the effective dose associated with exposure pathways concerning the

Sainte-Hélène river in 1979 was estimated. These particular scenarios necessarily lead to a dosimetric impact higher than what could have been assessed in 1976 since the average activity per unit volume of the water in the Sainte-Hélène river for the month of October 1976 (7400 $Bq.l^{-1}$) was less than the average value measured at Pont-Durand in 1979. The maximum value of tritium in 1979 in the water in the Sainte-Hélène is a direct consequence of the 1976 tritium incident since this incident was the cause of "chronic" tritium contamination of the water in Sainte-Hélène river (see GT1 report).

- Tritium releases into the atmosphere

The operation to retrieve tritiated waste in trench TB2 caused atmospheric releases of tritium between December 1977 and March 1978, with the estimated total activity of 32 TBq. For comparison, releases of tritium into the atmosphere from COGEMA La Hague reprocessing plants were 2.3 TBq in 1977 and 4.4. TBq in 1978. The dosimetric impact of these releases was estimated on the basis of the model recommended by GT3 for the transfer of tritium through the terrestrial environment. Initially, GT4 carried out a calculation of the effective dose to estimate the order of magnitude of the impact of this event to deduce whether or not there was any need for a precise analysis as a function of the dose level, for the cohort.

The effective dose was calculated for a group of inhabitants living in the direction of the prevailing winds and therefore likely to be most significantly exposed to tritiated releases into the atmosphere. Tritium was released at a height of 10 m. The most highly exposed inhabited location, according to atmospheric dispersion calculations based on the methods used by GT3, is the "Es Clerges" hamlet. Therefore, the dose was calculated for a group of inhabitants living in this hamlet throughout the release period (four months from December 1977 to March 1978), and consuming land food products cultivated locally. The dose-relevant habit (dietary habit, breathing rate, etc.) used for these individuals is the same as the average dose-relevant habit adopted for adults in the cohort (see section 3.3.1). The effective dose is 6 µSv for an adult. The effective dose for children is of the same order of magnitude. Therefore, the dosimetric impact associated with tritium releases into the atmosphere is very low. Furthermore, only a small fraction of the cohort could be exposed at the level evaluated in this way (inhabitants in the line of the prevailing winds). The exposure level is lower for the rest of the cohort. In the light of these considerations, GT4 decided to neglect the dosimetric impact of these releases on the cohort.

- Break in COGEMA release pipe

Shore samples taken during the month of December 1979 detected a break in the release pipe from COGEMA La Hague reprocessing plants. This break had consequences on the dispersion of radionuclides and produced an increase in radioactivity in marine species in the environment close to the location of the break (the Moulinets Bay). COGEMA carried out an analysis of this event in COGEMA technical note "La Hague plant impact study. Summary note". GT4 wanted to make its own analysis of the event after having seen the results of measurements supplied by GT2. The results collected by GT2 and their analysis by GT3 demonstrated that the consequences of the break are restricted to the immediate vicinity of the Moulinets Bay. Based on available measurements for some radionuclides and for some marine species, GT3 proposed a method of reconstructing activities throughout the entire marine environment (see GT3 report).

Initially, this method was applied to estimate effective doses received for two groups of individuals; the average population (adults and children) and fishermen who consume more seafood than the average population. Then, the way in which this accident was taken into account in determining doses and the risk for the cohort was considered.

It is assumed that the dietary habits, values of self-consumption ratios of seafood, times spent and all individual characteristics for the average population are equal to average values for the cohort, and that the corresponding values for sea fishermen are equal to

values used for particular scenarios for fishermen (see section 4). The average population and fishermen are assumed to consume local sea products only from the Moulinets Bay, although the intense media coverage of this event resulted in lower consumption of products from this sector.
According to GT2, the influence of the pipe break on the results of the activity measurement in the marine environment can be measured during the last quarter of 1979, and for the entire year 1980. Therefore, effective doses associated with this event correspond to a calculation for 1/3 of the year for 1979 (therefore 1/3 of the food intake), and for the entire year 1980.
Theoretical effective doses for an average adult and a fishermen whose entire seafood ration is derived from the Moulinets Bay are 86 µSv in 1979 (September to December) and 267 µSv in 1980, and 212 µSv in 1979 and 662 µSv in 1980 respectively. The effective dose for children is of the same order of magnitude.

GT4 attempted to determine the number of individuals in the cohort that could have been affected by radiological consequences associated with the pipe break in order to quantify the consequences of the break in terms of risk for the cohort. This evaluation was very difficult since GT4 could not find any information about seafood tonnages caught in the Moulinets Bay in 1979 and 1980. The assumption that was adopted is based on the quantification of linear measurements on the shore that were affected by releases. According to the analysis of activity measurements made in the environment by GT2, the geographic area (figure 3.2.3.a) affected extends as far as Herquemoulin (in the South-East) and Ecalgrain (in the North-West). Under these conditions, and with reference to an IGN (National Geographic Institute) map, it was found that 24% of the coastal facade of the Beaumont-Hague canton was affected by COGEMA release pipe break. Since contamination was probably not uniform over the entire sector concerned, a marine environment concentration reduction factor equal to 2 with respect to Moulinets Bay was used.

The dosimetric impact of the pipe break on the cohort is presented in section 3.4.2. The risk increment is presented in section 3.5.3.

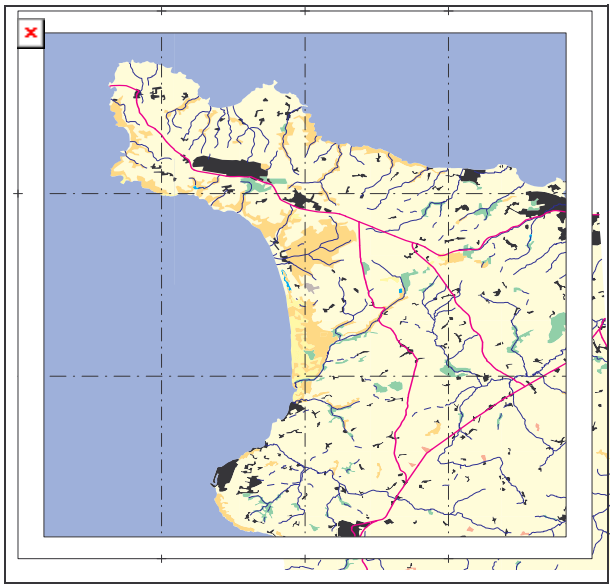

Figure 3.2.3.a: Map of the area affected by the pipe break

- Fire at COGEMA silo

On January 6 1981, combustion caused by uranium and magnesium in the irradiated graphite liners storage silo at COGEMA La Hague reprocessing plants resulted in radionuclide releases into the atmosphere. COGEMA carried out an analysis of this event in COGEMA technical note "Impact study for the La Hague establishment. Summary note". GT4 wanted to make its own analysis of the event having seen the results supplied by GT2.

In particular, some measurement results (see GT2 report) show that ^{137}Cs was not the only radionuclide released during this fire. GT1 reconstructed the source-term, at the same time as the measurement results were being analyzed (see GT1 report). Based on this source term, an IPSN program for the calculation of the radiological consequences of accidental releases through the atmosphere (ACCI38) [Thomassin 1999] was used to estimate activities in the terrestrial environment and to compare them with measurement results in order to make the estimate of doses to the local population.

Initially, the calculations applied to a group of population that was apparently the most exposed, since they were in the direction of the prevailing winds on the day of the fire. In particular, this initial calculation made it possible to compare model predictions with the results of measurements in the environment collected by GT2. Secondly, after checking the model adjustment, the possibility of taking into account the dosimetric impact of the fire on the entire cohort was studied.
It was possible to compare estimates made by ACCI38 calculation program and measurement results for grass and milk since GT2 has measurements for these two compartments of the environment. The comparison applied mainly to ^{137}Cs and ^{134}Cs due to the available measurement results. Some measurements of ^{90}Sr, ^{106}Ru and $^{239+240}Pu$ were also used. Calculations of environmental activities and doses carried out by ACCI38 are limited to one year (1981) since according to GT2; "the fire in the silo […] caused marking of the grass […] that was eliminated by the end of 1981" and "[…] concentrations in milk returned to levels close to their values before the fire by the end of 1981". Calculations were carried out at 1500 m from the release point, in the direction of the prevailing winds on the day of the fire. Tables 3.2.3.A and 3.2.3.B contain the main points in the comparison between the model and measurements.

Table 3.2.3.A: Comparison of measurement results in grass with ACCI38 estimates

LOCATION	ORIGIN	RADIONUCLIDE	MEASUREMENT		CALCULATION (LOW ASSUMPTION)	
			DATE	VALUE	DATE	VALUE
Herqueville	OPRI	^{137}Cs	January 7	$1.07\ 10^{4}$ ($Bq.kg^{-1}$)	January 7	$7.44\ 10^{3}$ ($Bq.kg^{-1}$)
		^{134}Cs	January 7	$1.59\ 10^{3}$ ($Bq.kg^{-1}$)	January 7	$1.14\ 10^{3}$ ($Bq.kg^{-1}$)
		$^{239}Pu + ^{240}Pu$	January 7	$1.10\ 10^{1}$ ($Bq.kg^{-1}$)	January 7	1.39 ($Bq.kg^{-1}$)
A_8	COGEMA	^{137}Cs	January 12	$3.83\ 10^{3}$ ($Bq.m^{-2}$)	January 12	$9.66\ 10^{3}$ ($Bq.m^{-2}$)
		^{134}Cs	January 12	$3.85\ 10^{2}$ ($Bq.m^{-2}$)	January 12	$1.47\ 10^{3}$ ($Bq.m^{-2}$)
		^{106}Ru	January 12	$1.00\ 10^{3}$ ($Bq.m^{-2}$)	January 12	$4.10\ 10^{3}$ ($Bq.m^{-2}$)
A_8	COGEMA	^{137}Cs	April 28	$2.07\ 10^{2}$ ($Bq.m^{-2}$)	April 28	$4.50\ 10^{2}$ ($Bq.m^{-2}$)
		^{134}Cs	April 28	$2.07\ 10^{1}$ ($Bq.m^{-2}$)	April 28	$6.26\ 10^{1}$ ($Bq.m^{-2}$)
		^{106}Ru	April 28	$1.52\ 10^{2}$ ($Bq.m^{-2}$)	April 28	$1.77\ 10^{1}$ ($Bq.m^{-2}$)
A_8	COGEMA	^{137}Cs	August 10	6.66 ($Bq.m^{-2}$)	August 10	$2.67\ 10^{1}$ ($Bq.m^{-2}$)
A_8	COGEMA	^{137}Cs	November 24	$2.61\ 10^{1}$ ($Bq.m^{-2}$)	November 24	5.51 ($Bq.m^{-2}$)
		^{134}Cs	November 24	1.9 ($Bq.m^{-2}$)	November 24	$6.39\ 10^{-1}$ ($Bq.m^{-2}$)

Table 3.2.3.B: Comparison of measurement results in milk with ACCI38 estimates

LOCATION	ORIGIN	RN	MEASUREMENT ($Bq.L^{-1}$)		CALCULATION (LOW ASSUMPTION), ($Bq.L^{-1}$)	
			DATE	VALUE	DATE	VALUE
Company 2454	COGEMA	^{137}Cs	January 12	$8.41\ 10^{2}$	January 12	$1.93\ 10^{3}$
		^{134}Cs	January 12	$1.01\ 10^{2}$	January 12	$2.93\ 10^{2}$
		^{90}Sr	January 12	6.2	January 12	$2.03\ 10^{1}$
	COGEMA	^{137}Cs	February 1	$3.31\ 10^{1}$	February 1	$1.08\ 10^{3}$
		^{134}Cs	February 1	3.3	February 1	$1.62\ 10^{2}$
	COGEMA	^{137}Cs	March 1	$1.17\ 10^{1}$	March 1	$4.83\ 10^{2}$
		^{134}Cs	March 1	1.2	March 1	$7.02\ 10^{1}$
	COGEMA	^{137}Cs	April 28	6.7	April 28	$9.00\ 10^{1}$
		^{134}Cs	April 28	< 0.9	April 28	$1.25\ 10^{1}$

For grass (table 3.2.3.A), there is good agreement between the calculated deposit and measurements in grass immediately after the fire (January 7) for cesium isotopes (^{137}Cs and ^{134}Cs). The calculation is 30% lower than the measurement immediately after the deposit, whereas it is higher by a factor of 3 to 4 until August, and then drops by a factor of 3 to 5 in November. For $^{239+240}Pu$, the calculated deposit of plutonium is about 10 times less than the measurement. There are no measurement results for other radionuclides in the source-term defined by GT1. Therefore, available measurements do not invalidate ACCI38 estimates in terms of deposits and therefore the dose received by external exposure to the deposit.

There are no measurement results in air at the time of the passage of the plume due to atmospheric releases associated with the fire. The good agreement demonstrated in the previous section between the deposit and cesium measurements indicates that GT1's estimate of ^{137}Cs, and to a lesser extent of $^{239+240}Pu$, in the source-term is not implausible. The source-term given by GT1 is not reconsidered, and GT4 used doses by inhalation and external exposure to the plume given by ACCI38.

For milk (table 3.2.3.B), ACCI38 estimates for January 12 are a factor of 2 to 3 greater than the measurement results for ^{137}Cs, ^{134}Cs and ^{90}Sr. For February 1 and March 1, the factor is about 30 to 40 and is about 15 for April 28, for cesium isotopes only (no measurement of ^{90}Sr available at these dates). Therefore, the model gives higher estimates than measurement results in milk. However, measurement results do not cover all food in the food ration, consequently GT4 decided to use ACCI38 estimates by default to carry out dose calculations.

Although the comparison between the model and measurements is extremely limited, by default GT4 decided to use estimates made by ACCI38 model as an order of magnitude of doses to nearby inhabitants most exposed to the dosimetric consequences of the silo fire. The dosimetric results (effective doses) due to the silo fire are as follows for populations at 1500 m:

- 3.42 mSv for an adult,
- 2.68 mSv for a 12-year-old child,
- 2.15 mSv for a 1-year-old child.

Doses calculated on the basis of ACCI38 model may be compared with the results of a previous study carried out by COGEMA and sent to the Radioecology Group within the framework of the Souleau Commission [Beutier 1997]. In this previous analysis of the dosimetric consequences of the silo fire, the effective dose was estimated for a 1-year-old child based on the results of average monthly ^{137}Cs measurements in milk. It was assumed that this 1-year-old child consumed only milk originating from the area in which milk concentrations were highest. The effective dose for 1981 due to ingestion of ^{137}Cs in milk is estimated at 100 µSv in this study. This dose level is about a factor of 10 less than the dose

level estimated based on ACCI38 model for a 1-year-old child, and the ingestion exposure pathway. Failure to take into account radionuclides other than ^{137}Cs in COGEMA analysis is not sufficient to explain the difference between the two calculations since ^{137}Cs contributes about 3/4 of the total ingestion dose calculated by ACCI38. The dietary habit of the 1-year-old child, and the ingestion dose coefficient for ^{137}Cs are identical in the two calculations. The difference between the operator's evaluations and evaluations made with ACCI38 are due to the fact that ACCI38 evaluation includes a theoretical estimate of the concentration of radionuclides at 1500 m without considering whether or not cows were present at this location at the time of the fire, whereas the operator's evaluation is based on levels measured in milk; the atmospheric transfer coefficient (CTA) in pasture land is not the theoretical ATC calculated by ACCI38.

However, even if this comparison between the two calculations shows that ACCI38 calculatory for the exposure pathway, the radionuclide and the cohort considered, are overestimates, this conclusion cannot be extended to all calculations carried out based on ACCI38. For adults, the contribution of ^{137}Cs to the total dose is also about 75%, but only 1/5 of the dose due to ^{137}Cs originates from the ingestion of milk. In conclusion, even if ACCI38 model probably overestimates transfers of ^{137}Cs through milk, the use of this model is the only means available for GT4 to obtain a complete evaluation of the dose (to take into account all radionuclides in the source term, modeling of all transfer and exposure pathways, possibility of carrying out calculations at difference distances from the release location) and applying it to the cohort study.

Despite limits to the use of ACCI38, after seeing the exposure levels, GT4 decided that it is worthwhile quantifying the influence of the fire on the entire 0 to 24-year-old cohort in the Beaumont-Hague canton, in terms of doses to the red bone marrow and the risk of leukemia. Therefore, it is firstly necessary to quantify the fraction of the cohort affected by the consequences of the fire. Considering the weather on the day of the fire and the results of measurements in the environment, populations concerned by the fire are mainly individuals located to the South-East of the site (figure 3.2.3.b), namely essentially inhabitants of the Herqueville, Beaumont-Hague, Vauville and Biville villages located at 2 km, 3.5 km, 6 km and 9.5 km respectively from the release point. In order to simplify the calculations, GT4 considered that other villages in the Beaumont-Hague canton were sufficiently remote from the release point or from the centerline of the prevailing winds so that their contribution to the collective dose and the risk of leukemia for the cohort could be neglected. Not all inhabitants of the four villages considered are necessarily concerned by the consequences of the fire. After seeing the map in figure 3.2.3.b, GT4 selected the following approximations:

- 100% of 0 to 24 year old persons in the Herqueville village, namely 20 individuals,
- 50% of 0 to 24 year old persons in the Beaumont-Hague village, namely 321 individuals,
- 100% of 0 to 24 year old persons in the Vauville village, namely 132 individuals,
- 100% of 0 to 24 year old persons in the Biville village, namely 108 individuals.

Figure 3.2.3.b: Map of the area under the prevailing winds at the time of releases associated with the silo fire (January 6 1981)

These assumptions mean that about 20% of the cohort was concerned by fallout from the fire. However, not all these individuals are concerned by the same exposure levels since releases were diluted and concentrations in air during passage of the plume and deposits on the ground decrease as a function of the distance from the release point and as a function of the distance from the centerline of the prevailing winds. The decay effect as a function of the distance was taken into account directly in ACCI38 calculation program since dose calculations were made for distances of 2 km, 3.5 km, 6 km and 9.5 km. In order to take into account decay due to distance from the centerline of the prevailing winds, a correction was made for each of the four calculations. The distribution of concentrations in air and deposits on the ground at the same distance from the release point depends on the distance from the centerline of the plume. This function follows a Gaussian law. Since ACCI38 calculation is carried out along the centerline of the plume, the correction factor introduced is designed to correct results from the maximum Gaussian value (on the centerline of the plume) to the average value. The correction factor is equal to 0.42 (which corresponds to 3 standard deviations from the Gaussian value).

After taking into account this correction to ACCI38 calculation code, doses by external exposure to the red bone marrow have been calculated directly by the calculation code. For internal exposure, annual intakes by ingestion and inhalation have been extracted from ACCI38 and included in GT4 dose calculation program in order to estimate annual doses to the red bone marrow. These calculations were carried out based on ACCI38 for the 1-year, 12-year and adult age groups. GT4 treated the 5-year-old, 10-year-old and 15-year-old cohorts in the same way as ACCI38 12-year-old cohort in order to adapt these results to the cohort.

The dosimetric impact of the silo fire on the cohort calculated by this method, which remains very approximate, is given in section 3.4.2. The risk increment is described in section 3.5.3.

3.2.4. Modeling of other sources of exposure

- Medical exposure

Medical exposure is treated directly as a dose in section 3.4.2.

- Artificial exposure due to fallout from the Chernobyl accident and atmospheric testing of nuclear weapons

For concentrations in the various compartments of the environment originating from nuclear activities outside Nord-Cotentin facilities (fallout from the Chernobyl accident, atmospheric testing of nuclear weapons), concentrations in the environment used in this study were calculated from a model developed by the UNSCEAR and adapted to the deposits that occurred in France [UNSCEAR 1982][UNSCEAR 1988].

- Natural exposures

The estimate used for *the concentration of radon in dwellings* is the arithmetic mean of measurements made by the IPSN in the Nord-Cotentin as part of national radon campaigns (Pirard *et al* in Métivier and Robé 1998]. This value is considered to be stable throughout the study period.

Exposure to cosmic and terrestrial radiation is dealt with directly as a dose in section 3.4.2.

Concerning *intake of natural radionuclides*, concentrations of natural radionuclides in the environment originate from an analysis of values available in the literature, except for ^{210}Po for which GT2 collected and analyzed measurements results. Therefore the concentrations used are average values for France or the world, based on existing data except for ^{210}Po for which the measurement results were obtained from the Nord-Cotentin.

3.3. Definition of "representative" parameters for the cohort

Dose calculations envisaged by GT4 are based on exposure pathways which are modeled using different types of parameters.

Some *GT4 modeling parameters* are not directly applicable to the population but are influenced by the population dose-relevant habit:

- protection factors associated with the habitat for external exposure to the plume or to the deposit,
- deposits on the ground put back into suspension for internal exposure by inhalation.

Habit parameters characterize population habit:

- times spent for external exposure,
- dietary habits, self-consumption ratios and accidental ingestion rates for internal exposure by ingestion,
- respiratory rates for internal exposure by inhalation.

Values were selected for each group of parameters listed above for the 81 radionuclides (see table 3.3.A), the five age groups[49] and the different exposure pathways considered by GT4. The selected values were defined for the cohort of individuals between 0 and 24 year old, and are not systematically applicable for particular scenarios.

Table 3.3.A: List of radionuclides studied for the cohort

^{3}H	^{93}Mo	^{127m}Te	^{236}U
^{10}Be	^{99}Tc	^{127}Te	^{238}U
^{14}C	^{93}Zr	^{129}I	^{237}Np
^{36}Cl	^{95}Zr	^{131}I	^{236}Pu
^{41}Ca	^{94}Nb	^{133}I	^{238}Pu
^{54}Mn	^{95}Nb	^{134}Cs	^{239}Pu
^{55}Fe	^{103}Ru	^{135}Cs	^{240}Pu
^{57}Co	^{106}Ru	^{137}Cs	^{241}Pu
^{58}Co	^{103m}Rh	^{137m}Ba	^{242}Pu
^{60}Co	^{106}Rh	^{144}Ce	^{241}Am
^{59}Ni	^{107}Pd	^{144}Pr	^{242}Am
^{63}Ni	^{110m}Ag	^{147}Pm	^{242m}Am
^{65}Zn	^{113m}Cd	^{151}Sm	^{243}Am
^{75}Se	^{124}Sb	^{152}Eu	^{242}Cm
^{79}Se	^{125}Sb	^{154}Eu	^{243}Cm
^{85}Kr	^{126}Sb	^{155}Eu	^{244}Cm
^{87}Rb	^{126m}Sb	^{203}Hg	^{245}Cm
^{89}Sr	^{121m}Sn	^{232}U	^{246}Cm
^{90}Sr	^{121}Sn	^{233}U	
^{90}Y	^{126}Sn	^{234}U	
^{91}Y	^{125m}Te	^{235}U	

3.3.1. Model parameters

- Resuspension rate

This parameter is located at the interface of work done by GT3 and GT4 since it is used for transfers of radionuclides through the biosphere at the ground/air interface (GT3 work) and for internal exposure by inhalation (GT4 work). The value of this parameter was discussed within GT3 and validated by GT4. The range of values proposed in the literature for resuspension is extremely wide (10^{-3} to 10^{-13} m^{-1}). The value used by GT4 for the resuspension factor is 10^{-8} m^{-1}, which corresponds to the value recommended by [Besnus and Peres 1994] and [CCE 1996] for the general environment.

- Protection factor

Two protection factors are used in GT4 calculations. One is associated with protection from external exposure to the plume[50] and the second is associated with protection from external

[49] The five age groups are "1-year-old" (individuals from 0 to 2 year old)
"5-year-old" (individuals from 3 to 7 year old)
"10-year-old" (individuals from 8 to 12 year old)
"15-year-old" (individuals from 13 to 17 year old)
and "adults" (individuals from 18 to 24 year old)

[50] The shielding protection factor from the plume is ignored for pure β emitters such as ^{85}Kr, since the contribution of these emitters to far radiation dose that could potentially be stopped by residences is negligible.

exposure to the deposit. These factors can take into account protection provided by the habitat to an individual within the habitat (ratio of the dose when the person is located indoors and the dose when the person is located outdoors). Therefore, in the model, these parameters are related to the time spent indoors. Values used by GT4 are national averages [Rommens 1998]:

- 0.15 for external exposure to the plume,
- 0.05 for external exposure to the deposit.

3.3.2. Habit parameters

- Dietary habits

For the dietary habit, the question arose about whether there had been a significant variation of the dietary habit during the study period (1954-1996). In order to answer this question, GT4 compared food consumptions by the rural agricultural population in 1967 and in 1991, using the INSEE data base [Nguyen Huu 1969] [Bertrand 1993]. This comparison showed that consumption had not changed very much for most food categories considered within the study.

Following this comparison, GT4 decided to ignore the variation of dietary habits in time, and to use an average dietary habit for the study period. This choice is similar to choices made by the NRPB for British studies for which habits were considered as being invariable in time (even if some studies considered periods longer than 40 years [Simmonds 1995]).

The dietary habit determined during the dietary survey carried out for EDF in 1978 around the Flamanville site best satisfies the needs of GT4 [Mathieu and Mathieu 1978] since it is based on a local survey carried out approximately in the middle of the study period (1954-1996). Consumptions of the various food categories determined from the survey are presented in table 3.3.2.A. Values of the survey around the Flamanville site are consistent with values derived from the INSEE. The higher consumption of seafood in the Flamanville region is related to the maritime location of the region. The higher consumption of root vegetables is probably a local feature.

Table 3.3.2.A: Results of the dietary survey carried out in the Flamanville region

Food category	Flamanville survey ($kg.year^{-1}$)
Cereals[51]	123
Milk	122
Dairy products[52]	33
Potatoes	74
Root vegetables	57
Fruit vegetables[53]	73
Leaf vegetables	24
Meat[54]	76
Eggs	12
Fish	23
Shellfish	20
Cider	38

In addition to the food proposed in the dietary habit in table 3.3.2.B, the reference [Mathieu and Mathieu 1978] mentions a large local consumption of jam. This point was confirmed by discussions between some members of GT4 and inhabitants of the Beaumont-Hague canton. Based on this information, jam was added to the list of foods considered. The average jam dietary habit for adults was two teaspoons per day, or 10 g per day, or 4 kg per year.

Meat in the dietary habit proposed for the Flamanville region is broken down according to the various meat categories usually used to determine the dosimetric impact (beef, pork, mutton, poultry). In order to distinguish between the various meat categories, meat in the dietary habit determined in the survey around Flamanville was distributed into the different meat categories using ratios estimated from INSEE dietary habits. These ratios were not different in 1967 and in 1991. The following distribution is used:

- 28% beef,
- 2% mutton,
- 40% pork,
- 30% poultry and rabbit.

The mollusc and crustaceans dietary habit was broken down assuming 1/3 for molluscs and 2/3 for crustaceans. These ratios are equal to the ratios observed in the CREDOC dietary survey for COGEMA [Dufour 1998].

Root vegetables and potatoes in the dietary habit were combined under the term root vegetables since the same model for radionuclide transfers is used for these two food categories.

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[51] Cereals in the dietary habit is equal to the sum of the "starch" and "rice" categories in the study [Mathieu and Mathieu 1978].

[52] Dairy products in the dietary habit is equal to the sum of the “cheese-yogurt” and “ butter-cream” categories in the study [Mathieu and Mathieu 1978].

[53] Fruit vegetables in the dietary habit is equal to the sum of the “fruit” and “fresh vegetables-fruit” categories in the study [Mathieu and Mathieu 1978].

[54] Meat in the dietary habit is equal to the sum of the “meat” and “pork butchery” categories in the study [Mathieu and Mathieu 1978].

Individuals in this cohort are assumed to consume water not contaminated by releases from Nord-Cotentin nuclear facilities. However, GT4 chose to define a water consumption so that it would be able to carry out calculations of natural exposures that require this value. According to the survey carried out by the CREDOC [Dufour 1998], the consumption of drinking water for the entire population covered by the survey is about 1 $l.day^{-1}$ (this value is equal to the sum of consumptions of cold drinks, hot drinks, tap water and mineral water). This value is lower than the value usually given in the literature which is 1.5 $l.day^{-1}$ for an adult [Métivier and Roy 1997]. However, the local value was preferred to the bibliographic reference. The proportion of mineral water is about 0.25 $l.day^{-1}$ [Dufour 1998].

Finally, the average consumption by an adult during the study period selected by GT4 to carry out dose calculations is shown in table 3.3.2.B.

Table 3.3.2.B: Dietary habit of an adult in the cohort

Food category	Dietary habit of an adult in the cohort ($kg.year^{-1}$ or $l.year^{-1}$)
Drinking water	365
Cereals	123
Root vegetables	131
Fruit vegetables	73
Leaf vegetables	24
Jam	4
Cider	38
Beef	21
Mutton	2
Pork	30
Poultry and rabbit	23
Eggs	12
Milk	122
Dairy products	33
Seafood	23
Molluscs	7
Crustaceans	13

However, this dietary habit should be varied as a function of the various age groups in the study "1 year", "5 years", "10 years", "15 years" and "adult". Due to the lack of knowledge of French dietary habits for these different age groups, GT4 based its work on the corresponding English dietary habits [Garrow et al 1989] [Mills and Tyler 1992]. The English surveys provide dietary habits for 6 month-1 year old, 10-11 year old, 15-16 year old and adults. Milk consumption by 3-month-old babies (0 to 6 months) is derived from [Robinson 1996]. Based on these data, the ratios between English dietary habits for the various age groups compared with adults were calculated. These ratios were compared with ranges of values derived from a group of dietary surveys across the CCE [Van de Ven-Breken *et al* 1990]. It is impossible to draw any precise conclusions from this comparison since the uncertainty around these ratios is high. Ratios derived from the English surveys are the most precise available data in terms of age group, and food categories considered. Therefore, GT4 chose to apply them to the adult dietary habit in the Beaumont-Hague canton to estimate dietary habits of children and young adults. Table 3.3.2.C shows the food rations that were used subsequently for all age groups.

Table 3.3.2.C: Dietary habits for various age groups in the cohort

	Food ration in kg.year^{-1}				
	1 year old	**5 year old**	**10 year old**	**15 year old**	**adult**
Cereals	19	65	111	123	123
Root-vegetables	16	63	109	142	131
Fruit-vegetables	18	46	73	49	73
Leaf-vegetables	1.5	4	7	11	24
Jam	1	3	5	4	4
Cider	0	0	38	38	38
Beef	2	8	14	14	21
Mutton	0	0.5	1	2	2
Pork	1	9	16	20	30
Poultry and rabbit	1.5	6	11	12	23
Eggs	3	7	10	11	12
Cows milk	253	197	141	141	122
Dairy products	12	19	25	25	33
Sea fish	2	6	10	10	23
Molluscs	0	0.5	1	1[55]	7
Crustaceans	0	1	2	2	13

- Self-consumption table[56]

In the same way as for dietary habits, GT4 based its work for the determination of self-consumption ratios mainly on the results of the survey carried out in the Flamanville region [Mathieu and Mathieu 1978]. Therefore the resulting self-consumption ratios are not specific to a single age group. The values used are presented in table 3.3.2.D.

[55] There appears to be a large difference between an adolescent's dietary habit and an adult's dietary habit in molluscs and crustaceans. This is due to the technique used to reconstruct children's dietary habits from adult dietary habits, which is approximative. This difference causes a sudden step in doses between the 15 year old and adult classes when the calculated doses include a non-negligible contribution of exposure by ingestion of seafood.

[56] The self-consumption rate is considered here as being the proportion of foods derived locally, but not necessarily produced or caught by the consumer.

Table 3.3.2.D: Self-consumption ratio of the cohort

Food category	Self-consumption ratio (%)
Drinking water	0[57]
Cereals	0
Root-vegetables	60
Fruit-vegetables	40
Leaf-vegetables	60
Jam	84
Cider[58]	100
Beef	56
Mutton	56
Pork	56
Poultry and rabbits	56
Eggs	80
Milk	62
Dairy products[59]	30
Sea fish	53
Molluscs[60]	75
Crustaceans	53

- Accidental ingestion

In the absence of any French work done on this subject, the values selected for this parameter are the values recommended by the National Radiological Protection Board (NRPB) [Robinson 1996]. They are presented in table 3.3.2.E.

Table 3.3.2.E: Values used by GT4 for accidental ingestion

Accidental ingestion rate	1 year old	5 year old	10 year old	15 year old	adult
sea water ($l.year^{-1}$)	0.05	0.1	0.1	0.1	0.1
sand ($g.year^{-1}$)	5	2	1	0.5	0.5
soil ($g.year^{-1}$)	36.5	7.3	3.7	1.8	1.8

- Respiratory rates

The values selected for this parameter are the values proposed by the CIPR66 [ICRP66 1993], as presented in table 3.3.2.F. Several values are proposed in the CIPR66 for adults. The value used by GT4 is the value corresponding to the average for men and women qualified as “sedentary workers”, as opposed to individuals doing physical work.

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[57] The self-consumption rate equal to 0% for drinking water means that it is assumed that there is no ingestion of river water for the 0-24 year age group.

[58] By default, the self-consumption rate of cider was fixed at 100%.

[59] Since the reference [Mathieu and Mathieu 1978] does not give any values, the value used is taken from the CREDOC survey for COGEMA [Dufour 1998] (average of values used for the “butter” and “cheese” categories).

[60] The self-consumption rate for all seafood is the same in the survey [Mathieu and Mathieu 1978]. After comparison with the values given by [Dufour 1998], the value for molluscs was re-estimated at 75%, value given by [Dufour 1998].

Table 3.3.2.F: Values of breathing rates used by GT4

	Respiratory rates $m^3.year^{-1}$
1 year	1900
5 years	3200
10 years	5600
15 years	6500
adult	7300

- Time spent in different locations

The values of time budgets selected by GT4 are not directly taken from the literature. However, a bibliographic search was carried out, from which the values used by members of GT4 during their discussions were extracted. The values selected by GT4 are presented in table 3.3.2.G.

For time spent on the beach, the NRPB and the European methodology represent a value equal to 30 $h.year^{-1}$ on average for an individual, for all age groups combined. GT4 is particularly interested in young age groups (0 to 24 year old by definition of the cohort) and their habit in the past (study period from 1954 to 1996). GT4 considered that children and young individuals spend more time on the beach than an average person, and a value of 100 $h.year^{-1}$ was selected for time spent on the beach (including time spent shore fishing) for the 0 to 24 year old cohort, which corresponds to about 15 to 20 minutes time on the beach every day throughout the year.

The bathing time selected by GT4 was 20 $h.year^{-1}$ for all age groups, in other words "20 minutes per day for 2 months", except for the "1 year old" group which bathes less frequently and for which GT4 uses a value of 5 $h.year^{-1}$.

The time spent at sea (pleasure boats, sea fishing or water sports) assumed by GT4 is 2 $h.year^{-1}$ for the "1 year" cohort, 5 $h.year^{-1}$ for the "5 year" age group, 10 $h.year^{-1}$ for the "10 year" age group and 25 $h.year^{-1}$ for the "15 year" and "adult" age groups. These values were chosen based on the results of the CREDOC survey for COGEMA concerning outdoors and indoors activities in the Nord-Cotentin [CREDOC 1998].

For time spent indoors, the value of 90% is often mentioned in the literature for modern western populations. GT4 considered that children and young people in the study period (1954-1996) were outdoors more frequently, particularly for leisure activities. A value of 7000 $h.year^{-1}$ was selected for time spent indoors (which is equal to 80% of the time).

Table 3.3.2.G: Values used by GT4 for time budgets

Time spent ($h.year^{-1}$)		1 year	5 year old	10 year old	15 year old	adult
indoors		7000 (80%)	7000 (80%)	7000 (80%)	7000 (80%)	7000 (80%)
outdoors	bathing	5	20	20	20	20
	on the beach (including shore fishing)	100	100	100	100	100
	in the sea	2	5	10	25	25

3.4. Estimate of exposure

3.4.1. *Ex utero* dose coefficients and modeling of *in utero* exposure

An estimate of the risk of leukemia requires knowledge of doses to the red bone marrow over the years. Doses to the population are calculated based on concentrations in the environment and habit parameters, using dose coefficients. GT4 uses different dose coefficients:

- for external exposure: dose coefficients by immersion in air, in water or due to deposition on the ground
- for internal exposure: dose coefficients by inhalation and by ingestion.

- External *ex utero* exposure

The annual dose for external exposure is simple to calculate since there is no intake. GT4 has identified two main sources of values for dose coefficients due to external exposure, namely American values from Oak Ridge National Laboratory published in [Eckerman and Ryman 1993] and German values published in [Jacob and Rosenbaum 1990]. The American values were preferred because they are easier to use since they are included in IPSN data bases. They are also more complete in terms of the number of radionuclides considered. However, the German values have the advantage that they take the age effect into account since values are suggested for several age groups, namely “fetus”, “baby” (2 months), “child” (7 years) and “adult”. The age effect is essentially due to the effect of the person's size reflecting the average height above the ground and its maximum value is a factor of 3 according to [Petoussi *et al* 1991].

Values used by GT4 were derived from [Eckerman and Ryman 1993]. In the case of external exposure to marine sediments, the activity of sediments is known in the form of an activity per unit mass rather than a deposit. Dose coefficient used correspond to an infinite soil thickness since sand is permanently mixed[61].

- Internal *ex utero* exposure

In the case of exposure by ingestion and by inhalation, incorporated radionuclides can be fixed in organs and tissues and can deliver doses over many years. Published dose coefficients, particularly by the ICRP [ICRP71 1996] [ICRP72 1996] for inhalation by members of the public, [ICRP67 1993] [ICRP69 1995] [ICRP72 1996] for ingestion by members of the public, are “engaged dose” coefficients over an entire lifetime. They give the accumulated dose over an entire lifetime and cannot be used to determine what fraction of this dose is delivered during the year of intake and what fractions are delivered in subsequent years.

Due to the lack of any published data that could be used as a basis for this work, annual dose coefficients to the red bone marrow were calculated based on values of dose coefficients contained in the “beta3” version of the ICRP dose coefficients CD-Rom supplied by the NRPB[62]. This “beta3” version has not yet been finally validated[63]. Data supplied are doses to the red bone marrow engaged at 1 year, 5 years, 10 years, 20 years and 50 years. They concern six age groups at the time of intake: 3 months, 1 year, 5 years, 10 years, 15 years and adult. The work done consists of:

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[61] For deposits, values of Eckerman's dose coefficients are proposed in $Sv.s^{-1}$ / $Bq.m^{-3}$ for a soil density equal to 1600 $kg.m^{-3}$. This value of the density is the value used for marine sediments in the transfer and dose calculation model.

[62] ICRP dose coefficients take account of the possible contribution of radionuclides created by radioactive decay after intake of the parent radionuclide.

[63] Since then, the ICRP has validated the CD-Rom [ICRP 1998]. A verification of values of the version published on the CD-Rom compared with values in the “ beta3 ” version shows that these values are identical for radionuclides making the major contribution to the collective dose to the red bone marrow (^{3}H, ^{14}C, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{137}Cs and ^{244}Cm by ingestion).

- inputting values provided by the NRPB into a Microsoft® EXCEL 5.0.a file,
- spreadsheet programs were written so that dose coefficients can be interpolated at different ages, to reconstruct the dose delivered during each year. Coefficients of the dose supplied by the NRPB correspond to accumulated doses at 1 year, 5 years, etc. Dose coefficients corresponding to accumulated doses at each age of an individual (figure 3.4.1.a) can be estimated by linear interpolation (figure 3.4.1.a). The dose coefficient corresponding to the dose delivered during year n can then be obtained by subtracting the dose coefficient accumulated at year n-1 from the dose coefficient accumulated at year n (figure 3.4.1.b).

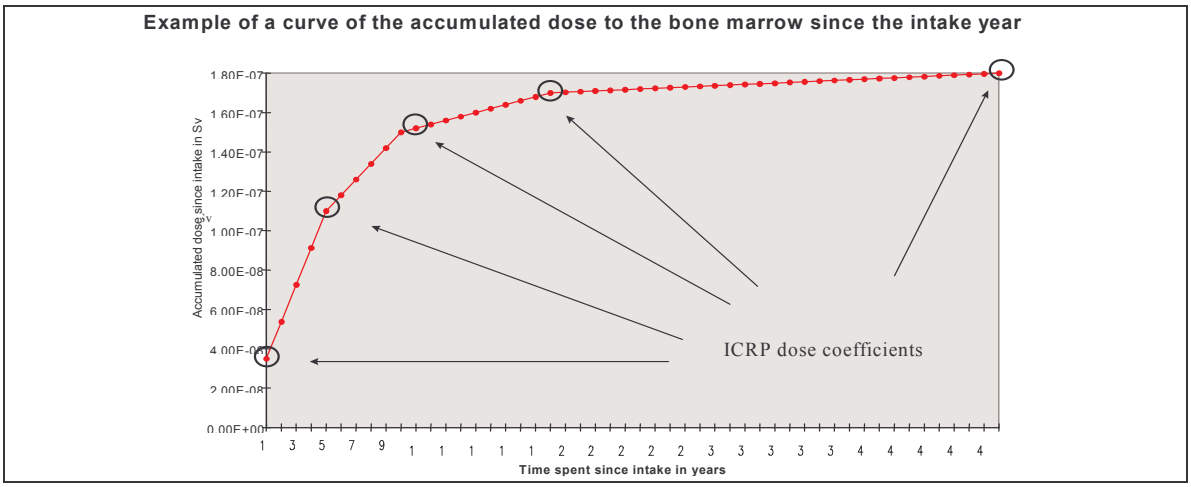


Figure 3.4.1.a: Example curve of accumulated dose as a function of time after intake of a radionuclide in year zero
(case of a radionuclide with a long biological half-life, for example ^{90}Sr)

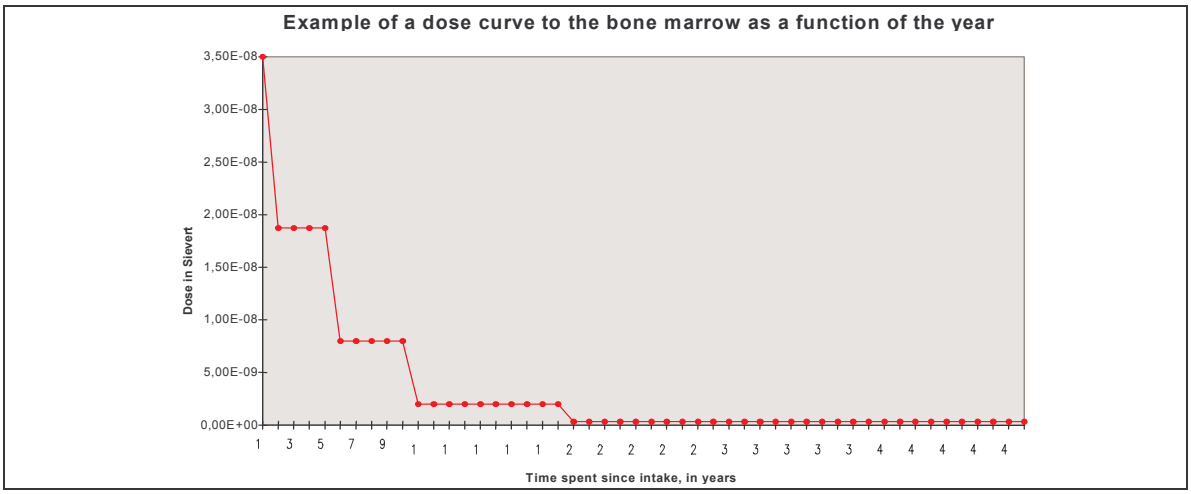


Figure 3.4.1.b: Example curve of annual dose to the red bone marrow following intake of radionuclide in year zero
(case of a radionuclide with a long biological half-life, for example ^{90}Sr)

For aerosols, dose coefficients by inhalation correspond to particles with an aerodynamic mean activity diameter (AMAD) of 1 µm, which the ICRP 72 recommends should be used for members of the public [ICRP72 1996]. The type of pulmonary absorption (F for fast pulmonary clearance, M for medium pulmonary clearance or S slow pulmonary clearance) selected for each aerosol is the value proposed by default in ICRP 72, or type M will be used in accordance with the ICRP 71 recommendation [ICRP71 1996] if nothing is proposed in the ICRP 72.

For tritium, the chosen dose coefficient by inhalation corresponds to the distribution of atmospheric releases of tritium from COGEMA La Hague reprocessing plants, in other words 2/3 of tritium in gaseous form HT and 1/3 of tritium in the form of tritiated water HTO. This distribution is as proposed by GT1. The dose coefficient for tritium in HTO form is much greater than the dose coefficient for tritium in HT form, but the transformation of HT tritium into HTO tritium was not considered since this transformation takes place very slowly in air according to Belot [Belot *et al* 1996]. However, the influence of the particular meteorological conditions on the La Hague site, and particularly stagnant sea spray, on the rate of transformation of tritium in HT form in air into tritiated water vapor HTO, are unknown.
For ingestion, the dose coefficient used corresponds to the OBT (organically bound tritium) form.

Individual annual dose calculations are then made for each exposure pathway considered, for each age group and for each year, using estimates of radionuclide concentrations in the environment.

- *in utero* exposure

Due to the lack of an ICRP publication concerning exposure of the fetus and particularly a dose coefficients database for the fetus, GT4 and the Plenary Group chose to calculate doses to the red bone marrow and the *in utero* risk using two provisional models:

  - the first model consists of producing an overestimate of doses to the fetal red bone marrow and the associated increment to the risk of leukemia. This is referred to as the "overestimate approach" in the rest of the report.

  - a second model corresponds to the model used by the NRPB for the study around Sellafield [Simmonds *et al* 1995] except for an adaptation concerning ^{90}Sr.

After the ICRP work has been published, the Radioecology Group's calculations can be updated based on the ICRP's recommendations.

Overestimate approach

The three *in utero* exposure pathways are modeled as follows:

- External exposure of the fetus during the 9 months of pregnancy is considered as a dose to the mother's uterus. This approximation was decided upon following an international consensus and has already been used, particularly in the Sellafield site study [Simmonds *et al* 1995]. GT4 makes the additional assumption that the dose to the fetal red bone marrow is the same as the full body dose, which is acceptable compared with the size of the fetus. Dose coefficients by external exposure to the plume, the deposit and by immersion in water are as given by Federal Guidance 12 [Eckerman et Ryman 1993], in accordance with GT4's previous decisions about external *ex utero* exposure.

- External exposure of the fetal red bone marrow to radionuclides deposited in the mothers tissues is considered like the dose to the mother's uterus. This assumption has already been used in the Sellafield site study [Simmonds *et al* 1995]. Assumed dose coefficients to the mother's uterus are as given on the ICRP's CD-Rom, interpolated to reconstruct doses delivered year after year, as GT4 had already done for dose coefficients to the red bone marrow. The only intakes used are those received during the year of pregnancy.

- Internal exposure of the fetus is modeled using the ICRP's dose coefficients to the red bone marrow by ingestion and inhalation of a three-month old infant [ICRP 1998]. This method is not unrealistic since the muscle/bone ratio for a fetus and for an infant are similar. It does not underestimate the dose to the fetus since a three-month old infant does not benefit from the placenta effect that provides protection against most radionuclides by limiting radionuclide transfers. According to [Simmonds *et al* 1995], the ratios of concentrations of radionuclides in fetal tissues to concentrations in maternal tissues are less than 1 for all radionuclides except for tritium in the form of tritiated water (ratio 1.4). For tritium in the form of tritiated water, the estimate dose is multiplied by 1.4 to maintain the overestimate nature of the proposed model.

  Values of dose coefficients due to ingestion and inhalation used by GT4 to calculate doses to the fetal red bone marrow are taken from the ICRP CD-Rom [ICRP 1998]. These are the same values that were used for 3-month old infants in the 0 to 24 year old cohort in the Beaumont-Hague canton. In particular, they can be used to calculate doses delivered each year by long life isotopes.

  The same method is used for intakes by the mother before conception. The effect on the fetus of these intakes only concerns radionuclides for which doses due to intakes are delivered over several years (for example Sr, transuranium elements).

The NRPB approach

The three *in utero* exposure pathways are modeled as follows:

- External exposure of the fetus during the 9 months of pregnancy is modeled in the same way as before.

- External exposure of the fetal red bone marrow to radionuclides deposited in mother's tissues is modeled in the same way as before.

- The model used for transfers through the placenta is as described in the Sellafield site study [Simmonds *et al* 1995]. Protection provided by the placenta acting as a barrier is modeled by a " concentration in fetal tissues/concentration in maternal tissues " (Cf/Cm) ratio that is a function of the radionuclide. Values of the Cf/Cm ratio are proposed for a large number of radionuclides. The default value of Cf/Cm for radionuclides in the source-term defined by GT1 which are not mentioned in [Simmonds *et al* 1995], is assumed to be equal to 1. The value of Cf/Cm used for ^{90}Sr is the value given in [Fell *et al* 1998], which is equal to 5, rather than the value for the site study around Sellafield (0.4). The values of ingestion dose coefficients and inhalation dose coefficients used to calculate doses to the fetal red bone marrow are values for the mother (adult) derived from the ICRP's CD-Rom [ICRP 1998]. The same values are used as for 18 to 24 year old individuals ("adults" age group) in the 0 to 24 year old cohort in the Beaumont-Hague canton. Intakes by the mother before pregnancy (the first 23 years of life) and during the year of pregnancy are included.

In both methods, it is assumed that the mother has lived in the Beaumont-Hague canton since her birth. Therefore she has incorporated long-life radionuclides that deliver doses to the fetus during pregnancy. The age of procreation is assumed to be 24. This choice was made because it simplifies calculations since dose coefficients are already available for ages 0 to 24 as a result of *ex utero* dose calculations for the cohort. Furthermore, this assumption is relatively realistic compared with the retrospective nature of the dosimetric reconstruction carried out and the fact that the average procreation age of women in France was of the order of 28 in 1994 [WHO 1998].

The models described in this document were selected to give an initial estimate of doses and the risk associated with *in utero* exposure, while waiting for the ICRP to publish its work on *in utero* exposure.

Since these models are temporary, they were not used for sources of exposure (natural, fallout from atmospheric testing of nuclear weapons and the Chernobyl accident) other than sources associated with releases from nuclear facilities in the Nord-Cotentin (apart from incidents/accidents). Therefore, *in utero* exposure is considered for all pregnancies from 1966 to 1995, in other words all births from 1967 to 1996. This exposure pathway does not concern populations that arrived during the Major Construction period. About 60% of the 6656 individuals in the cohort receive one *in utero* dose due to routine releases from nuclear facilities in the Nord-Cotentin.

The results in terms of doses to the red bone marrow and the risk of leukemia are presented in sections 3.4.2. and 3.5.3 respectively.

3.4.2. Dosimetric results

GT4 used a Microsoft® EXCEL 5.0.a program described in the reference [Merle-Szeremeta and Rommens 1998] to calculate doses to the red bone marrow as a result of nuclear facilities in the Nord-Cotentin, except for *in utero* exposure described in the previous section. The program starts by calculating annually inhaled and ingested activities based on activities in marine and terrestrial environments supplied by GT3 [GT3 detailed report 1999]. Secondly, the program uses Microsoft® EXCEL calculation modules developed by the CEPN [Degrange 1999] to calculate individual and collective doses.

A quality assurance procedure described in reference [Rommens and Drombry 1998] was carried out on the Microsoft® EXCEL program.

- *Ex utero* doses due to routine releases from nuclear facilities in the Nord-Cotentin

  - Individual ex utero doses (apart from incidents/accidents)

The variation of cumulated individual doses to the red bone marrow is shown in figure 3.4.2.a for generations born from 1954 to 1996. The cumulated individual dose to the red bone marrow varies between 4 µSv for the generation born in 1996 and 77 µSv for the generation born in 1971. The generation with the highest cumulated individual dose was born in 1971, since the total dosimetry includes 25 years of exposure (from 1971 to 1995) during the period in which the dosimetric impact of releases from the reprocessing plant were highest. The most recent generations have the lowest individual dose rate since the total number of years included in the dosimetry total is small, because the cumulation period stops in 1996. Similarly, generations born between 1954 and 1966 were actually exposed for less than 25 years, since releases from the first nuclear installation in the Nord-Cotentin (COGEMA La Hague reprocessing plants) did not begin until 1966.

Regardless of the age of the person, the shape of the dose curve is approximately the same shape with a peak in 1985, at the time that the activity of releases into the sea from the reprocessing plant were highest.

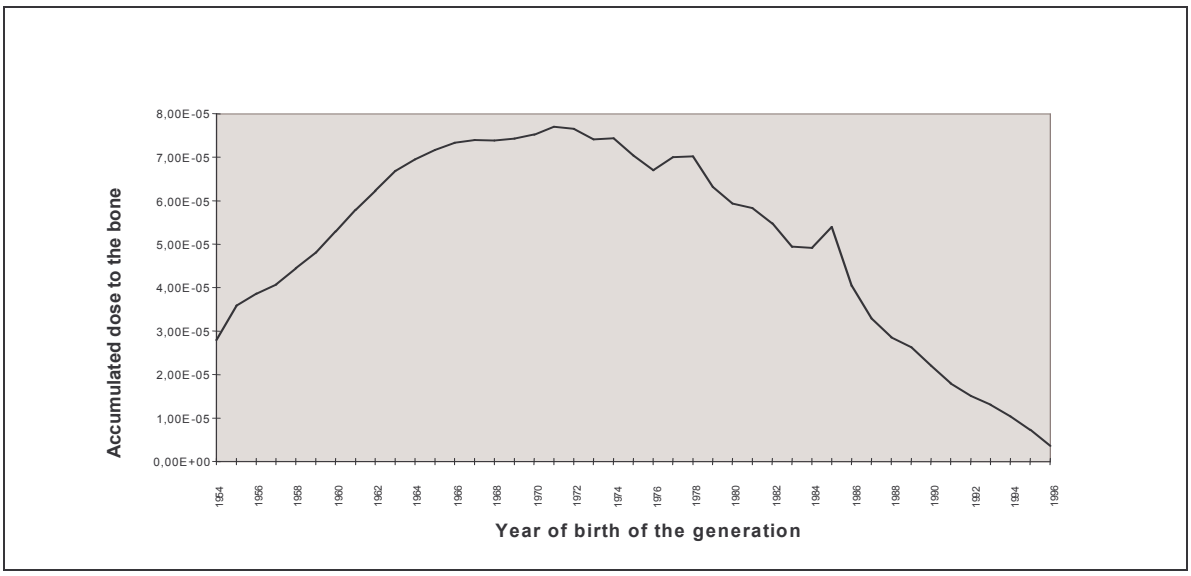


Figure 3.4.2.a: Variation of the individual *ex utero* dose to the red bone marrow cumulated over the first 24 years of life for each generation of the cohort due to routine releases from the Nord-Cotentin nuclear facilities

- Collective *ex utero* doses apart from incidents/accidents

The collective dose due to routine releases from nuclear facilities in the Nord-Cotentin for the entire 0-24 year old cohort for the period from 1966 to 1996 is equal to 0.30 m.Sv. Figure 3.4.2.b shows the contribution of radionuclides and exposure pathways.

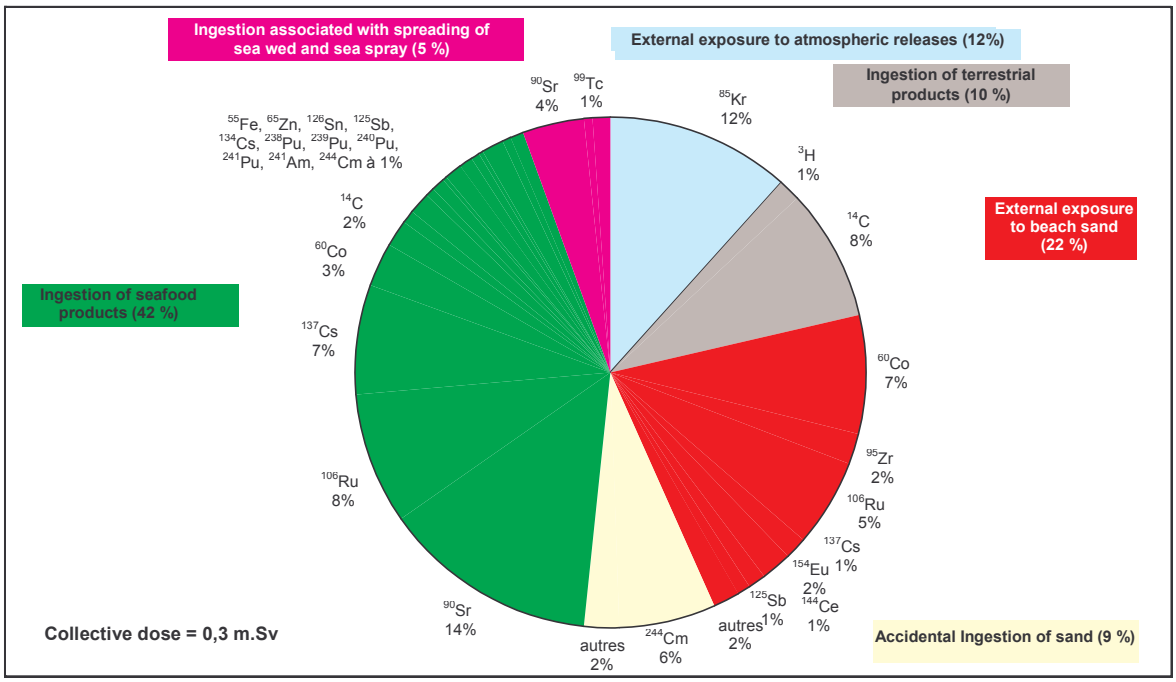


Figure 3.4.2.b: Contribution of radionuclides and exposure pathways to the collective *ex utero* dose to the entire cohort over the period from 1966 to 1996 due to routine releases from nuclear facilities in the Nord-Cotentin.

The predominant exposure pathways for the dose are ingestion of seafood (42% mainly due to ^{90}Sr, ^{106}Ru, ^{137}Cs, ^{60}Co and ^{14}C) and external exposure to beach sand (22% mainly due to ^{60}Co, ^{106}Ru, ^{95}Zr and ^{154}Eu). The other exposure pathways with a non-negligible contribution are external exposure to the plume of atmospheric releases (12% mainly due to ^{85}Kr),

ingestion of land products (10% mainly due to ^{14}C), accidental ingestion of sand (9% mainly due to ^{244}Cm) and ingestion due to spreading of seaweed, and sea spray (5% mainly due to ^{90}Sr).
In general, the dose to the red bone marrow is determined by releases from the reprocessing plant into the sea (figure 3.4.2.b). However, the activity released into the sea reduced very much by the end of the 1980s, and consequently the contribution of radionuclides released into the atmosphere and associated exposure pathways increased in relative terms in the 1990s.

The contributions of different radionuclides to the collective dose to the red bone marrow due to routine releases from nuclear facilities in the Nord-Cotentin do not all have the same degree of reliability.

For some radionuclides released into the sea (^{106}Ru, ^{137}Cs, ^{125}Sb and ^{60}Co), GT2 analyzed measurement results in many compartments of the environment, and GT3 was thus able to carry out a detailed comparison between the model and measurements.
GT2 and GT3 both mentioned that few measurements were available for exposure pathways associated with releases into the atmosphere. However, the radionuclides that contribute most to the collective dose were studied as precisely as possible. In particular, GT1 reevaluated releases of ^{85}Kr into the atmosphere, and GT3 compared model and measurement results for ^{14}C, including the most recent measurement results.

Concerning exposure by accidental ingestion, GT4 wanted to verify the plausibility of the dose level at the red bone marrow obtained due to the contribution of ^{244}Cm (accidental ingestion of beach sand). Consequently, estimates of ^{244}Cm in marine sediments as obtained by GT3's model were compared with GT2's measurements results. Unfortunately, the almost complete lack of measurement results available for ^{244}Cm in marine sediments makes it impossible to come to any conclusion about the plausibility of the contribution of ^{244}Cm for the exposure pathway due to accidental ingestion. In the absence of better information, the estimates provided by GT3 model were used for the calculation of dose and risk.

- *Ex utero* doses due to all sources of exposure

    - Individual *ex utero* doses

An essentially bibliographic study was carried out to estimate the exposure of Nord-Cotentin populations to remote natural, medical and artificial exposures (Chernobyl accident, atmospheric testing of nuclear weapons). The various sources of exposure considered are:

- medical exposure,
- exposure to fallout from atmospheric testing of nuclear weapons and the Chernobyl accident,
- exposure to radon,
- exposure to cosmic radiation,
- exposure to terrestrial radiation,
- exposure by intake of natural radionuclides.

Medical exposure (diagnosis)

Despite national and international estimates about doses potentially received during a specific examination and for specific equipment, there is a very little literature about doses to populations in general. The only French reference to a dose to the red bone marrow [Maccia *et al* 1988] mentions an equivalent dose to the red bone marrow of 0.74 mSv per year based on a survey into French medical practices in 1982. Due to the lack of a better estimate (a local survey is currently being made), the value proposed for medical exposure of the Nord-Cotentin population is 0.74 mSv per year to the red bone marrow.

This value only represents an average for the population. The exposure of most individuals is much less than this value, and the annual dose for some individuals may be much higher, for example the average effective dose associated with an intravenous urography is 11 mSv in France [Maccia 1993].

Exposure to fallout from atmospheric testing of nuclear weapons and the Chernobyl accident

The same model (the model recommended by the UNSCEAR [UNSCEAR 1993]) was used to estimate exposure due to fallout from atmospheric testing of nuclear weapons and exposure to fallout from the Chernobyl accident. The radionuclide deposits used for the calculations are:

- radionuclide deposits reconstructed from the statement of fallout from tests produced by the UNSCEAR after the most recent Chinese explosions [UNSCEAR 1982]; fallout from tests may be considered as being uniform over France;

- values published by the UNSCEAR for fallout from Chernobyl [UNSCEAR 1988]; the fallout is considered as being uniform for the Western French region.

Doses to the red bone marrow varied with the time (Figure 3.4.2.c). Table 3.4.2.A contains estimates of these doses.

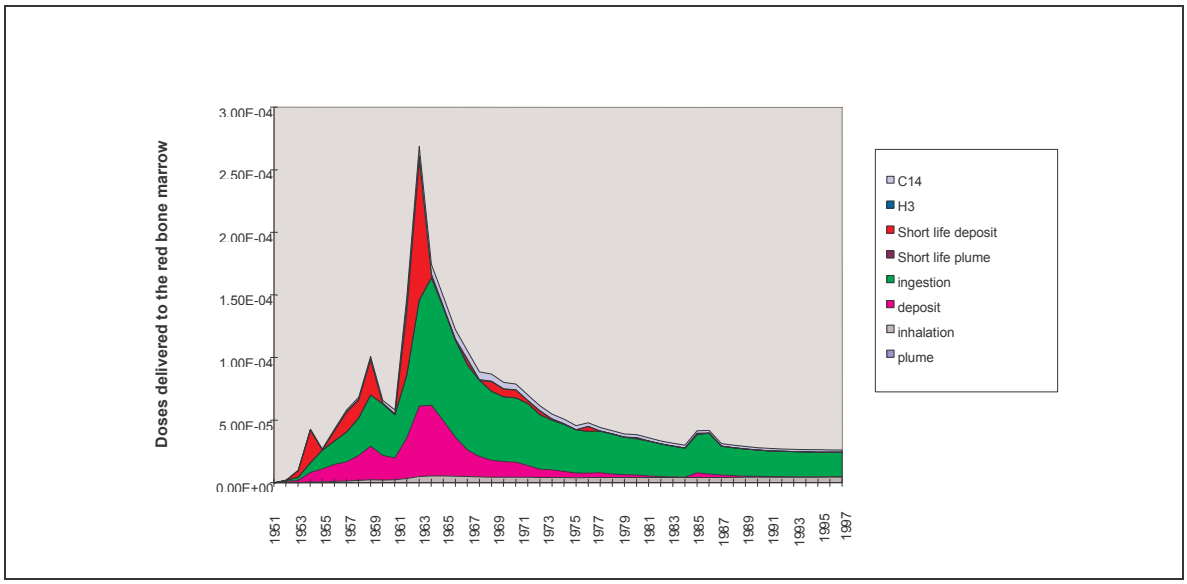


Figure 3.4.2.c: Individual doses to the red bone marrow as a result of fallout from atmospheric testing of nuclear weapons and the Chernobyl accident.

Table 3.4.2.A: Annual doses to the red bone marrow due to fallout from atmospheric testing of nuclear weapons and the Chernobyl accident for the Nord-Cotentin population.

	Dose in mSv
1954	0.04
1955	0.03
1956	0.04
1957	0.06
1958	0.07
1959	0.10
1960	0.07
1961	0.06
1962	0.15
1963	0.27
1964	0.18
1965	0.15
1966	0.12
1967	0.11
1968	0.09
1969	0.09

	Dose in mSv
1970	0.08
1971	0.08
1972	0.07
1973	0.06
1974	0.06
1975	0.05
1976	0.05
1977	0.05
1978	0.04
1979	0.04
1980	0.04
1981	0.04
1982	0.04
1983	0.03
1984	0.03
1985	0.03

	Dose in mSv
1986	0.04
1987	0.04
1988	0.03
1989	0.03
1990	0.03
1991	0.03
1992	0.03
1993	0.03
1994	0.03
1995	0.03
1996	0.03

Natural exposure

Assumed doses to the red bone marrow of the Nord-Cotentin population are summarized in table 3.4.2.B.

Table 3.4.2.B : Doses to the red bone marrow from the main sources of natural exposure for the Nord-Cotentin population

Exposure pathway		Dose to the red bone marrow ($mSv.year^{-1}$)
Radon		0.33
Cosmic		0.27
Terrestrial		0.41
Intake of natural radionuclides	^{40}K	0.27
	^{210}Po	depending on the age refer to table 3.4.2.C
	^{210}Pb	
	^{226}Ra	
	^{228}Ra	
	^{14}C	0.022

Table 3.4.2.C: Annual doses in mSv to the red bone marrow in the 0 to 24 year old cohort by intake (including descendants generated after intake)

Age	^{238}U	^{234}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po	^{232}Th	^{228}Ra	^{228}Th	^{224}Ra	Total
0-1	1.27E-03	1.41E-03	4.00E-03	0.13	0.30	1.54	1.70E-03	0.17	4.80E-03	5.50E-03	**2.16**
1-2	2.76E-04	2.95E-04	1.65E-03	0.02	0.16	0.49	7.28E-04	0.13	1.14E-03	8.50E-04	**0.80**
2-3	2.90E-04	3.14E-04	1.77E-03	0.02	0.18	0.49	7.84E-04	0.15	1.21E-03	8.50E-04	**0.85**
3-4	2.96E-04	3.29E-04	1.87E-03	0.02	0.18	0.52	8.35E-04	0.16	1.26E-03	7.90E-04	**0.89**
4-5	3.21E-04	3.54E-04	2.01E-03	0.03	0.20	0.52	9.00E-04	0.18	1.35E-03	7.90E-04	**0.94**
5-6	3.06E-04	3.40E-04	1.27E-03	0.02	0.18	0.52	6.23E-04	0.11	7.30E-04	7.90E-04	**0.83**
6-7	3.20E-04	3.51E-04	1.33E-03	0.02	0.18	0.52	6.55E-04	0.12	7.60E-04	7.90E-04	**0.84**
7-8	3.34E-04	3.61E-04	1.39E-03	0.03	0.18	0.52	6.88E-04	0.12	7.90E-04	7.90E-04	**0.85**
8-9	3.16E-04	3.40E-04	1.33E-03	0.03	0.15	0.52	6.70E-04	0.12	6.68E-04	6.80E-04	**0.82**
9-10	3.24E-04	3.49E-04	1.32E-03	0.03	0.15	0.52	6.72E-04	0.13	6.41E-04	6.80E-04	**0.83**
10-11	3.25E-04	3.54E-04	1.00E-03	0.03	0.15	0.52	5.04E-04	0.11	5.14E-04	6.80E-04	**0.81**
11-12	3.31E-04	3.59E-04	9.63E-04	0.03	0.15	0.52	4.91E-04	0.11	4.77E-04	6.80E-04	**0.81**
12-13	3.36E-04	3.65E-04	9.24E-04	0.03	0.15	0.52	4.78E-04	0.11	4.40E-04	6.80E-04	**0.81**
13-14	4.22E-04	4.53E-04	9.39E-04	0.05	0.17	0.31	4.74E-04	0.12	4.46E-04	9.00E-04	**0.65**
14-15	4.47E-04	4.78E-04	9.66E-04	0.05	0.18	0.31	4.73E-04	0.15	4.37E-04	9.00E-04	**0.69**
15-16	4.71E-04	5.04E-04	9.92E-04	0.06	0.19	0.31	4.73E-04	0.17	4.28E-04	9.00E-04	**0.73**
16-17	4.96E-04	5.29E-04	1.02E-03	0.06	0.20	0.31	4.73E-04	0.19	4.19E-04	9.00E-04	**0.76**
17-18	5.21E-04	5.55E-04	1.05E-03	0.07	0.21	0.31	4.73E-04	0.21	4.10E-04	9.00E-04	**0.80**
18-19	3.56E-04	3.72E-04	9.85E-04	0.05	0.17	1.21	4.73E-04	0.20	3.12E-04	2.55E-04	**1.63**
19-20	3.48E-04	3.54E-04	9.58E-04	0.04	0.16	1.21	4.85E-04	0.17	3.05E-04	2.55E-04	**1.58**
20-21	3.39E-04	3.34E-04	7.97E-04	0.04	0.14	1.21	4.31E-04	0.15	2.98E-04	2.55E-04	**1.54**
21-22	3.30E-04	3.17E-04	7.56E-04	0.03	0.13	1.21	4.40E-04	0.12	2.92E-04	2.55E-04	**1.49**
22-23	3.20E-04	3.01E-04	7.16E-04	0.03	0.12	1.21	4.48E-04	0.10	2.85E-04	2.55E-04	**1.46**
23-24	3.26E-04	3.19E-04	7.37E-04	0.03	0.12	1.21	4.56E-04	0.09	2.85E-04	2.55E-04	**1.45**

A perspective view of *ex utero* exposure levels due to different sources of exposure

Individual doses to the red bone marrow due to natural and medical exposure, and exposure to fallout from atmospheric testing of nuclear weapons and the Chernobyl accident are compared with individual doses to the red bone marrow due to nuclear facilities in the Nord-Cotentin in figures 3.4.2.d for all generations. However, GT4 emphasizes that not all sources of exposure have been studied with the same precision; the analysis for exposure pathways from nuclear facilities in the Nord-Cotentin was very precise, whereas the analysis for other sources of exposure and particularly medical exposure for which few elements are available at the present time, was more global[64]. Furthermore, habits liable to result in exposure levels due to sources of exposure other than routine releases from nuclear facilities in the Nord-Cotentin greater than those mentioned above (for example the frequency of air travel for exposure to cosmic radiation, or smoking for the intake of natural radionuclides) were ignored in calculating doses to the red bone marrow for the entire cohort.

[64] The Nord-Cotentin Radioecology Group and Professor Spira initiated the creation of a workgroup to study exposure of the Nord-Cotentin population to ionizing radiation from medical sources. This workgroup is composed of representatives of the OPRI, the INSERM and the IPSN and experts specialized in this subject. The work done by this workgroup is not yet ready (the first information is expected at the end of 1999).

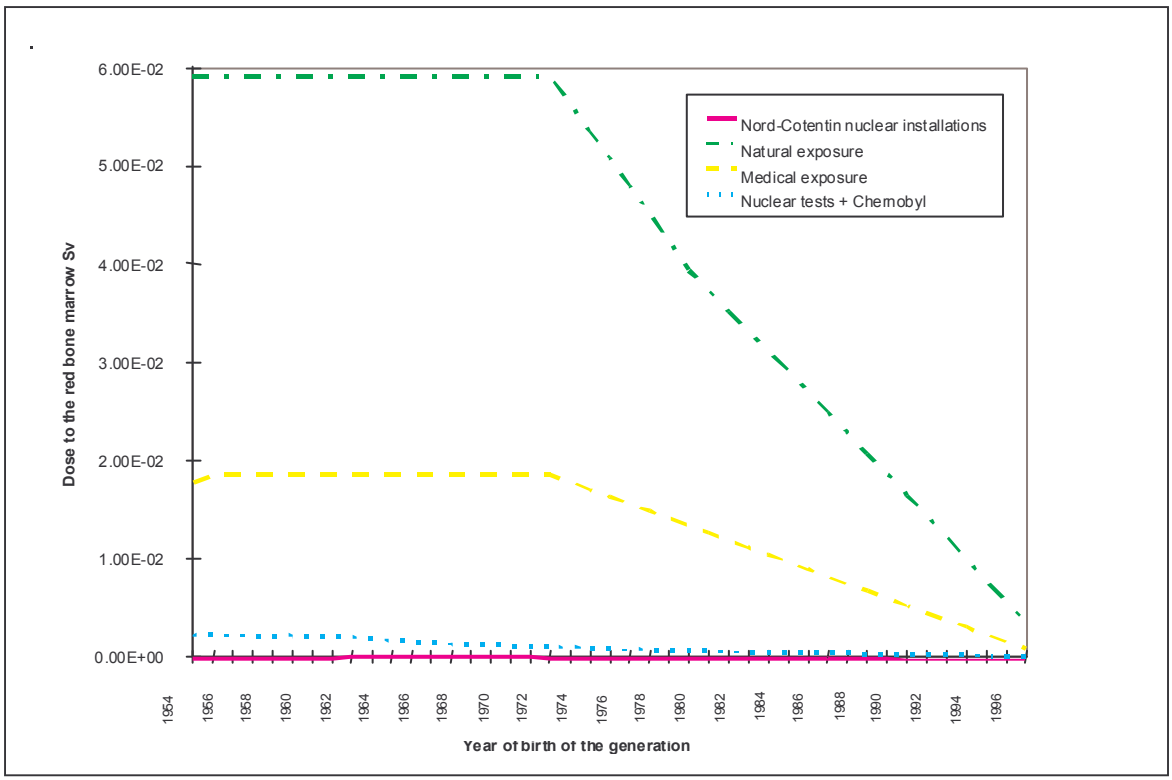


Figure 3.4.2.d: Cumulated individual *ex utero* doses to the red bone marrow due to all sources of exposure as a function of the generation (the contribution of Nord-Cotentin nuclear facilities is the *ex utero* exposure due to routine releases)

Figure 3.4.2.d shows that cumulated individual doses reduce based on the generation born in 1973, since doses are not cumulated over more than 25 years of exposure. Generations born after 1973 leave the cohort in 1996, before they are 25 year old.

Collective ex utero doses

The variation with time of the collective dose to the red bone marrow received by the entire cohort is shown in figure 3.4.2.e. The collective dose to the red bone marrow due to all sources of exposure varies from 0.5 m.Sv in 1954 to 13.8 m.Sv in 1993.
The curves increase uniformly from 1954 to 1978 because more individuals enter the cohort every year (see figure 3.1.1.a). Then they remain approximately stable (since the number of individuals in the cohort is stable - see figure 3.1.4.a) until 1984, when arrivals for the Major Construction Site cause a sudden increase in the collective dose in 1984. Between 1984 and 1994, all curves vary in the same way as the curve for the number of individuals in the cohort (see figure 3.1.4.a). The curves drop suddenly in 1994, since 15 year olds who arrived at the time of the Major Construction site reach the age of 25 years and therefore leave the cohort.
There are two small bumps in the curve corresponding to fallout from atmospheric testing of nuclear weapons and the Chernobyl accident; the first during the period from 1962 to 1966 is due to the larger number of test firings carried out during this period; the second in 1986 and 1987 is due to fallout from the Chernobyl accident (see also figure 3.4.2.c). The contribution of nuclear facilities in the Nord-Cotentin does not start until 1966, at the time of the first releases from COGEMA La Hague reprocessing plants.

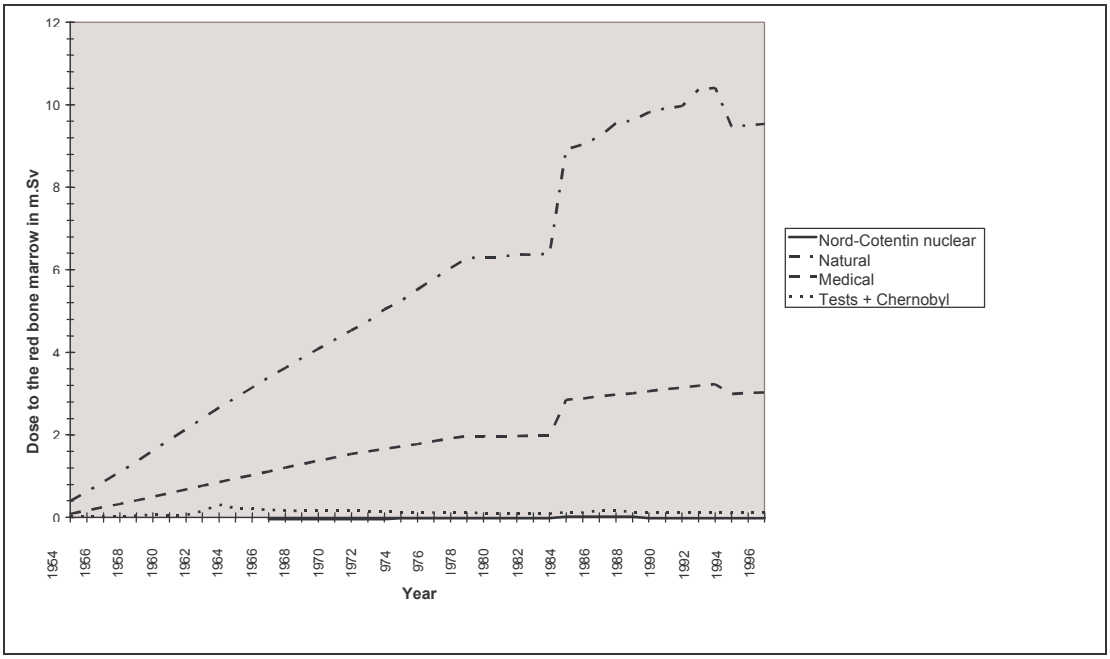


Figure 3.4.2.e: Variation of the collective *ex utero* dose to the red bone marrow due to all sources of exposure for each year

The total collective dose for the period from 1954 to 1996 is equal to 322 m.Sv . The contributions of the various sources of exposure to the total collective dose are shown in figures 3.4.2.e and 3.4.2.f. The preponderant exposure source is natural exposure with a contribution of about 3/4, namely 241 m.Sv. The main natural exposure pathway is ingestion of ^{210}Po (21% of the total collective dose), mainly through the ingestion of seafood. Medical exposure is a non-negligible source of exposure (24% of the total collective dose, namely 76 m.Sv). Exposure due to fallout from atmospheric testing of nuclear weapons and the Chernobyl accident contribute about 2% (5 m.Sv). Finally, routine releases from nuclear facilities in the Nord-Cotentin contribute less than 0.1% (0.30 m.Sv).

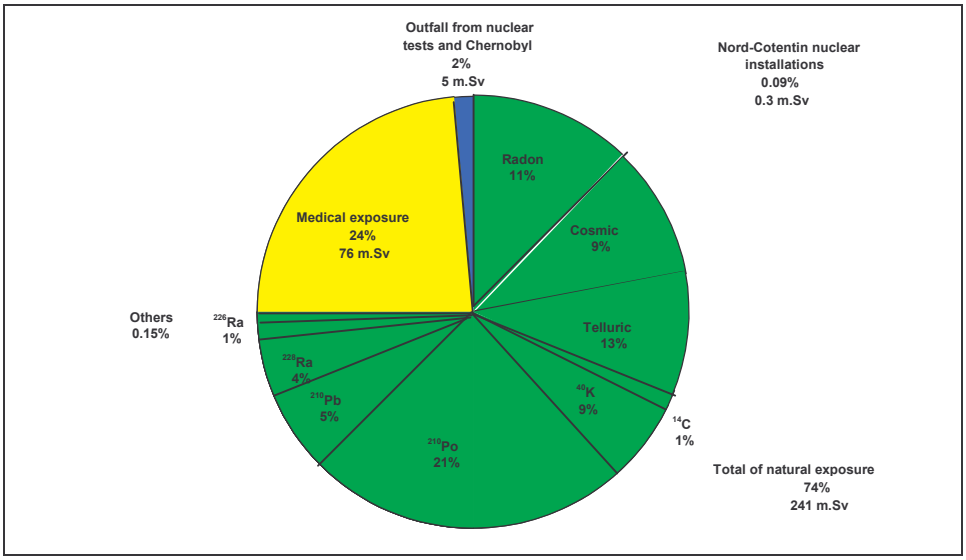


Figure 3.4.2.f: Contribution of various sources of exposure to the collective *ex utero* dose to the red bone marrow (the contribution of Nord-Cotentin nuclear facilities corresponds to the *ex utero* exposure due to routine releases)

***Ex utero* doses due to incidents/accidents**

COGEMA release pipe break

Individual and collective doses to the red bone marrow due to the pipe break were calculated using the model presented in section 3.2.3.

The additional collective dose to the red bone marrow for the cohort due to the pipe break is 0.04 m.Sv (compared with 0.30 m.Sv during normal operation). The contribution of exposure pathways and radionuclides is shown in figure 3.4.2.g. Ingestion (mainly due to ^{90}Sr and ^{106}Ru) contributes almost 50% of the dose to the red bone marrow due to the pipe break. External exposure (mainly due to ^{106}Ru and -^{125}Sb) contributes about 25%, accidental ingestion of sand on beaches (mainly due to ^{244}Cm) contributes about 16%, and ingestion due to spreading seaweed and sea spray (mainly ^{90}Sr) contributes about 11%.

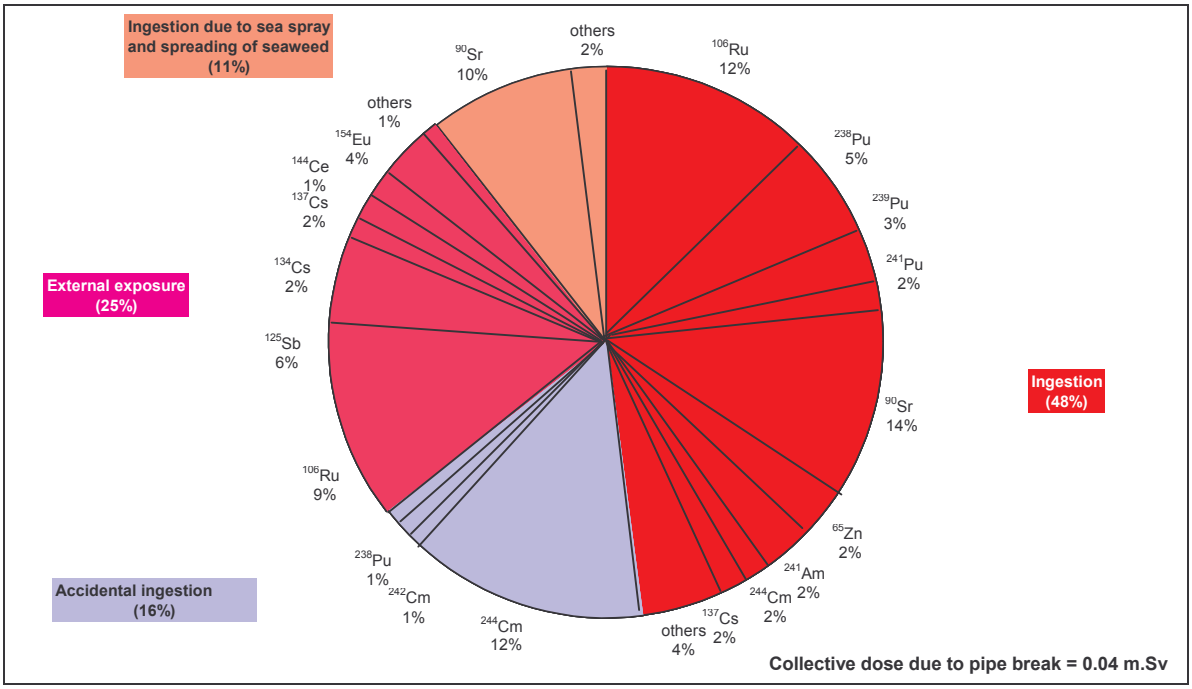


Figure 3.4.2.g: Contribution of the main radionuclides to the additional collective *ex utero* dose to the red bone marrow as a result of the pipe break

COGEMA silo fire

Collective and individual doses to the red bone marrow due to the silo fire in 1981 were calculated using the model described in section 3.2.3.

The additional collective dose to the red bone marrow for the cohort due to the silo fire is 0.14 m.Sv (compared with 0.30 m.Sv in normal operation). The contribution of exposure pathways and radionuclides is shown in figure 3.4.2.h. Ingestion of land products (mainly due to ^{137}Cs, ^{90}Sr and ^{134}Cs) contribute about 64% of the dose to the red bone marrow due to the silo fire. External exposure to the plume and to deposits (mainly due to ^{137}Cs and ^{134}Cs) contributes about 35%, and inhalation about 1%.

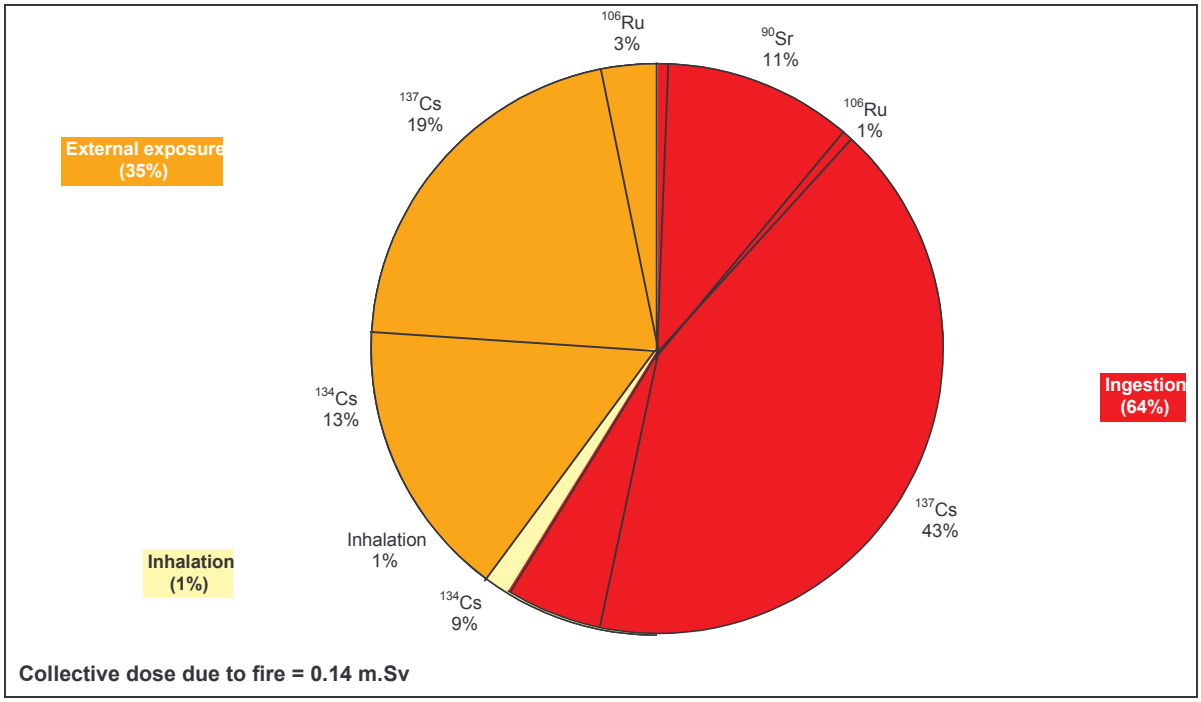


Figure 3.4.2.h: Contribution of the main radionuclides to the additional collective *ex utero* dose to the red bone marrow as a result of the silo fire

Other incidents/accidents

GT4 carried out dosimetric calculations for the three most significant accidents in terms of released activity, out of the six incidents/accidents identified by GT1; these three were the silo fire (effective dose and dose to the red bone marrow), the pipe break (effective dose and dose to the red bone marrow) and tritium releases (effective dose only).
The other incidents/accidents only concerned COGEMA La Hague reprocessing plants. Since released activities were much lower, GT4 considered that calculations for these incidents/accidents would not change the order of magnitude of the collective dose to the red bone marrow of the cohort, and therefore did not reconstruct the corresponding dosimetric impacts.

Doses due to *in utero* exposure as a result of routine releases from Nord-Cotentin nuclear facilities

Individual and collective doses to the red bone marrow due to *in utero* exposure were calculated using the two models presented in section 3.4. Since the ICRP has not published its report on the model of exposure of the fetus, the first model used by GT4 is an overestimate model hereinafter called the "overestimate" method. Only the collective dose is presented for the "overestimate" method. Calculations made with the second model, hereinafter called the "NRPB[65]" method, are more realistic, but no international consensus has been reached for the model used. Calculations made using the "NRPB" method are broken down into individual doses and collective doses. The corresponding risk is estimated in section 3.5.3.

[65] This model was actually used by the NRPB for the study around Sellafield, except for a modification introduced by the Nord-Cotentin Radioecology Group concerning ^{90}Sr (see section 3.4).

"Overestimate" method

The collective dose to the red bone marrow due to *in utero* exposure due to routine releases from nuclear facilities in the Nord-Cotentin is estimated by the "overestimate" method as being equal to 0.15 m.Sv. The contribution of *in utero* exposure pathways and the main radionuclides is presented in figure 3.4.2.i. The main exposure pathway (75%) is internal exposure of the fetus due to intake by the mother.

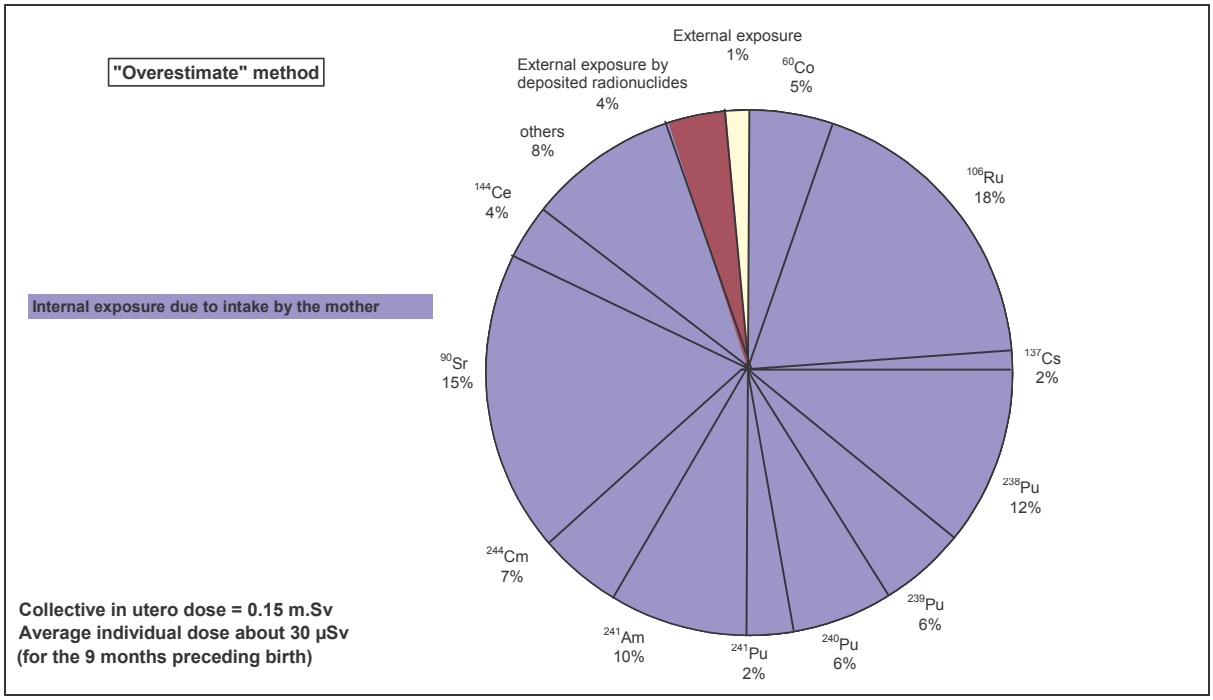


Figure 3.4.2.i: Contribution of *in utero* exposure pathways and the main radionuclides to the collective dose to the red bone marrow due to *in utero* exposure

"NRPB" method

The individual dose to the red bone marrow due to *in utero* exposure as a result of routine releases from nuclear facilities varies as shown in figure 3.4.2.j. The first generation that received *in utero* exposure was born in 1967, and had been exposed in 1966, the first year of releases from COGEMA La Hague reprocessing plants. The individual *in utero* exposure delivered to the red bone marrow varies depending on the generation between 0.3 for the 1967 generation and 10 µSv for the 1972 generation. The 1972 peak is due mainly to the increase in COGEMA's releases of ^{134}Cs and ^{137}Cs into the sea in 1971. The peak in 1985-1986 is explained by the activity released by COGEMA into the sea, which was greater in the middle of the 1980s.

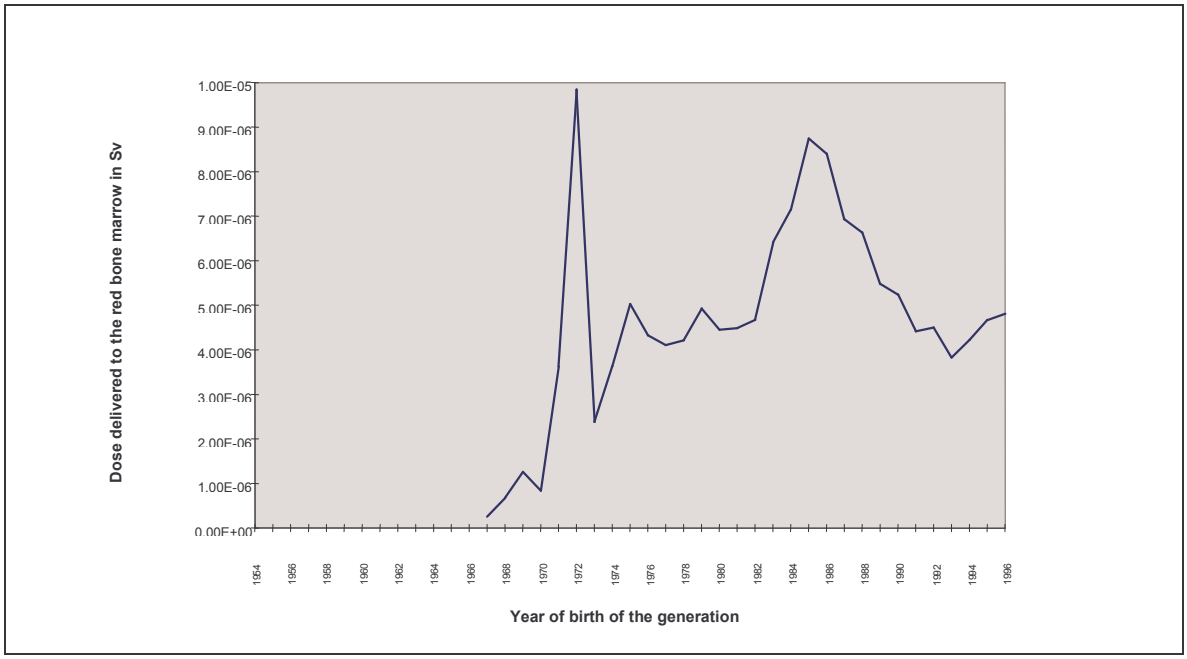


Figure 3.4.2.j: Variation of the individual *in utero* dose to the red bone marrow for each generation in the cohort due to routine releases from nuclear facilities in the Nord-Cotentin

The collective dose to the red bone marrow due to *in utero* exposure as a result of routine releases from nuclear facilities in the Nord-Cotentin is estimated using the "NRPB" method as being equal to 0.02 m.Sv. The contribution of *in utero* exposure pathways and the various radionuclides are shown in figure 3.4.2.k. Internal exposure of the fetus due to intake by the mother contributes 59% (mainly due to ^{90}Sr). External exposure of the fetus due to radionuclides deposited in the mother's tissues contributes 29% (mainly due to ^{137}Cs, ^{106}Ru and ^{14}C). External exposure of the fetus due to external exposure of the mother contributes 12%.

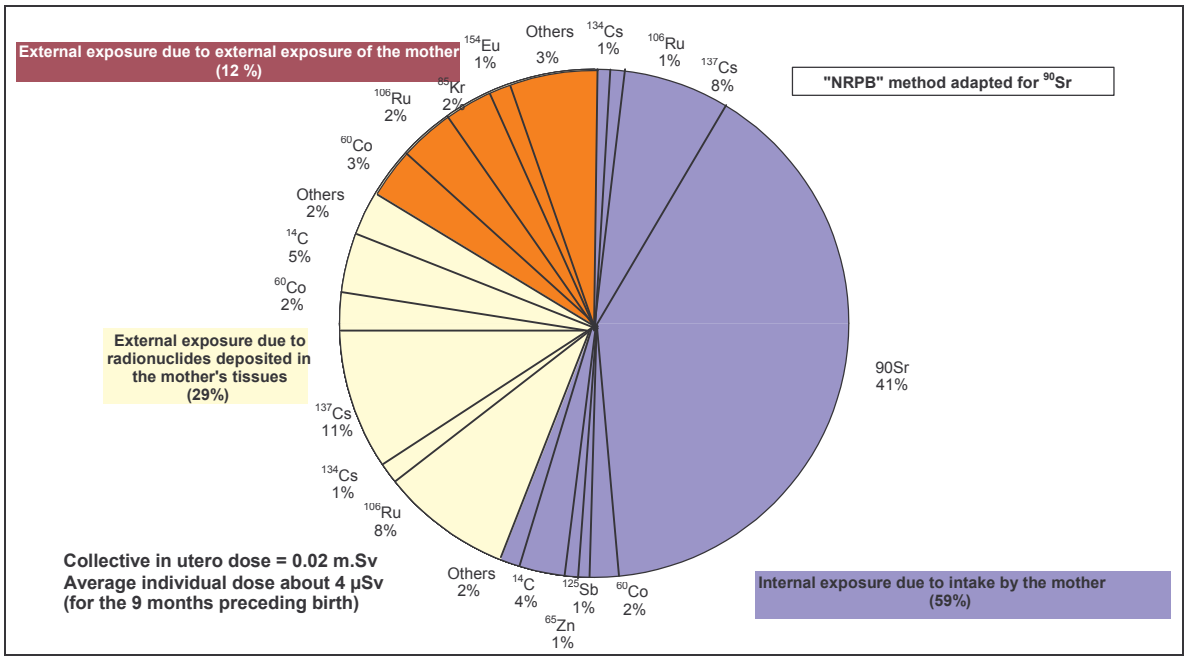


Figure 3.4.2.k: Contribution of *in utero* exposure pathways to the individual dose to the red bone marrow due to *in utero* exposure

Comparison with the results of previous radioecological studies

Study around Sellafield

As presented in Section 1, the method used for the evaluation of doses and risk in the Beaumont-Hague canton is based on a review of previous studies carried out in the United Kingdom. Table 3.4.2.D presents a comparison of the results of these studies in terms of collective doses.

Table 3.4.2.D: Comparison of results with the results of previous British radioecological studies

	Seascale (Sellafield) [COMARE 96]	**La Hague 1999**
Period	1945-92	1966-96
Size of cohort	1348	6656
Individuals-years (PY)	≈ 25300 *	94296
Collective dose		
Routine releases (*in utero* and *ex utero*)	2.39 m.Sv	0.32 m.Sv
Collective dose for 100,000 PY		
Routine releases (*in utero* and *ex utero*)	9.45 m.Sv	0.34 m.Sv

* : approximation

The calculation of collective doses was corrected to 100 000 individuals-years, to make the results obtained for different size cohorts comparable. There is a factor of about 30 between collective doses per 100,000 PY at Seascale and at La Hague. This difference is normal since many parameters (dispersion, environmental transfers, dose-relevant habits and especially activities released into the sea) were different in the two studies. The activity released at Sellafield in the past was much greater than the activity released by COGEMA La Hague reprocessing plants. For example, the total activity released into the sea in Sellafield in its maximum year (1975) was 10 times greater than the greatest activity released in by COGEMA for its maximum year (1985).

"Souleau" Commission Report

Dosimetric results presented by the "Souleau" Commission are only applicable to the whole body (effective dose engaged). Therefore, they are not comparable with dosimetric estimates made by the Radioecology Group for the cohort concerning doses to the red bone marrow. However, the results are put in perspective for particular scenarios (see section 4).

3.5. Estimate of the number of cases that can be assigned to exposure to ionizing radiation

The final step in the radioecology evaluation is to use all doses to the red bone marrow, to estimate the number of cases that can be assigned to exposure to ionizing radiation in the cohort of young people between 0 and 24 year old who have lived in the Beaumont-Hague canton.

The risk of radiation-induced leukemia within the cohort is estimated for the period from 1978 to 1996. This is the only period for which epidemiological data are available on the incidence of leukemia in 0-24 year old young individuals in the Beaumont-Hague canton. Our results were compared with these data considering the contribution to the risk from 1978 to 1996 only. Nevertheless, the estimated risk of radiation-induced leukemia during these years depends on all exposure received since birth, in other words from 1954 for some individuals. This risk estimation step requires the use of risk coefficients derived from the literature to estimate the risk.

3.5.1. Leukemia risk coefficients associated with the dose to the red bone marrow

The risk of leukemia due to the dose to the red bone marrow for each individual in the cohort is estimated using risk coefficients:

- for exposure during childhood (*ex utero*),
- for exposure during pregnancy (*in utero)*.

Models described in the literature were reviewed.

Two models can be considered to estimate the risk associated with exposure during childhood (*ex utero)*, namely the models in the BEIR report V [BEIR 1990] and in the 1994 UNSCEAR report [UNSCEAR 1994]. Both models were used to estimate the risk of leukemia, so that the estimates obtained can be compared.

In both cases, coefficients are derived from the study of Hiroshima-Nagasaki survivors. The two models are used to take into account risk variations as a function of the age at exposure and the time spent since exposure. The two models assume a latency delay of 2 years between exposure and risk; in other words, a dose delivered at a given age does not cause any excess risk during the first two years after exposure. The BEIR V model provides the excess relative risk (ERR) per unit dose to the red bone marrow, which should be multiplied by the leukemia base incidence rate to obtain the estimate of the number of cases. This method can be used to adapt estimates of the number of cases to the base incidence for the country. It was used by the NRPB in the radioecology study around Sellafield [Simmonds *et al* 1995, COMARE 1996]. The UNSCEAR 94 model provides values of the excess absolute risk (EAR) of incidence [Preston 1994] per unit dose to the red bone marrow, and therefore base incidence data are not necessary.

The two models were applied to estimate the risk of radiation-induced leukemia within the cohort. However, we preferred to use the results of the UNSCEAR 94 model for the following reasons:

- the UNSCEAR 94 model is more recent than the BEIR V model,
- the UNSCEAR 94 model is based on coefficients estimated from data on the incidence of leukemia in Hiroshima and Nagasaki survivors, whereas the BEIR V model is based on mortality data, and involves the assumption that the risk of death is similar to the risk of incidence,
- the UNSCEAR 94 model is an added risk model: it assumes that the risk of radiation-induced leukemia is not dependent on the basic risk, and this assumption appears the most likely after monitoring data for Hiroshima and Nagasaki survivors,
- the BEIR V model uses the base incidence of leukemia to calculate the radiation-induced risk. In France, incidence of leukemia is not systematically recorded, and data supplied by FRANCIM, although very interesting, only provide the estimate of the base incidence making use of data in local registers and mortality data.

Therefore, the risk estimates presented in this report were made using the UNSCEAR 94 model.

The Oxford Survey of Childhood Cancer (OSCC) [Muirhead 1989] model is used to estimate the risk of leukemia associated with *in utero* exposure. Two forms are available, firstly a model for estimating the relative risk used by the NRPB in the radioecology study around Sellafield [Simmonds 1995], and secondly a model for determining the absolute risk put forward by the NRPB to estimate the risk in the English population [NRPB 1993] [Doll 1997]. These two forms will be used in combination with the BEIR V model (estimate using the relative risk model) and the UNSCEAR 94 model (estimate using the absolute risk model), respectively. Risk estimates presented in this report will be carried out by applying the additive form of the *in utero* risk model.

It should be noted that application of the BEIR V, UNSCEAR 94 and OSCC risk models for the purposes of this risk estimate are based on several assumptions, the main of which are as follows:

- these models can be used unchanged in order to make a risk estimate,
- there is no threshold for the models used; therefore, it is assumed that any dose to the red bone marrow will increase the risk of leukemia;
- the BEIR V and UNSCEAR 94 models, derived from the study of Hiroshima and Nagasaki survivors in which exposure was instantaneous with an average dose of a few hundred mSv, are applicable to a population exposed chronically to low doses and dose rates; it is assumed that the linear-quadratic form of the models eliminates the need to use a correction factor for low doses and dose rates,
- Hiroshima and Nagasaki survivors were exposed mainly to radiation with low linear energy transfer (TEL): it is assumed that the models are also applicable to the estimate of the risk associated with high TEL radiation.

3.5.2. Leukemia risk calculation procedure

Several criteria have to be satisfied when using these leukemia risk calculation models:

- verification of procedure quality and validation,
- compatibility of risk calculation modules with outputs from red bone marrow dose calculation modules,
- speed and flexibility of use to satisfy the need to carry out the large number of calculations required (risk by exposure pathway, by radionuclide, by generation, etc.),
- the capacity to consider miscellaneous information (doses, population, incidence) on standard data tables (43 generations x 25 ages),
- ease of outputting results in table or graphic form.

It was decided that the risk models existing in the ASQRAD software [Degrange *et al* 1997] would be used to satisfy these various criteria. The ASQRAD software was developed by the CEPN and the NRPB to estimate the risk of death due to cancer caused by exposure to ionizing radiation, over a lifetime. The ASQRAD data base already includes BEIR V and UNSCEAR 94 risk coefficients. However, the software had to be extended to enable the use of *in utero* models. The software was also modified to estimate risks of incidence, rather than risks of death. Finally, it should be noted that the ASQRAD software includes a modification to the UNSCEAR 94 model introduced to enable better agreement between lifetime risk evaluations and the corresponding evaluations published in the UNSCEAR 94 report; a correction factor of 0.5 years was applied to the delay after exposure used in the initial equation in the UNSCEAR 94 model.

The risk calculation procedures made using the ASQRAD software were then programmed in EXCEL, after the dose calculation program.

GT4 added a results verification step: an internal check (compared with outputs from the ASQRAD software) and an external check (compared with spreadsheets using only the equations in the BEIR V and UNSCEAR 94 models).

3.5.3. Results of calculations of the risk of leukemia caused by exposure

This section presents the results of estimates of the risk of leukemia associated with doses to the red bone marrow, for the 0 to 24 year old cohort in the Beaumont-Hague canton. By construction, the risk is determined only during the time period between 1978 and 1996.

Risk of leukemia associated with exposure during childhood *(ex utero)* due to routine releases from Nord-Cotentin nuclear facilities.

Individual ex utero risk due to routine releases from nuclear facilities
The individual risk of leukemia corresponds to the probability of occurrence of leukemia. This probability may be calculated for each individual and each generation, for each year of age.

Figure 3.5.3.a presents the accumulated risk from 0 to 24 year old (or until the leaving age in 1996 if less than 24 years) for an individual in each of the 43 generations. The highest risk is observed for the 1970 to 1980 generations, since these are the generations with the largest number of years in residence (and therefore contribution to the risk) during the period from 1978 to 1996.

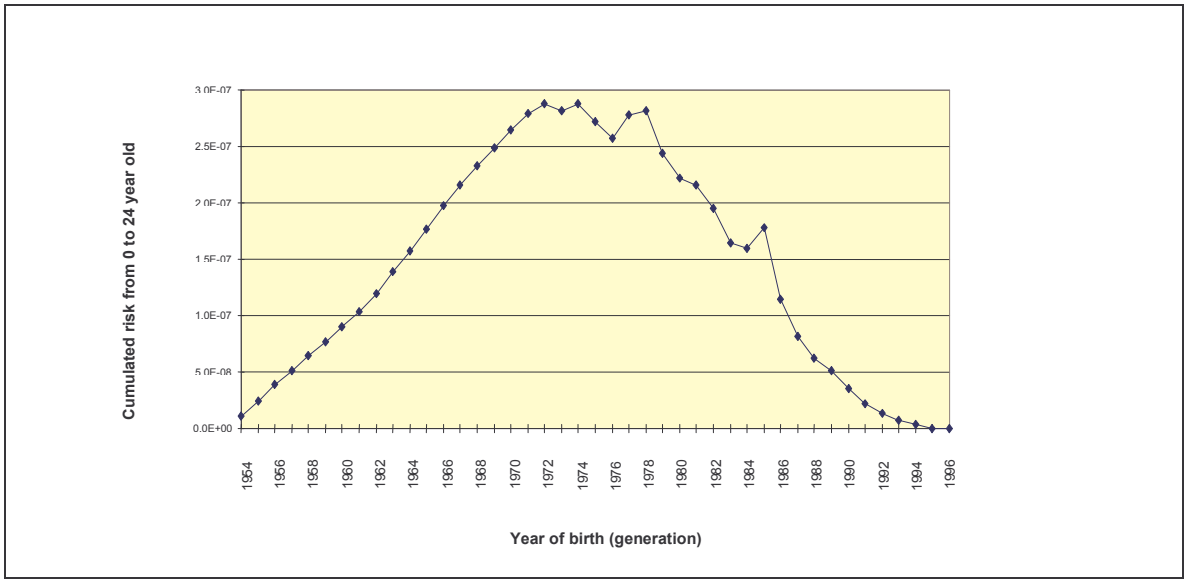


Figure 3.5.3.a: Accumulated individual risk between 1978 and 1996 associated with exposures received during childhood *(ex utero)* due to routine releases from the Nord-Cotentin nuclear facilities, by generation

Collective *ex utero* risk due to routine releases from nuclear facilities

The collective risk is represented by a number of radiation-induced cases of leukemia, obtained by the product of the individual risk and the number of individuals, for each calendar year between 1978 and 1996, and for each age group affected.

The total estimated number of cases of leukemia for the 0-24 year old cohort in the Beaumont-Hague canton for the period from 1978 to 1996 associated with exposure received during childhood *(ex utero)* due to the Nord-Cotentin nuclear facilities is 0.0009.

Figure 3.5.3.b shows the proportion of the risk corresponding to each exposure pathway. This figure should be compared with figure 3.4.2.b that presents the proportion of the collective dose associated with each exposure pathway. It should be noted that 87% of the

risk is due to the marine pathway. Furthermore, it is surprising that the risk due to accidental ingestion of beach sand is equal to 14% of the total risk (see discussion on the estimate of the dose due to ^{244}Cm, section 3.4.2).

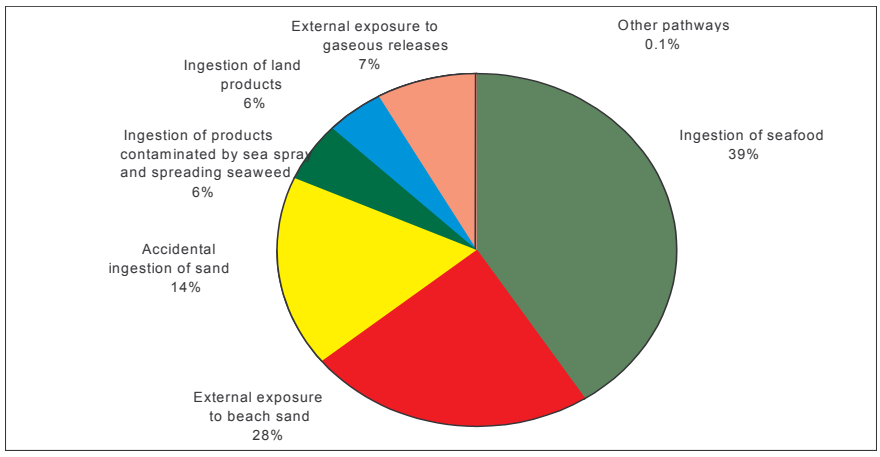


Figure 3.5.3.b: Breakdown of the risk of leukemia associated with exposure received during childhood *(ex utero)* due to routine releases from nuclear facilities in the Nord-Cotentin as a function of exposure pathways (0-24 year old cohort in the canton of Beaumont-Hague, 1978-1996)

Figure 3.5.3.c presents the distribution of the risk within the cohort as a function of the period. The highest estimated risk is during the period from 1987 to 1993. These seven years contribute 50% to the total collective risk for the cohort.

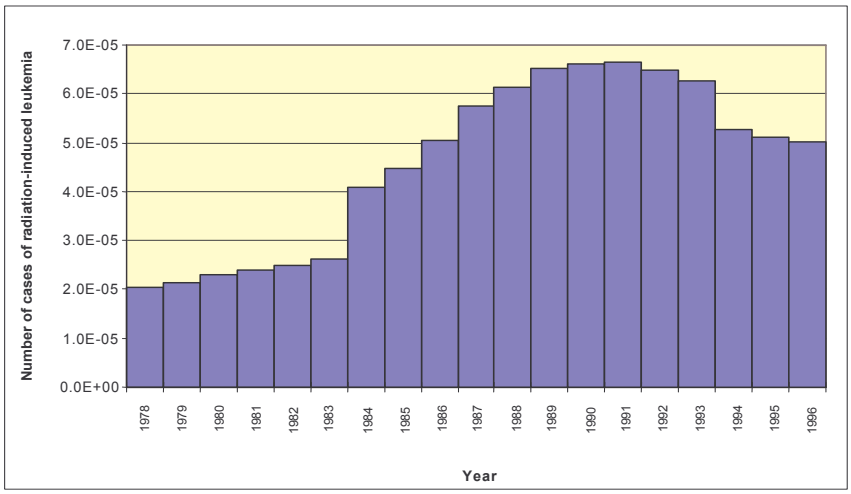


Figure 3.5.3.c: Number of cases of leukemia, associated with exposure received during childhood *(ex utero)* due to routine releases from Nord-Cotentin nuclear facilities within the cohort as a function of the year

Risk of leukemia associated with exposure during childhood (*ex utero*) due to all sources of exposure

Individual *ex utero* risk due to all sources

Figure 3.5.3.d shows the cumulated risk from 0 to 24 years (or until the leaving age in 1996 if less than 25 year old) for an individual in each of the 43 generations, for exposure to each of the sources during childhood (*ex utero*). The risk increases until the 1972 generation and then decreases, mainly due to the presence (and therefore the contribution to the risk) during the period from 1978 to 1996.

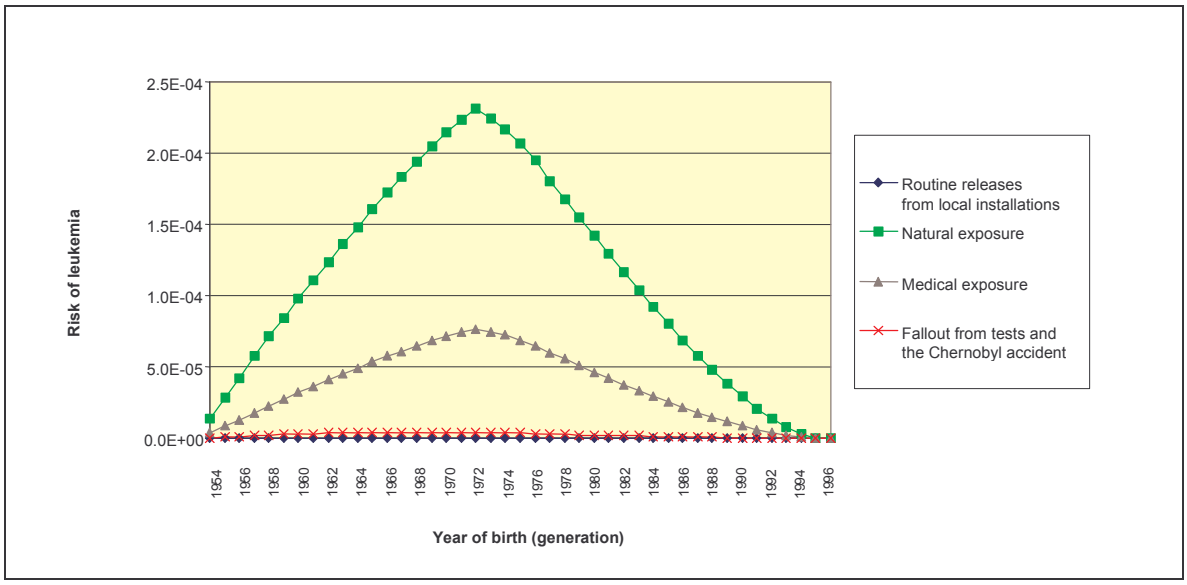


Figure 3.5.3.d: Accumulated individual risk between 1978 and 1996 associated with exposure received during childhood *(ex utero)* due to different sources of exposure, by generation

Collective *ex utero* risk due to all sources of exposure

The total number of cases within the cohort that can be assigned to exposure to ionizing radiation during childhood (*ex utero*) in the Nord-Cotentin is 0.835. Figure 3.5.3.e shows the proportion associated with each exposure source. This figure should be compared with figure 3.4.2.f that shows the proportion of the collective dose associated with each exposure source. Natural exposure and medical exposure are the main contributors to the risk (74% and 24% respectively). Nuclear facilities in the Nord-Cotentin contribute 0.1% to the collective risk.

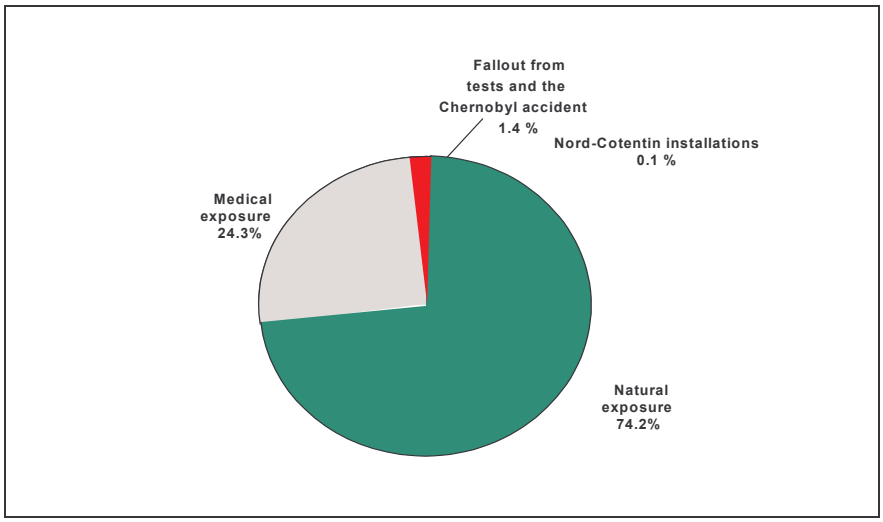


Figure 3.5.3.e: Distribution of the risk of leukemia associated with exposures received during childhood *(ex utero)* as a function of sources of exposure (0-24 year old cohort in the Beaumont-Hague canton, 1978-1996)

Figure 3.5.3.f presents the contribution for each year between 1978 and 1996, of each exposure source to the calculated number of cases of leukemia.

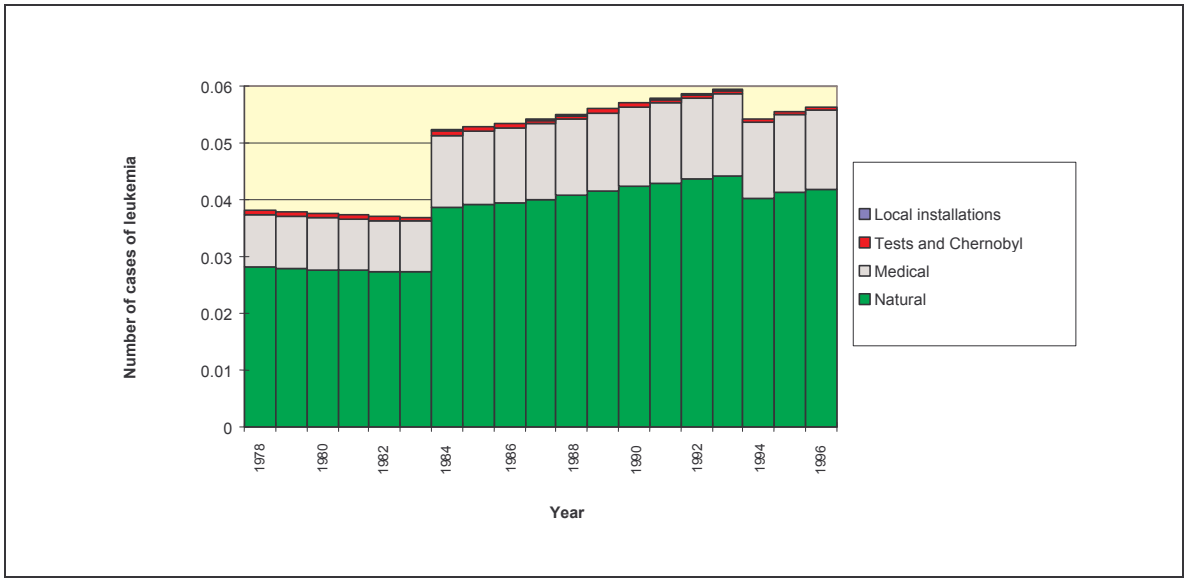


Figure 3.5.3.f: Number of cases of leukemia associated with exposure received during childhood *(ex utero)* due to each exposure source within the cohort as a function of the year (the contribution of the Nord-Cotentin nuclear facilities corresponds to *ex utero* exposure to routine releases)

Risk of leukemia due to incidents/accidents

Pipe break

The estimated number of cases of radiation-induced leukemia during the period from 1978 to 1996 is 0.0001 cases, namely about 16% of the number of cases estimated for routine releases from local nuclear facilities.

Silo fire

It is assumed that the consequences of the silo fire only affected individuals living in the villages of Beaumont-Hague, Biville, Herqueville and Vauville. The number of cases of radiation-induced leukemia thus estimated over the period from 1978 to 1996 is 0.0004 cases, namely about 40% of the collective risk estimated for routine releases from local nuclear facilities. The village of Beaumont-Hague contributes 72% of the additional collective risk to the cohort due to the silo fire.

Risk of leukemia associated with exposure during pregnancy (*in utero*) due to routine releases from the Nord-Cotentin nuclear facilities

The method used to estimate the dose to the fetus was derived from the "NRPB model" (see section 3.4.1), to estimate the associated risk of radiation-induced leukemia.

Individual risk

Figure 3.5.3.g presents the accumulated risk from 0 to 24 year old (or until the age reached by the person in 1996 if less than 24 years) due to *in utero* exposure for an individual in each of the 43 generations. This should be compared with figure 3.4.2.i which presents the individual *in utero* dose to the red bone marrow for an individual in each of the 43 generations. There is no calculated risk for individuals born before 1967, since releases did not start until 1966. The increase in the risk for the 1972 generation corresponds to the temporary increase in activity released into the sea in 1971. The risk associated with

exposure received during pregnancy is maximum for individuals born between 1983 and 1986.

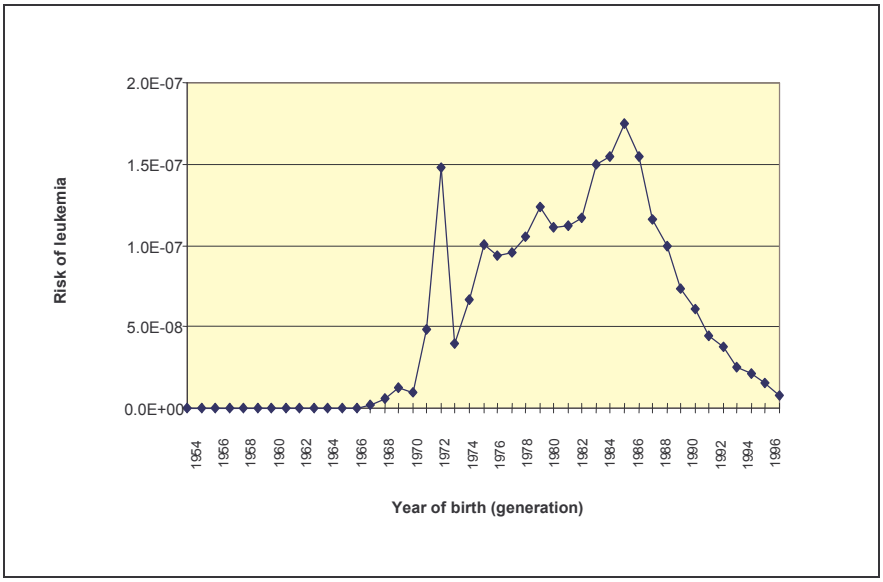


Figure 3.5.3.g: Individual risk cumulated until 24 year old associated with *in utero* exposure due to routine releases from Nord-Cotentin nuclear facilities, by generation

Collective risk

Remember that only individuals born after 1987 in the Beaumont-Hague canton were exposed to routine releases from local nuclear facilities during pregnancy (by definition, new arrivals are born outside the area exposed to routine releases from Nord-Cotentin nuclear facilities). The total cohort contributing to the risk for *in utero* exposure is thus 3937 individuals, or 59% of the total number of individuals in the cohort.

The estimated total number of leukemia cases in 0-24 year old in the Beaumont-Hague canton during the period from 1978 to 1996 related to exposure during pregnancy (*in utero*) due to routine releases from Nord-Cotentin nuclear facilities is 0.0003 (NRPB methods – see section 3.4.1). The sum of the risk related to *in utero* exposure and *ex utero* exposure gives the number of cases that can be assigned to routine releases from local nuclear facilities equal to 0.0012 (table 3.5.3.A).

Table 3.5.3.A: Number of cases of leukemia due to *in utero* exposure and exposure during childhood (*ex utero*) to routine releases from local nuclear facilities (0-24 year old cohort in the Beaumont-Hague canton, 1978-1996)

	Estimated number of cases	Percent
Ex utero exposure	0.0009	75%
In utero exposure	0.0003	25%
Total	0.0012	

Discussion

Risk estimates made for the purposes of this work are based on several assumptions, of which the main ones are as follows.

- The results of risk estimates depend directly on the result of calculations of doses to the red bone marrow, and therefore on all steps used to calculate doses.

- The method assumes that any dose to the red bone marrow induces a risk of leukemia, even if this relation has not been proven. For example, this is the case for the existence of a risk associated with the very low doses delivered at very low dose rates, or for the

existence of a risk of leukemia associated with exposure to radon, but conversely there is no consensus by which these assumptions could be rejected. Furthermore, it should be noted that the results are not sufficient to discuss the existence of a cause and effect relation between exposures and the risk of leukemia, since this is implicitly assumed.

- The risk models used are models that are currently available for a risk estimate. However, it should be noted that these models (*in utero* and *ex utero*) were prepared for populations exposed essentially to external exposures with low linear energy transfer (TEL) and relatively high rates. The risk estimates made are based on the assumption that these models are also adapted to the risk estimate for radiation with high TEL, at low doses and dose rates, and for all pathways and sources of exposure.

- The collective risk calculation required the reconstruction of a "cohort" of individuals in the Beaumont-Hague canton who were between 0 and 24 year old between 1978 and 1996. This reconstruction is only the estimate of the real population, but it was made such that the number of individuals match census data. It should be noted that ignoring the population influx around 1984 would have underestimated the risk by the order of 20%.

- Due to the lack of precise information about the exact location of cases of leukemia observed in epidemiological studies, exposure and risk estimates applied to the entire Beaumont-Hague canton for which an excess risk had been suggested [Viel 1995]. This area is large compared with English radioecological studies carried out earlier (the village of Seascale for the study in the Sellafield area [Simmonds 1995], the town of Thurso for the study in the Dounreay area [Dionan 1986]). Our method assumes that doses are received uniformly by all individuals in the reconstructed cohort, for a given age and a given year.

Risk estimates were made as realistically and comprehensively as possible. Nevertheless, all steps in the risk estimate involved many assumptions and approximations, which means that there is some uncertainty about the final results, which in general are difficult to quantify.

Table 3.5.3.B presents a summary of results obtained within the cohort for exposures received during childhood *(ex utero)*. The table also presents these results corrected for 100 000 person-years, which is the number conventionally used for epidemiological incidence rates.

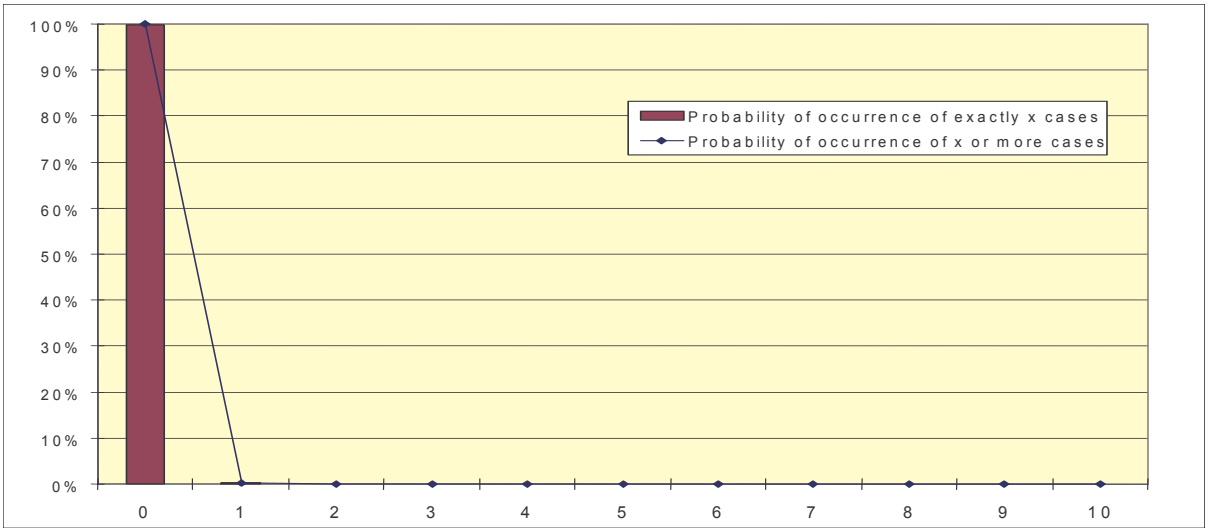
Table 3.5.3.B: Risk of leukemia assignable to exposure during childhood *(ex utero)*, for each exposure source (individuals in the 0-24 year old cohort in the Beaumont-Hague canton, 1978-1996)

	Estimated number of cases in the cohort	%	Risk for 100 000 person years
Local nuclear facilities			
Routine releases	0.0009	0.10%	0.0012
Pipe break	0.0001	0.02%	0.0002
Silo fire	0.0004	0.04%	0.0005
Total	0.0014	0.16%	0.0019
Natural exposure	0.619	74.13%	0.893
Medical exposure	0.203	24.31%	0.293
Exposure due to tests and the Chernobyl accident	0.012	1.44%	0.017
Total	0.835		1.205

The risk of radiation-induced leukemia associated with exposure due to Nord-Cotentin nuclear facilities during childhood *(ex utero)* in the 0-24 year old cohort in the Beaumont-Hague canton between 1978 and 1996 is estimated at 0.0014 cases. 64% of this risk is due to routine releases, and 36% due to the two accidents (pipe break and silo fire).

The risk associated with exposure due to Nord-Cotentin nuclear facilities is 500 times smaller than the risk associated with other sources of exposure. The risk of radiation-induced leukemia in the 0-24 year old cohort in the Beaumont-Hague canton between 1978 and 1996 is estimated at 0.835 cases due to exposure to all sources during childhood *(ex utero)*. 74% of this risk is due to natural radioactivity and 24% is due to exposure to ionizing radiation for medical diagnoses. However, it should be noted that the degree of detail in estimated doses due to other sources is much less than the degree of detail used for local nuclear facilities, and this estimate is only useful for providing a baseline to be compared with the risk due to local nuclear facilities.

The result of 0.0014 cases that can be assigned to exposure to Nord-Cotentin nuclear facilities during childhood *(ex utero)* is a best estimate. Based on this average estimate, the probability of occurrence of 1, 2 or 3 or more cases of radiation-induced leukemia can be calculated (based on a Poisson distribution). As shown in figure 3.5.3.h, there are 999 chances out of a thousand that this will result in zero cases. The probability of occurrence of one radiation-induced case is 1.4 per thousand. The probability of two or more cases occurring is less than 1 in a million.



Number of cases x	Probability of occurrence of exactly x cases	Probability of occurrence of x or more cases
0	$9.99\ 10^{-01}$	1
1	$1.40\ 10^{-03}$	$1.40\ 10^{-03}$
2	$9.79\ 10^{-07}$	$9.79\ 10^{-07}$
3	$4.57\ 10^{-10}$	$4.57\ 10^{-10}$
4	$1.60\ 10^{-13}$	$1.60\ 10^{-13}$
5	$4.48\ 10^{-17}$	$4.48\ 10^{-17}$

Figure 3.5.3.h: Probability of occurrence of a number of cases x, assuming Poisson distribution with mean equal to 0.0014

Given the average estimated risk based on doses due to local installations reconstructed by the Nord-Cotentin Radioecology Group, the probability of occurrence of one case is 1.4 per thousand. Therefore, it can be considered that it is improbable that even one case can be assigned to local nuclear facilities in the 0-24 year old cohort in the Beaumont-Hague canton during the period from 1978 to 1996. Assuming that the average estimated risk is multiplied by a factor of 35, the probability that one case could be assigned to exposure caused by local nuclear facilities would still be less than 5%.

An estimate of the risk of leukemia associated with the dose delivered *in utero* was made for routine releases from local nuclear facilities. The results show that in the entire cohort, the *in utero* dose increases the estimated number of cases by the order of 33%. The total number of cases that can be assigned to *in utero* exposure and *ex utero* exposure to routine releases from local nuclear power stations is 0.0012. In the same way as above, there is a statistical distribution of the probability of occurrence of an integer number of leukemia cases associated with this average estimate. Nevertheless, it can be considered that it is improbable that even one case can be assigned to *in utero* and *ex utero* doses due to routine releases from local nuclear facilities within the 0-24 year old cohort in the Beaumont-Hague canton during the period from 1978 to 1996.

Comparison of results with previous radioecology studies

As described in Section 1, the method used to estimate the risk in the Beaumont-Hague canton was based on the review of previous studies carried out in the United Kingdom. Table 3.5.3.C presents a comparison of the results of these studies in terms of the estimate of the average risk assigned to routine releases from installations.

Table 3.5.3.C: Comparison of the estimate of the average risk assigned to routine releases from installations (*in utero* and *ex utero* doses), and the results of previous British radioecological studies

	Thurso (Dounreay) [Dionan 86]	Seascale (Sellafield) [COMARE 96]	Beaumont-Hague (Nord- Cotentin nuclear facilities**))
Period	1950-84	1945-92	1978-96
Number of individuals	4550	1348	6656
Person-years	74750	≈ 25300 *	69308
Estimated number of radiation-induced cases in the cohort	0.004 [a]	0.020 [a]	0.0012 [b]
Risk of leukemia for 100 000 person-years	0.005 [a]	0.079 [a]	0.002 [b]

*: approximation **: La Hague reprocessing plant, Flamanville power station, Cherbourg arsenal
a: leukemia + non-Hodgkin lymphoma, relative risk model
b: leukemia, additive risk model

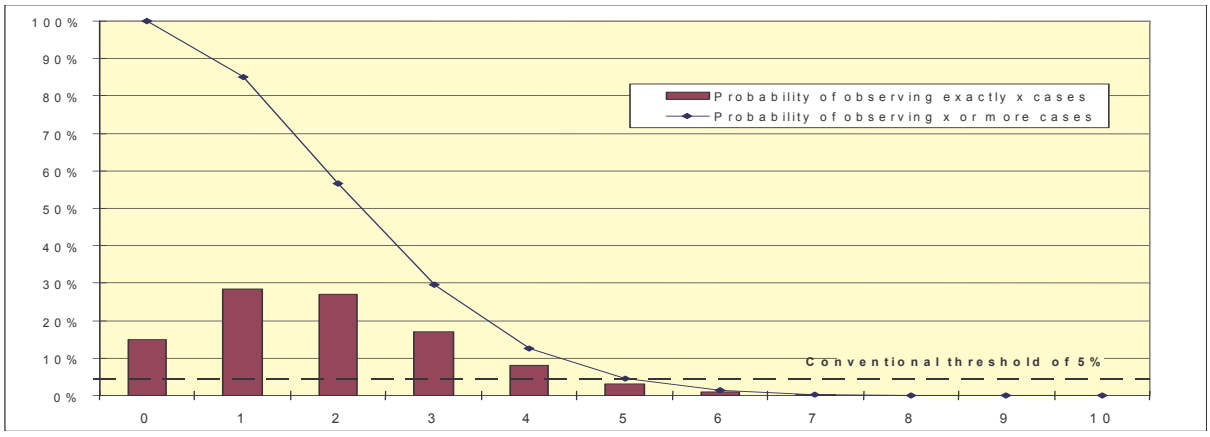
The risk calculation was corrected for 100 000 person-years to make the results obtained with different sizes of cohorts comparable. The risk of radiation-induced leukemia that can be assigned to routine releases is about 40 times higher in the Seascale study than in the Nord-Cotentin Group study. This difference is consistent with dose estimates; the estimated average dose to the red bone marrow in the Seascale cohort is about 30 times greater than the average value estimated within the Beaumont-Hague cohort. Compared with the Thurso study, the risk of radiation-induced leukemia that can be assigned to routine releases is of the same order of magnitude (factor of the order of 2.8 between the results in the two studies).
Therefore, the results obtained by the Nord-Cotentin Group agree well with the results of previous radioecological studies.

Comparison with epidemiological data

Four cases of leukemia were observed in the Beaumont-Hague canton in the 0-24 year old cohort between 1978 and 1996 [Viel and Pobel 1995] [Guizard *et al* 1997].

The number of cases expected is the number of cases that there would have been if the leukemia incidence rates were identical to the rates recorded elsewhere in France (called reference rates). The number of cases expected for the period from 1978 to 1996 calculated by Guizard *et al* is 2.07 [Guizard *et al* 1997]. This estimate is close to the expected number of cases equal to 1.91 obtained by applying national reference rates supplied by FRANCIM in our cohort.

Therefore, compared with our estimate of the expected number of cases, the calculated excess number of cases in the 0-24 year old cohort in the Beaumont-Hague canton during the period from 1978 to 1996 was 2.1 (4 minus 1.9). Nevertheless, the probability of the occurrence of 4 or more cases when an average of 1.9 is expected is 12% (figure 3.5.3.i). This probability is greater than the 5% significance threshold conventionally accepted in epidemiology. Therefore, the theory that this excess number of cases is due to chance cannot be rejected. Nevertheless, even if it is not statistically significant, the incidence of leukemia during the period from 1978 to 1996 in the Beaumont-Hague canton remains high compared with what is expected based on reference rates, which justifies firstly continued surveillance of the incidence of leukemia in the region, and secondly setting up the Nord-Cotentin Radioecology Group.



Number of cases x	Probability of observing exactly x cases	Probability of observing x cases or more
0	14.957%	1
1	28.418%	85.043%
2	26.997%	56.625%
3	17.098%	29.628%
4	8.122%	12.529%
5	3.086%	4.408%
6	0.977%	1.321%
7	0.265%	0.344%
8	0.063%	0.079%
9	0.013%	0.016%
10	0.003%	0.003%

Figure 3.5.3.i: Probability of observing a number of cases x assuming a Poisson distribution with mean equal to 1.9

The work done by the Nord-Cotentin Radioecology Group over the same period leads to the estimated number of cases of leukemia that can be assigned to exposure during childhood *(ex utero)* due to local nuclear facilities equal to 0.0014. The probability that one or more cases could be explained by exposure to local nuclear facilities is 1.4 per thousand. The probability of explaining 2 or more cases would be of the order of 1 per million. **Therefore, it is very improbable that exposure due to local nuclear facilities could significantly contribute to an explanation of the high incidence of leukemia observed on 0-24 year old in the Beaumont-Hague canton during the period from 1978 to 1996.**

The results can be put into perspective compared with the average number of cases of leukemia in France. The average annual risk of leukemia in France in the 0-24 year old cohort is now 2.5 cases per 100,000 individuals (FRANCIM data for the year 1995). The average rate of leukemia obtained by applying the FRANCIM rates from 1978 to 1996 to our cohort is 2.8 per 100,000 person-years. For comparison, the estimated risk of leukemia that can be assigned to exposure due to local nuclear facilities in the cohort is 0.002 to 100,000 person-years. The risk of leukemia that can be assigned to exposure due to local nuclear facilities is therefore low (by a factor of 1400) compared with the average risk of occurrence of leukemia in France.

The estimated number of cases of leukemia in the cohort assignable to all exposure sources is 0.835. Based on this average estimate, the probability of occurrence of one case is 36%, and the occurrence of exactly two cases is 15%. Therefore, it can be considered that all sources of radioactivity combined can play a role in explaining the incidence of leukemia observed in the 0-24 year old cohort in the Beaumont-Hague canton. Nevertheless, remember that the estimate of the risk associated with other sources was made for the purposes of comparing the risk associated with local installations and that the degree of precision assigned to these estimates was much lower, particularly for natural exposure and medical exposure which contribute to more than 98% of the total estimated risk to the cohort. Note also that these exposures also exist throughout the country.

3.6. “Cohort” scenarios

Subsequent to a descriptive study that suggests the existence of an excess number of cases of leukemia in young people living close to La Hague [Viel *et al* 1995], the same authors published the results of a case-control epidemiological study at the beginning of 1997 with the objective of searching for factors that could be associated with the risk of leukemia in the Nord-Cotentin [Pobel et Viel 1997]. In this study, four risk factors showed a statistically significant association with the risk of leukemia:

- time spent on local beaches by children during childhood,
- time spent on local beaches by mothers during pregnancy,
- frequency of consumption of local fish and seafood,
- the time during which children live in a granite house.

GT4 decided to build four scenarios within the previously described cohort in order to estimate the dose to the red bone marrow associated with each of these four factors. These scenarios are called "cohort scenarios". The same simple approach was used for each of the four scenarios, by multiplying exposures associated with the habits involved with each scenario by a factor of 2 to 5 compared with the average exposure assumed for the cohort. The estimate of the additional individual risk associated with each of the four scenarios is made for an individual in the 1971 generation over the period from 1978 to 1996, all other things remaining equal. Only these four cohort scenarios were considered. Other scenarios could be considered, but were not treated in the form of “cohort scenarios” since they are treated as “particular scenarios” (see section 4).

3.6.1. "Time spent on beaches by children during childhood" scenario

Results of epidemiological studies

In the case-control study around La Hague, Pobel and Viel observed a significant increase in the risk of leukemia with the increased time spent on local beaches by children during their childhood [Pobel and Viel 1997]. Time spent on the beach was broken down into six classes: never, only during holidays, less than once a month, between once a month and once a week, between once a week and every day, and almost every day. All cases and all control individuals replied. An increase in the risk was found for all six classes. The probability that this association could be due to chance is less than 1% ($p < 0.01$). The risk is 2.9 times higher for the group that visits a beach more than once a month than for the group that visits a beach less than once a month (Relative risk = 2.9, 95% CI (CI95%) = [1.05 - 8.7]).

In the case-control study in the Seascale cluster [Gardner *et al* 1990], the relative risk including time spent on the beach was 0.6 (Non Significant, CI95%=[0.2 - 1.6]). In the case-control study around Dounreay [Urquhart *et al* 1991], a significant risk equal to 5% (p=0.04) was observed for children who spent time on local beaches, but the authors considered it to be non-conclusive since it was based on five cases only.

Scenario description

Visits to the beach were estimated for the cohort as a number of hours per year, rather than in terms of frequency. Four habits could be modified by intensive visits to local beaches:

- time spent on local beaches: this time is estimated at 100 $h.year^{-1}$ for the cohort,
- bathing time: this time is estimated at 5 $h.year^{-1}$ for the "1 year old" group, and 20 $h.year^{1}$ for other age groups,
- accidental ingestion of sea water: the ingestion rate for the cohort is estimated at 0.05 $l.year^{-1}$ for the "1 year old" group, and 0.1 $l.year^{-1}$ for other age groups,
- accidental sand ingestion: the ingestion rate for the cohort is estimated at 5 $g.year^{-1}$ for the "1 year old" group, 2 $g.year^{-1}$ for the "5 year old" group, 1 $g.year^{-1}$ for the "10 year old group" and 0.5 $g.year^{-1}$ for the over 15 year group.

To reflect intensive visits to beaches, the estimate of doses to the red bone marrow associated with these four habits was made assuming that these parameters are twice as high and 5 times higher than the values for the cohort. Table 3.6.1.A contains a comparison of the values thus obtained compared with the results of the CREDOC survey for COGEMA on outdoors and indoors activities in the Nord-Cotentin [CREDOC 1998].

Table 3.6.1.A: Comparison of the characteristics of the "time spent on beaches by children" cohort scenario with the results of the CREDOC survey

	Cohort				CREDOC 1998	
$h.year^{-1}$	**age**	**Cohort**	**x2 Scenario**	**x5 Scenario**	**age**	**95th perc.**
Time spent on local beaches	0-24 year old	100	200	500	0-24 year old	125 to 360 *
Bathing time	1 year	5	10	25	< 3 year	11
	5-24 year old	20	40	100	3-24 year old	24 to 53 **

* Visits to northern west coast beaches + collecting shells, shrimps, seaweed, etc. in the northern west coast area + walking along the sea front in the northern west coast area, 95th percentile according to age groups [CREDOC 1998]

** bathing in the sea in the La Hague coast area, 95th percentile according to age groups [CREDOC 1998]

The x2 scenario gives values close to values used in the CREDOC survey in 1998 for the 95th percentiles, whereas the x5 scenario overestimates times spent and is outside the upper bound of the results of the CREDOC survey. For example, 500 h.year^{-1} on local beaches corresponds to approximately 1 h 20 per day for every day of the year.

Results

Individual doses associated with the "time spent on beaches by children" cohort scenarios are presented in table 3.6.1.B for an individual in the 1971 generation.

Table 3.6.1.B: Individual doses to the red bone marrow cumulated from 0 to 24 year for an individual in the 1971 generation in the "time spent on beaches by children" cohort scenario

Exposure source	Cohort	x2 Scenario	x5 Scenario
Routine releases from local installations: external exposure due to releases into the sea sand and sea water ingestion other exposure pathways Total	 20 µSv 2 µSv 55 µSv 77 µSv	 39 µSv 4 µSv 55 µSv 98 µSv	 95 µSv 10 µSv 55 µSv 160 µSv
Increase in %	-	27%	108%
Natural exposure *	59 mSv	59 mSv	59 mSv
Medical exposure	18.5 mSv	18.5 mSv	18.5 mSv
Fallout from tests and the Chernobyl accident	1 mSv	1 mSv	1 mSv
Total	78.6 mSv	78.6 mSv	78.7 mSv
Increase in %	-	0.03%	0.10%

Table 3.6.1.C shows the individual risk associated with "time spent on beaches by children" cohort scenarios for an individual in the 1971 generation.

Table 3.6.1.C: Individual risk associated with "time spent on beaches by children" cohort scenarios

Exposure source	Cohort	x2 scenario	x5 scenario
Routine releases from local installations	2.80×10^{-7}	3.70×10^{-7}	6.56×10^{-7}
Increase in %		32%	135%
Natural exposure	2.23×10^{-4}	2.23×10^{-4}	2.23×10^{-4}
Medical exposure	7.43×10^{-5}	7.43×10^{-5}	7.43×10^{-5}
Fallout from tests and the Chernobyl accident	4.32×10^{-6}	4.32×10^{-6}	4.32×10^{-6}
Total	3.02×10^{-4}	3.02×10^{-4}	3.03×10^{-4}
Increase in %		0.03%	0.12%

3.6.2. "Time spent on local beaches by mothers during pregnancy" scenario

Results of epidemiological studies

In the case-control study around La Hague, Pobel and Viel observed a significant increase in the risk of leukemia with the time spent on local beaches by mothers during pregnancy [Pobel et Viel 1997]. Time spent on the beach was broken down into six classes - never, only during holidays, less than once a month, between once a month and once a week, between once a week and every day, and almost every day. Replies were received from 23 cases (85%) and from 186 case-controls (97%). An increase in the risk was found for all six classes ($p < 0.01$). The risk is 4.5 times higher for the group that visits local beaches more than once a month than for the group that visits a beach less than once a month (Relative risk = 4.5, (95% CI = [1.5 - 15.2]).

Scenario description

Two types of habit could be modified by intensive time spent on local beaches during pregnancy:

- time spent on local beaches: this time is estimated at 100 $h.year^{-1}$ for the cohort,
- bathing time: this time is estimated at 20 $h.year^{-1}$ for the adults in the cohort,

To reflect intensive time spent on beaches during pregnancy, doses to the fetus associated with these two types of habit are estimated assuming that the parameters are twice as high and 5 times higher than the values for the cohort. 500 $h.year^{-1}$ spent on the beach corresponds approximately to 1 h 30 every day throughout the 9 months of pregnancy. Table 3.6.2.A presents a comparison of the values thus obtained with the results of the CREDOC survey for COGEMA on outdoors and indoors activities in the Nord-Cotentin [CREDOC 1998].

Table 3.6.2.A: Comparison of the characteristics of the "time spent on beaches by mothers" cohort scenario with the results of the CREDOC survey

	Cohort				CREDOC 1998	
$h.y^{-1}$	age	Cohort	x2 Scenario	x5 scenario	age	95th perc.
Time spent on local beaches	15-24 years	100	200	500	25-44 years	196-218 *
Bathing time	15-24 years	20	40	100	25-44 years	10 to 20 **

* Visits to northern west coast beaches + collecting shells, shrimps, seaweed, etc. in the northern west coast area + walking along the sea front in the northern west coast area, 95th percentile according to age groups [CREDOC 1998]

** bathing in the sea in the La Hague coast area, 95th percentile according to age groups [CREDOC 1998]

It should be noted that the age groups in table 3.6.3.A are not the same as the age groups used in the CREDOC study; the age of mothers in the cohort is assumed to be the maximum age group (15-24 years) whereas the CREDOC values are given for a young adult (25-44 years). The x2 scenario gives values similar to values obtained in the 1988 CREDOC survey for the 95th percentiles, whereas the x5 scenario overestimates times spent.

Results

Individual doses to the red bone marrow associated with "time spent on beaches by mothers" cohort scenarios are given in table 3.6.2.B for an individual in the 1971 generation.

Table 3.6.2.B: Individual doses to the red bone marrow cumulated from 0 to 24 years for an individual in the 1971 generation in the "time spent on beaches by mothers" cohort scenario

Exposure to routine releases from local installations	Cohort	x2 scenario	x5 scenario
in utero	3.6 µSv	3.8 µSv	4.5 µSv
Increase in %		6%	25%
ex utero	77 µSv	77 µSv	77 µSv
Total	80.6	80.8	81.5
Increase in %		0.2%	1.1%

Table 3.6.2.C shows the individual risk associated with the "time spent on beaches by mothers" cohort scenario for an individual in the 1971 generation.

Table 3.6.2.C : Individual risk associated with the "time spent on beaches by mothers" cohort scenarios

Exposure to routine releases from local installations	Cohort	x2 scenario	x5 scenario
in utero	4.85×10^{-8}	5.13×10^{-8}	5.98×10^{-8}
Increase in %		6%	23%
ex utero	2.80×10^{-7}	2.80×10^{-7}	2.80×10^{-7}
Total	3.28×10^{-7}	3.31×10^{-7}	3.39×10^{-7}
Increase in %		1%	3%

In this scenario, the risk associated with exposure due to routine releases from local installations increases due to *in utero* exposure. The risk associated with exposure due to routine releases from local installations during childhood remains the same. It is found that the risk associated with *in utero* exposure remains less than the risk associated with *ex utero* exposure, even when mothers visit beaches for very long periods (1h30 per day throughout their pregnancy in the x5 scenario). In the x5 scenario, the total increase in the individual risk associated with exposure due to routine releases from local installations is only 3% compared with an average person in the cohort.

Furthermore, the risk associated with exposure to other sources (natural, medical, fallout from atmospheric testing of nuclear weapons and the Chernobyl accident) remains constant (which is not shown in table 3.6.2.C since *in utero* exposure is not considered for these sources). The increase in the risk associated with intensive time spent on beaches by mothers during pregnancy is very low compared with the risk associated with all sources of exposure.

3.6.3. "Consumption of local fish and seafood" scenario

Results of epidemiological studies

In the case-control study around La Hague, Pobel and Viel observed a significant increase in the risk of leukemia with the consumption frequency of local fish and seafood [Pobel and Viel 1997]. Time spent on the beach was broken down into six classes - never, only during holidays, less than once a month, between once a month and once a week, between once a week and every day, and almost every day. Replies were received from all cases and from all case-controls. An increase in the risk was found for all six classes ($p < 0.01$). The risk is 2.7 times higher (at the limit of statistical significance) for the group that eats fish and other seafood more than once a week than for the group that eats fish and other seafood less than once a week (Relative risk = 2.7, 95% CI=[0.9 - 9.5]).

This result is not corroborated by previous studies: in the Seascale case-control study [Gardner *et al* 1990], the relative risk was 1.2 (not significant, 95% CI =[0.5 - 3.0]) with the consumption of fish and 1.1 (not significant, 95% CI =[0.1 - 7.9] with the consumption of other seafood). In the study around Dounreay [Urquhart *et al* 1991], the relative risks associated with these two factors were much less than 1 and not significant.

Scenario description

Three types of habit could be modified by high consumption of local fish and other seafood:

- consumption of fish,
- consumption of crustaceans,
- consumption of molluscs.

In order to reflect a high consumption of local fish and seafood, doses to the red bone marrow associated with these three types of habit are estimated assuming that the parameters are twice and 5 times higher than values for the cohort. Table 3.6.3.A contains a

comparison of the values thus obtained compared with the results of the CREDOC survey for COGEMA on dietary habits in the Nord-Cotentin [Dufour 1998].

Table 3.6.3.A: Comparison of the characteristics of the "consumption of seafood" cohort scenario with the results of the CREDOC survey

kg.year^{-1}	Cohort age	Cohort	Cohort x2 scenario	Cohort x5 scenario	CREDOC 1998 age	CREDOC 1998 95th perc. *
Consumption of fish	1 year	2	4	10	< 2 years	6.5
	5 years	6	12	30	2-14 years	41.7
	10-15 yrs	10	20	50		
	15-24 yrs	23	46	115	15-34 yrs	23.5
Consumption of crustaceans	1 year	0	0	0	< 2 years	0
	5 years	1	2	5	2-14 years	20.8
	10-15 yrs	2	4	10		
	15-24 yrs	13	26	65	15-34 yrs	35.4
Consumption of molluscs	1 year	0	0	0	< 2 years	0
	5 years	0.5	1	2.5	2-14 years	4.1
	10-15 yrs	1	2	5		
	15-24 yrs	7	14	35	15-34 yrs	4.1

* consumption of seafood in the northern west coast area, 95th percentile for consumers only [Dufour 1998]

The 95th percentiles of consumed quantities of local seafood in the CREDOC 1998 survey are intermediate between values obtained for the x2 scenario and the x5 scenario. Nevertheless, it appears that the x5 scenario corresponds to an extreme and highly improbable consumption; in this case the quantity of local fish, crustaceans and molluscs ingested for this scenario in the 15-24 year old cohort is 590 g.d^{-1}.

Furthermore, the percentage of the cohort consuming local products is estimated as 53% for fish and crustaceans and 75% for molluscs. It has been assumed that 100% of the consumption was from local sources.

Results

Individual doses to the red bone marrow associated with the "consumption of seafood" cohort scenarios are given in table 3.6.3.B for an individual in the 1971 generation.

Table 3.6.3.B: Individual doses to the red bone marrow cumulated for the 0-24 year old cohort for an individual in the 1971 generation in the "consumption of seafood" cohort scenario

Exposure source	Pop. group	x2 scenario	x5 scenario
Routine releases from local installations:			
ingestion of seafood	36 µSv	129 µSv	322 µSv
other exposure pathways	41 µSv	41 µSv	41 µSv
Total	77 µSv	170 µSv	363 µSv
Increase in %	-	121%	371%
Natural exposure *	59 mSv	76 mSv	129 mSv
Increase in %	-	29%	119%
Medical exposure	18.5 mSv	18.5 mSv	18.5 mSv
Fallout from tests and the Chernobyl accident	1 mSv	1 mSv	1 mSv
Total	78.6 mSv	95.7 mSv	148.9 mSv
Increase in %	-	22%	89%

*: increase due to ingestion of lead 210 and polonium 210

Table 3.6.3.C shows the individual risk associated with the “consumption of seafood” cohort scenarios for an individual in the 1971 generation.

Table 3.6.3.C: Individual risk associated with the “consumption of seafood” cohort scenarios

Exposure source	P. group	x2 scenario	x5 scenario
Routine releases from local installations	2.80×10^{-7}	6.15×10^{-7}	1.34×10^{-6}
Increase in %		120%	380%
Natural exposure *	2.23×10^{-4}	2.78×10^{-4}	4.44×10^{-4}
Increase in %		24%	99%
Medical exposure	7.43×10^{-5}	7.43×10^{-5}	7.43×10^{-5}
Fallout from tests and the Chernobyl accident	4.32×10^{-6}	4.32×10^{-6}	4.32×10^{-6}
Total	3.02×10^{-4}	3.57×10^{-4}	5.24×10^{-4}
Increase in %		18%	73%

*: increase due to ingestion of lead 210 and polonium 210

In this scenario, the risk associated with exposure due to routine releases from local installations increases, but the risk due to natural exposure due to ^{210}Pb and ^{210}Po contained in molluscs and crustaceans also increases. The increase in the overall risk is then significant: +18% for the x2 scenario and 73% for the x5 scenario. Nevertheless, even if the increase in the risk associated with local nuclear facilities is very high (+120% for the x2 scenario and +380% for the x5 scenario), the proportion of this exposure source in the total risk remains very low (less than 0.3% in the x5 scenario).

3.6.4. "Residence in a granite house" scenario

Results of epidemiological studies

In the case-control study around La Hague, Pobel and Viel observed a very high relative risk with the time during which children live in a granite house, or a house built on granite. The risk of leukemia increases by 18% per year of residence (relative risk = 1.18 per year, 95% CI =[1.1 - 1.4]).

In their discussion, the authors suggest a relation between exposure to domestic radon and the risk of leukemia [Pobel and Viel 1997]. This interpretation does not agree with data in the epidemiological literature, which are inconclusive about the existence of an association between exposure to radon and the risk of leukemia [Lubin *et al* 1998].

Scenario description

Each person in this cohort is assumed to live at the same location from his birth until he leaves the cohort (25th birthday or December 1996). Therefore, the residence time cannot be varied. Nevertheless, the impact of the radon concentration in the home and exposure to terrestrial radiation on the dose to the red bone marrow can be determined.

Exposure to radon within the cohort is estimated based on the average of data obtained from the campaign measuring radon levels in homes in the Manche department, which was 74 Bq.m^{-3} (43 measurements). We propose to estimate doses to the red bone marrow associated with residence throughout childhood in homes in which the radon concentration is twice or 5 times the average level, which is 148 Bq.m^{-3} and 370 Bq.m^{-3} respectively. This value corresponds approximately to the value of the 95th percentile of the distribution of the concentration of domestic radon in the Manche department (301 Bq.m^{-3}).

Terrestrial exposure of the cohort is compared with the average exposure in France, namely 0.41 mSv.year^{-1}. We propose to multiply this average level by 2 and 5, to give 0.82 mSv.year^{-1} and 2.05 mSv.year^{-1} respectively.

Results

The concentration of radon in air does not give the dose directly. Quantities of air inhaled and the transfer through the red bone marrow have to be estimated in order to calculate the dose. Unfortunately, data on this subject are inconclusive. The estimate of doses to the red bone marrow vary by an order of magnitude, depending on which dosimetric model is chosen (table 3.6.4.A). The value proposed by GT4 corresponds to the [Richardson *et al* 1991] model. It is consistent with the choice of the estimate of average exposure of the cohort to radon.

Table 3.6.4.A: Doses to the red bone marrow for the "residence in a home with high radon concentration" cohort scenarios

	Radon concentration	Range given by dosimetric models	**value proposed by GT4**
	$Bq.m^{-3}$	$mSv.year^{-1}$	**$mSv.year^{-1}$**
cohort	74	0.06-0.6	**0.33**
x2 scenario	148	0.12-1.2	**0.66**
x5 scenario	370	0.3-3	**1.65**

Table 3.6.4.B contains individual doses to the red bone marrow associated with the “residence in the granite home” cohort scenarios for an individual in the 1971 generation.

Table 3.6.4.B: Cumulated individual doses to the red bone marrow from birth to 24 year old for an individual in the 1971 generation associated with the “residence in a granite home” cohort scenario

Exposure source	**Cohort**	**x2 scenario**	**x5 scenario**
Exposure due to radon	8.25 mSv	16.5 mSv	41.25 mSv
Terrestrial exposure	10.25 mSv	20.2 mSv	51.25 mSv
Total	18.5 mSv	37 mSv	92.5 mSv
Increase %		100%	400%
Routine releases from local installations	77 µSv	77 µSv	77 µSv
Other natural exposure	40.5 mSv	40.5 mSv	40.5 mSv
Medical exposure	18.5 mSv	18.5 mSv	18.5 mSv
Fallout from tests and the Chernobyl accident	1 mSv	1 mSv	1 mSv
Total	78.5 mSv	97 mSv	152.5 mSv
Increase %		24%	94%

Table 3.6.4.C presents the individual risk associated with the "residence in a granite home” cohort scenarios for an individual in the 1971 generation.

Table 3.6.4.C: Individual risk associated with the "residence in a granite home" cohort scenarios

Exposure source	Cohort	x2 scenario	x5 scenario
Exposure due to radon	3.31×10^{-5}	6.63×10^{-5}	1.66×10^{-4}
Terrestrial exposure	4.12×10^{-5}	8.24×10^{-5}	2.06×10^{-5}
Increase %		100%	401%
Routine releases from local installations	2.80×10^{-7}	2.80×10^{-7}	2.80×10^{-7}
Other natural exposure	1.49×10^{-4}	1.49×10^{-4}	1.49×10^{-4}
Medical exposure	7.43×10^{-5}	7.43×10^{-5}	7.43×10^{-5}
Fallout from tests and the Chernobyl accident	4.32×10^{-6}	4.32×10^{-6}	4.32×10^{-6}
Total	3.02×10^{-4}	3.77×10^{-4}	6.00×10^{-4}
Increase %		25%	98%

In this scenario, the risk associated with exposure to radon and terrestrial exposure increases, with the risk associated with other sources remaining the same. Apparently, living in a home in which the radon concentration is 5 times higher than the average in the Manche department throughout childhood would double the individual risk of radiation-induced leukemia compared with living in a home with an average concentration.

3.6.5. Summary of cohort scenarios

In their 1997 case-control study, D. Pobel and J.F. Viel concluded that their results "provided convincing arguments in favor of the existence of a cause and effect role of environmental exposure to radiation in the incidence of leukemia in children". In particular, three risk factors were associated with the risk of leukemia (time spent on beaches by children, time spent on beaches by mothers during pregnancy, and the frequency of consumption of local fish and seafood), which suggested a link with exposure to marine radioactivity [Pobel and Viel 1997].

The radioecological study shows that more than 90% of the collective risk associated with exposure due to routine releases from local nuclear facilities within the 0-24 year old cohort in the Beaumont-Hague canton between 1978 and 1996 is associated with the marine exposure pathway in the broad sense (external exposure to sediments and sand, ingestion of seafood, accidental ingestion of sand, ingestion of products contaminated by sea spray or spreading seaweed).
Three scenarios were defined to determine the impact of some habits associated with this exposure pathway on the risk of leukemia:

- The "time spent on local beaches by children during childhood" scenario shows that even intensive time spent on beaches (1h20 per day for the x5 scenario) throughout childhood does not significantly increase the risk of radiation-induced leukemia.

- The "time spent on local beaches by mothers during pregnancy" scenario shows that even intensive time spent on beaches (1h30 per day for the x5 scenario) throughout pregnancy does not significantly increase the risk of radiation-induced leukemia.

- In the "consumption of local fish and seafood" scenario, the radiation-induced risk of an individual who consumes a large quantity of local seafood (up to 590 g per day) would

increase by about 73%, but this increase is essentially due to the ingestion of natural radionuclides (almost 100%).

Another factor was associated with the risk of leukemia in the case-control study, namely the duration of residence in a granite house, or a house built on granite. In their discussion, the authors suggested that this association could reflect a link between the risk of leukemia and exposure to radon [Pobel and Viel 1997].
The "Residence in a granite house" scenario shows a significant increase in the risk with the radon concentration; living in a home with a radon concentration of 370 $Bq.m^{-3}$ and a terrestrial exposure multiplied by 5 (x5 scenario) increases the risk by almost 100% compared with the risk for a home with an average concentration (74 $Bq.m^{-3}$). Half of this increase in the risk is due to the increase in terrestrial exposure and half is due to radon. Nevertheless, this result cannot be used as a justification for a cause and effect link between exposure to radon and the risk of leukemia in young people, and in any case this association has not been established epidemiologically.

The number of cases estimated above does not take into account the variability of the dose received within the cohort, but is based rather on the use of the average values, as representative as possible of exposure of the cohort. Nevertheless, this type of approach cannot reflect the uncertainty around this estimate. A large number of approximations and assumptions are made at the various steps in the evaluation. A first estimate of the sensitivity of the model was presented in "cohort" scenarios. This analysis tested the sensitivity of the dose calculation model to some dose-relevant habit parameters, but did not take into account all model variability sources (equations, other parameters, etc.). A second approach to the sensitivity is now considered in which estimates of average doses for the cohort are put into perspective with doses associated with particular situations (construction of "particular scenarios") that could lead to exposures greater than those obtained for the cohort.

4. VARIATION OF THE DOSE AS A FUNCTION OF PARTICULAR SCENARIOS

GT4 identified different particular scenarios corresponding to situations that could lead to exposures higher than the average exposure. Effective doses associated with these particular scenarios were estimated. They can be compared with the annual effective dose calculated for the average scenario that corresponds to exposure of an average adult in the Beaumont-Hague canton.

The particular scenarios identified by GT4 may be classified in two groups: " chronic " particular scenarios for which the effective dose is calculated for a year of exposure:

- fishermen in the Huquets area,
- farmers living in the Pont-Durand district,
- fishermen in the Goury area (scenario presented in the detailed report)
- adults living in Digulleville (scenario presented in the detailed report),
- farmers living in the 1500 m area (scenario presented in the detailed report),

and particular "occasional" scenarios for which the effective dose is calculated for an occurrence of the action:

- fishing in the “near field” around the end of the release pipe into the sea,
- carrying out activities close to the release pipe in the Moulinets Bay,
- using the water from the Sainte-Hélène river in Pont-Durand,
- fishing in the Sainte-Hélène river in Pont-Durand,
- playing at the mouth of the Sainte-Hélène river,

- walking around the fence of the CM.

Doses associated with these scenarios can be compared with the dose associated with the:

- average scenario.

Information is also given about exposure associated with consumption of seaweed based products and the transport of irradiated materials.
Furthermore, effective dose calculations were carried out to provide information to public authorities about the choice of critical groups for the purposes of the regulatory investigation of the impact study submitted by COGEMA. These calculations are described in the “Explanatory note on calculations of effective doses to critical groups written by the Plenary Group of the Nord-Cotentin Radioecology Group", in an appendix to GT4 detailed report.

4.1. Average scenario

4.1.1. Description of the average scenario

The purpose of the dose calculation for the average scenario is to define the average level of the effective dose, this value can then be used as a reference for doses calculated for other particular scenarios.
Habit parameters for an average adult (time spent, dietary habit, self-consumption ratio, etc.) are used for this calculation (table 4.1.1.A). The values of concentrations in land and sea environments correspond to values used for dose estimates for the cohort. These are the average values supplied by GT3. The exposure pathways used are ingestion of marine and land products, accidental ingestion of soil, sand and sea water, inhalation of the plume and suspended particles, exposure pathways associated with sea spray, external exposure to the deposit and to the plume.

Table 4.1.1.A: Values of habit parameters for the average scenario, the "fishermen in the Huquets area" scenario and the "farmers living in Pont-Durand district" scenario

	Average scenario	Fishermen in the Huquets area	Farmers living in Pont-Durand district
Ingestion rates			
crustaceans	13 kg.year^{-1}	61 kg.year^{-1}	13 kg.year^{-1}
molluscs	7 kg.year^{-1}	31 kg.year^{-1}	7 kg.year^{-1}
fish	23 kg.year^{-1}	67 kg.year^{-1}	23 kg.year^{-1}
milk	122 kg.year^{-1}	122 kg.year^{-1}	297 kg.year^{-1}
dairy products	33 kg.year^{-1}	33 kg.year^{-1}	78 kg.year^{-1}
beef	21 kg.year^{-1}	21 kg.year^{-1}	30 kg.year^{-1}
mutton	2 kg.year^{-1}	2 kg.year^{-1}	2 kg.year^{-1}
pork	30 kg.year^{-1}	30 kg.year^{-1}	43 kg.year^{-1}
poultry	23 kg.year^{-1}	23 kg.year^{-1}	32 kg.year^{-1}
eggs	12 kg.year^{-1}	12 kg.year^{-1}	25 kg.year^{-1}
leaf-vegetables	24 kg.year^{-1}	24 kg.year^{-1}	55 kg.year^{-1}
root-vegetables	131 kg.year^{-1}	131 kg.year^{-1}	265 kg.year^{-1}
fruit-vegetables	73 kg.year^{-1}	73 kg.year^{-1}	178 kg.year^{-1}
cereals	123 kg.year^{-1}	123 kg.year^{-1}	123 kg.year^{-1}
jam	4 kg.year^{-1}	4 kg.year^{-1}	10 kg.year^{-1}
cider	38 kg.year^{-1}	38 kg.year^{-1}	170 kg.year^{-1}
Accidental ingestion			
soil	1.8 g.year^{-1}	1.8 g.year^{-1}	1.8 g.year^{-1}
sand	0.5 g.year^{-1}	0.5 g.year^{-1}	0.5 g.year^{-1}
sea water	0.1 l.year^{-1}	0.1 l.year^{-1}	0.1 l.year^{-1}
Respiratory rate	7300 m^3.year^{-1}	9200 m^3.year^{-1}	9200 m^3.year^{-1}
Resuspension rates	10^{-8} m^{-1}	10^{-8} m^{-1}	4.10^{-7} m^{-1}
Time spent			
outdoors	1750 h.year^{-1}	2400 h.year^{-1}	3500 h.year^{-1}
bathing	20 h.year^{-1}	20 h.year^{-1}	20 h.year^{-1}
on the beach	100 h.year^{-1}	100 h.year^{-1}	100 h.year^{-1}
handling fishing equipment	-	2400 h.year^{-1}	-

4.1.2. Results

Dose calculations were carried out for each year between 1966 and 1996. Figure 4.1.2.a shows the variation in doses. GT4 was particularly interested in two years, 1985 and 1996, 1985 being the year in which the activities of releases into the sea from COGEMA La Hague reprocessing plants were the highest, and 1996 being the year in which releases into the atmosphere from COGEMA La Hague reprocessing plants were the highest. The total effective dose for the average scenario was 18 µSv in 1985. It was essentially due to radionuclides released into the sea (^{106}Ru, ^{99}Tc and ^{154}Eu). In 1996, the total effective dose for the average scenario was 5 µSv due mainly to radionuclides released into the atmosphere (^{85}Kr, ^{14}C and ^{129}I), since releases into the atmosphere increased between 1985 and 1996, whereas releases into the sea reduced. Figures 4.1.2.b and 4.1.2.c show the contribution of the main radionuclides to the total effective dose for 1985 and 1996. The preponderant exposure pathway is ingestion (81% of the dose in 1985 and 70% in 1996), the remaining 20 to 30% being due mainly to external exposure (to deposit in 1985 and to the plume in 1996).

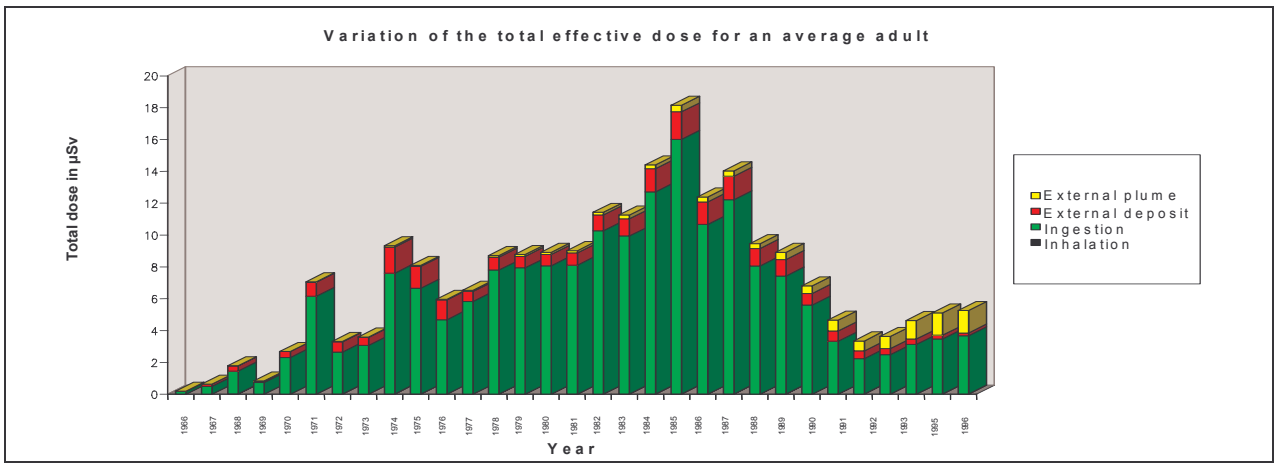


Figure 4.1.2.a: Variation of the effective dose for an adult in the average scenario as a function of time

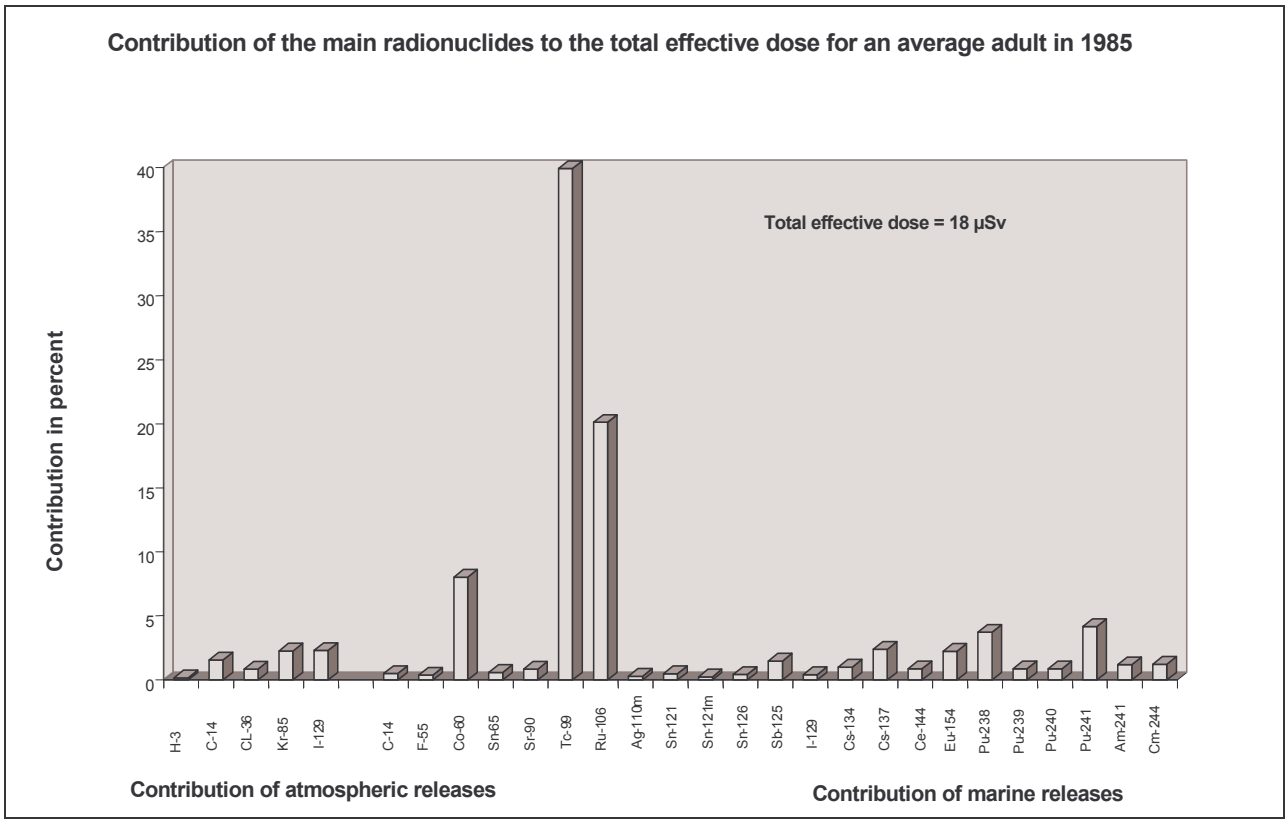


Figure 4.1.2.b: Contribution of the main radionuclides to the effective dose for an adult in the average scenario in 1985[66]

[66] The average adult is assumed to be exposed to exposure pathways associated with spreading of seaweed (see section 2.2.2), which is the reason for the high contribution of ^{99}Tc.

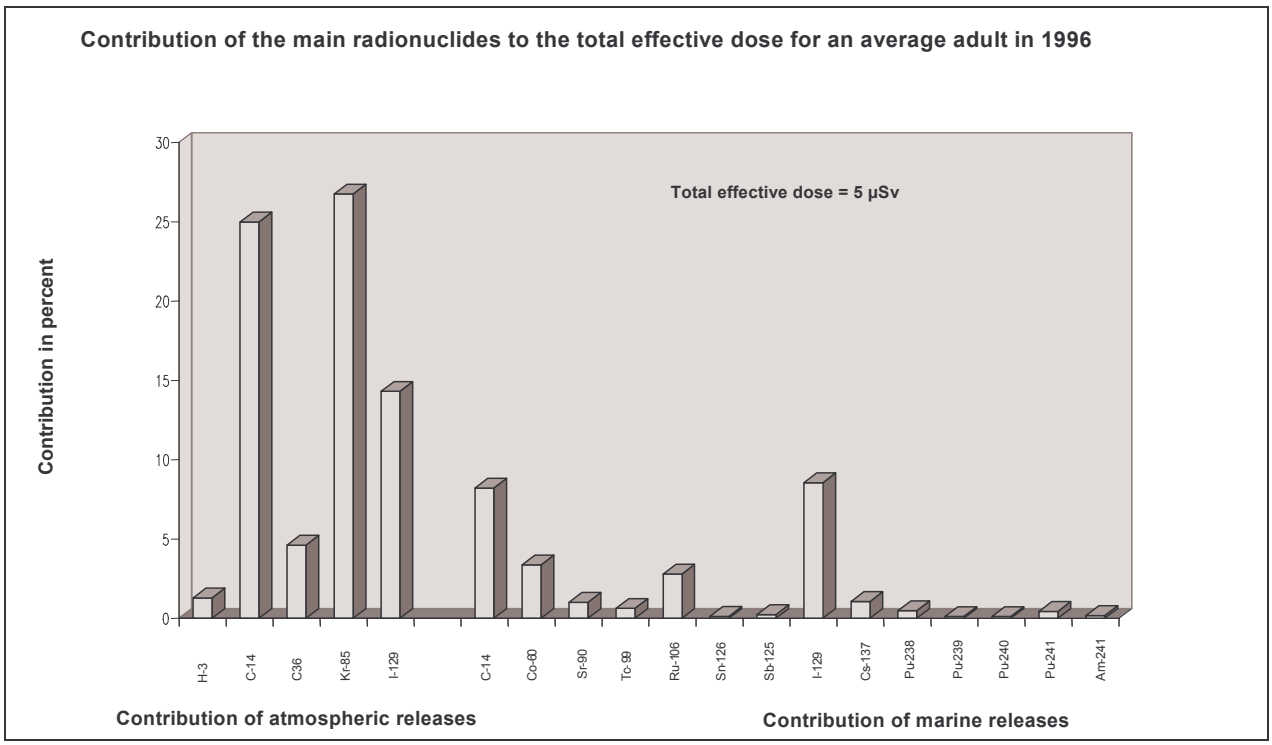


Figure 4.1.2.c: Contribution of the main radionuclides to the effective dose for an adult in the average scenario in 1996

4.1.3. Sensitivity study related to parameters defined by GT3

GT3 proposed different values for some parameters used in the terrestrial environment transfer model. All calculations of effective doses or doses to the red bone marrow presented above have been made using the values of parameters recommended by GT3. The purpose of this section is to present how the choice between values proposed by GT3 influences the dose. In order to limit the number of calculations, GT4 decided to carry out these sensitivity calculations on the average scenario for 1996. The sensitivity of the dose calculation is examined for calculation cases recommended by GT3:

- value of the dry weather capture ratio equal to 0.25 for all plants instead of 0.5 for leaf-vegetables and fruit-vegetables, 0.7 for root vegetables and grass and 0.9 for cereals, silo maize and hay (CASE 1),
- food ration of a chicken in the open air: 100 $g.d^{-1}$ of grass, 35 $g.d^{-1}$ of cereals and 0.1 $l.d^{-1}$ of water instead of 60 $g.d^{-1}$ of cereals and 0.2 $l.d^{-1}$ of water (CASE 2),
- transformation coefficient of fruit into jam equal to 0.8 instead of 0.5, and transformation coefficient of milk into dairy products equal to 9 for all radionuclides instead of 8.2 for strontium isotopes, 2.3 for iodine isotopes and 1 for other radionuclides (CASE 3),
- values of the root transfer factor for hay multiplied by 5 for all radionuclides (CASE 4).

All other calculation parameters remain unchanged.

Table 4.1.3.A shows differences in effective doses associated with each calculation case compared with the reference calculation for an average scenario (total effective dose 5 µSv in 1996).

Table 4.1.3.A: Sensitivity of the effective dose calculation to the parameters identified by GT3

	Difference in %
CASE 1	- 9%
CASE 2	+ 1%
CASE 3	+ 12%
CASE 4	+ 0.01%

Therefore, the effective dose is not very sensitive to the food rations of poultry (CASE 2) and is very insensitive to root transfer factors for hay (CASE 4). However, differences of the order of 10% are obtained depending on the choice of the dry weather capture ratio (CASE 1) and food product transformation coefficients (CASE 3). GT4 calculations presented in this report use the values of the capture ratio that give the highest effective dose among the two assumptions proposed by GT3. However, the values of the transformation coefficients used by GT4 give the lowest effective dose among the two assumptions proposed by GT3.

4.2. "Fishermen in the Huquets area" particular scenario

4.2.1. Description of the "Fishermen in the Huquets area" scenario

The dietary habit and self-consumption ratios of fishermen in this particular scenario were obtained from results of the survey in the Flamanville area [Mathieu and Mathieu 1978] (Table 4.1.1.A). GT4 had already made considerable use of this reference in choosing food rations and self-consumption ratios for the cohort. Unlike the approach that was used for the cohort, assumed rations of seafood for the "Fishermen" scenario are "high consumer" rations rather than average rations. Local fishermen were considered as being the individuals most likely to consume large quantities of seafood. Therefore, GT4 decided to use the 95 percentile of seafood consumers (average consumptions more than twice the standard deviation of the distribution of consumptions supplied in [Mathieu and Mathieu 1978]). Food rations for land products are average rations of adults. It would have been unrealistic to consider that fishermen are "high consumers of all food products". Self-consumption ratios are also the same as for the average adult.
In the absence of any particular study concerning the time spent in handling fishing equipment (this parameter is used in the model of external exposure), a typical value of 2400 $h.year^{-1}$ was used, which is equivalent to about 7 $h.d^{-1}$ (27% of the total time).
The assumed respiratory rate assumed for fishermen was the value recommended by ICRP 66 for outdoor workers. Accidental ingestion rates of soil, sand and sea water are the same as for an average adult (see Average scenario).

The values of concentrations in the marine environment correspond to values in the Huquets area. GT3 showed that with the exception of the near field around the release pipe, the Huquets fishing area is more highly exposed to liquid releases into the sea from COGEMA La Hague reprocessing plants than any other fishing area. The year 1985 was used since it was the year in which liquid releases into the sea were greatest.

The values of concentrations used for the terrestrial environment are values corresponding to the village of Auderville, the fishermen considered in this scenario being assumed to live in Goury. However, for 1985, the choice of the home village among the 19 villages in the canton does not significantly modify the dose.

4.2.2. Results

Effective doses were calculated for the entire study period (1966-1996). The variation in doses is presented in figure 4.2.2.a. The year 1985 is the year for which the effective dose was the highest (226 µSv) for the "fishermen in the Huquets area" scenario. The preponderant exposure pathway is ingestion of seafood (88%), the remaining 12% being due to external exposure to the deposit. Figure 4.2.2.b presents the contribution of the main radionuclides. ^{106}Ru is the main contributor to the dose (almost 40%).

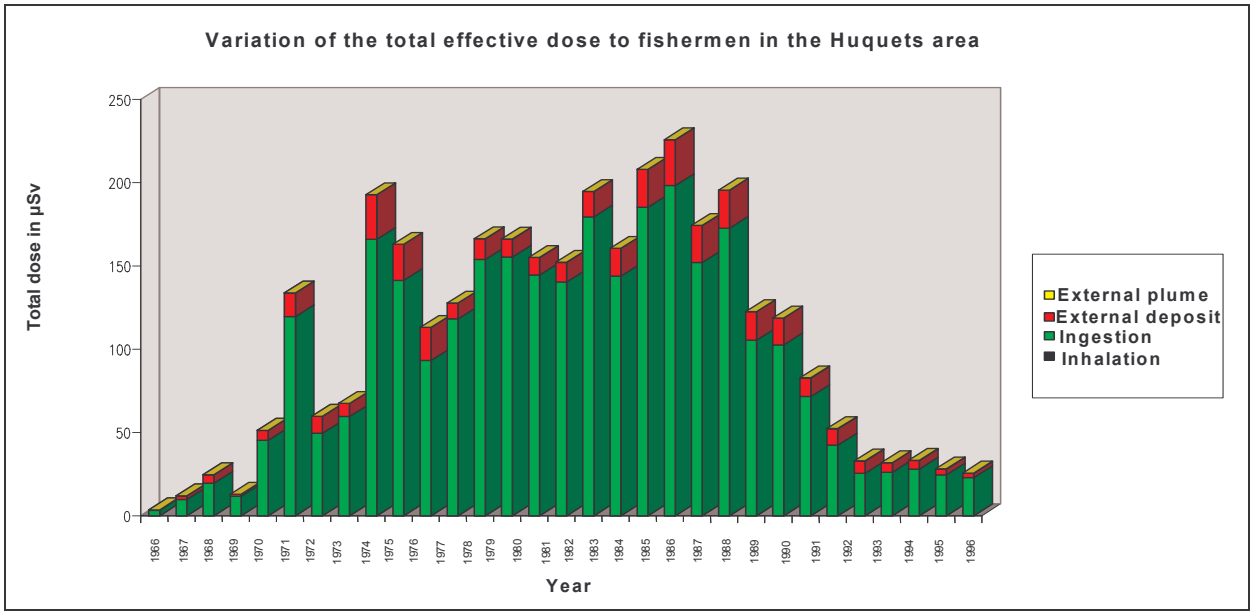


Figure 4.2.2.a: Variation of the effective individual dose for fishermen in the Huquets area as a function of time

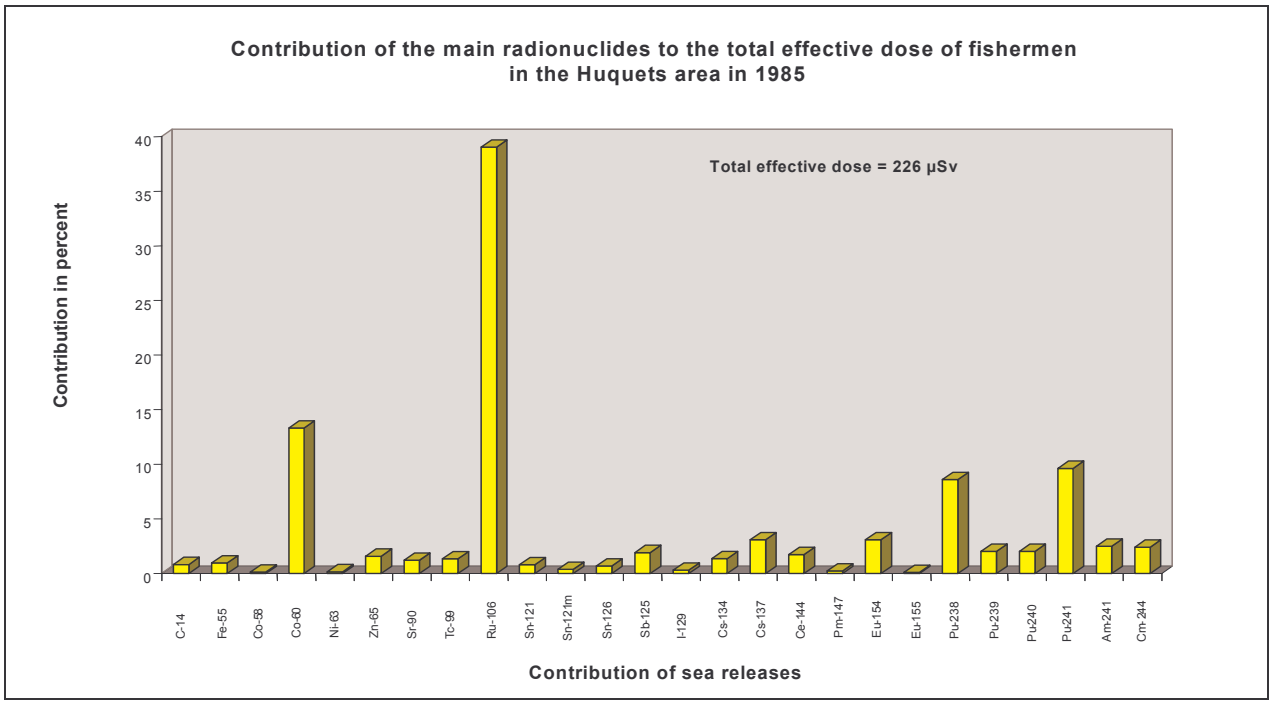


Figure 4.2.2.b: Contribution of the main radionuclides to the individual effective dose to fishermen in the Huquets area in 1985

4.3. “Pont-Durand resident farmers” particular scenario

4.3.1. Description of the “Pont-Durand farmers” scenario

The dietary habit and self-consumption ratios of farmers in this particular scenario were obtained from the results of the survey around Flamanville [Mathieu and Mathieu 1978] (Table 4.1.1.A). Rations used for land products for the "Farmers” scenario are “high consumer” rations. Local farmers are considered as being the individuals most likely to consume large quantities of land products derived from local agriculture. Therefore, GT4 decided to use the 95 percentile of land product consumers (average consumptions more than twice the standard deviation of the distribution of consumptions supplied in [Mathieu and Mathieu 1978]). Food rations for seafood are average rations for adults. It would have been unrealistic to consider that farmers are “high consumers of all food products”. Self-consumption ratios are also the same as for the average adult.

In the absence of any particular study concerning the time spent outdoors by farmers (this parameter is used in the model of external exposure), a typical value of 3500 $h.year^{-1}$ was used, which is equivalent to about 10 $h.d^{-1}$ (40% of the total time).
The assumed respiratory rate for farmers was the value recommended by ICRP 66 for outdoor workers. Accidental ingestion rates of soil, sand and sea water are the same as for an average adult.

The values of concentrations in the terrestrial environment correspond to values in the Pont-Durand district. A study of compass roses in dry weather and in wet weather, reconstructed by GT3 for the period from 1992 to 1997, shows that the Pont-Durand district is more highly exposed to deposits of radionuclides released by COGEMA La Hague reprocessing plants than anywhere else since it is located in the direction of the prevailing winds in wet weather. The year 1996 was used since it was the year in which atmospheric releases from the plant were greatest.

The assumed values of concentrations in the marine environment are average values used for the cohort.

4.3.2. Results

Effective doses were calculated for the entire study period (1966-1996). The variation in doses is presented in figure 4.3.2.a. The year 1996 is the year for which the effective dose was highest (59 µSv) for the Pont-Durand farmer scenario. The preponderant exposure pathways are ingestion (77%) and external exposure to the plume (20% corresponding to the contribution of ^{85}Kr). Figure 4.3.2.b presents the contribution of the main radionuclides. ^{129}I, ^{14}C and ^{85}Kr provide the main contributions to the dose (approximately 45%, 30% and 20% respectively).

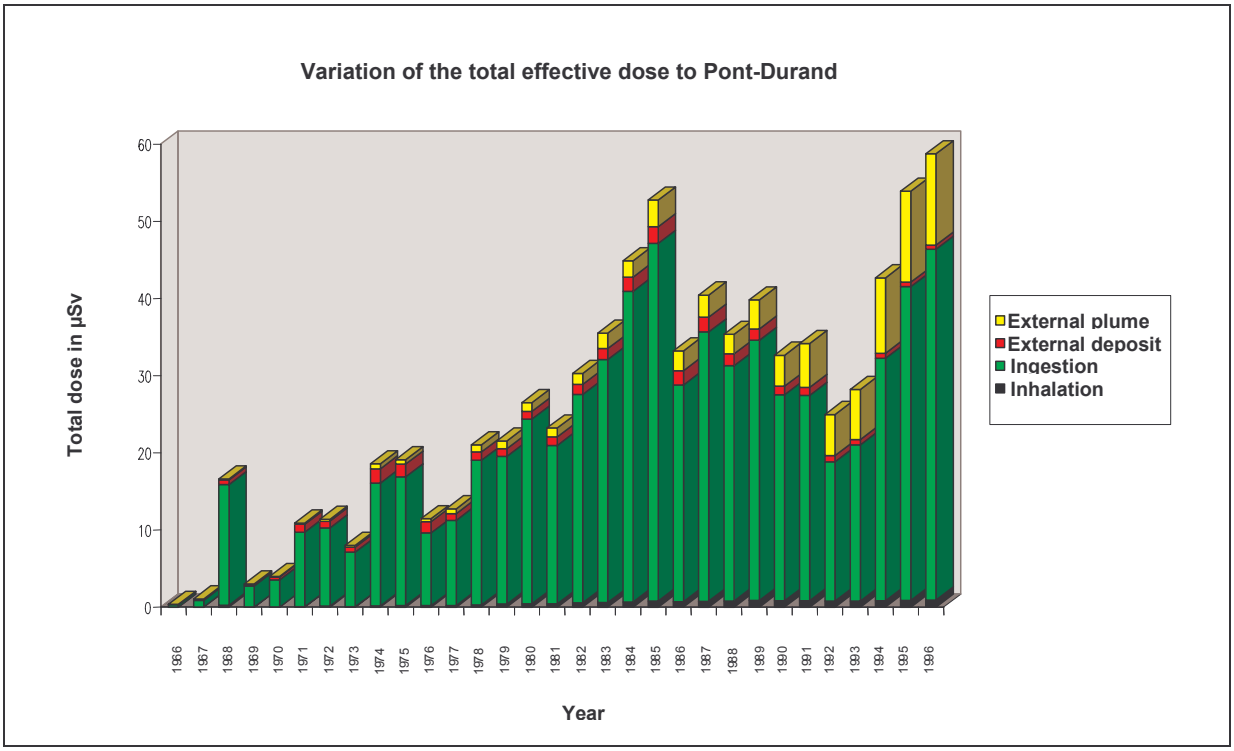


Figure 4.3.2.a: Variation of the individual effective dose for Pont-Durand farmers as a function of time

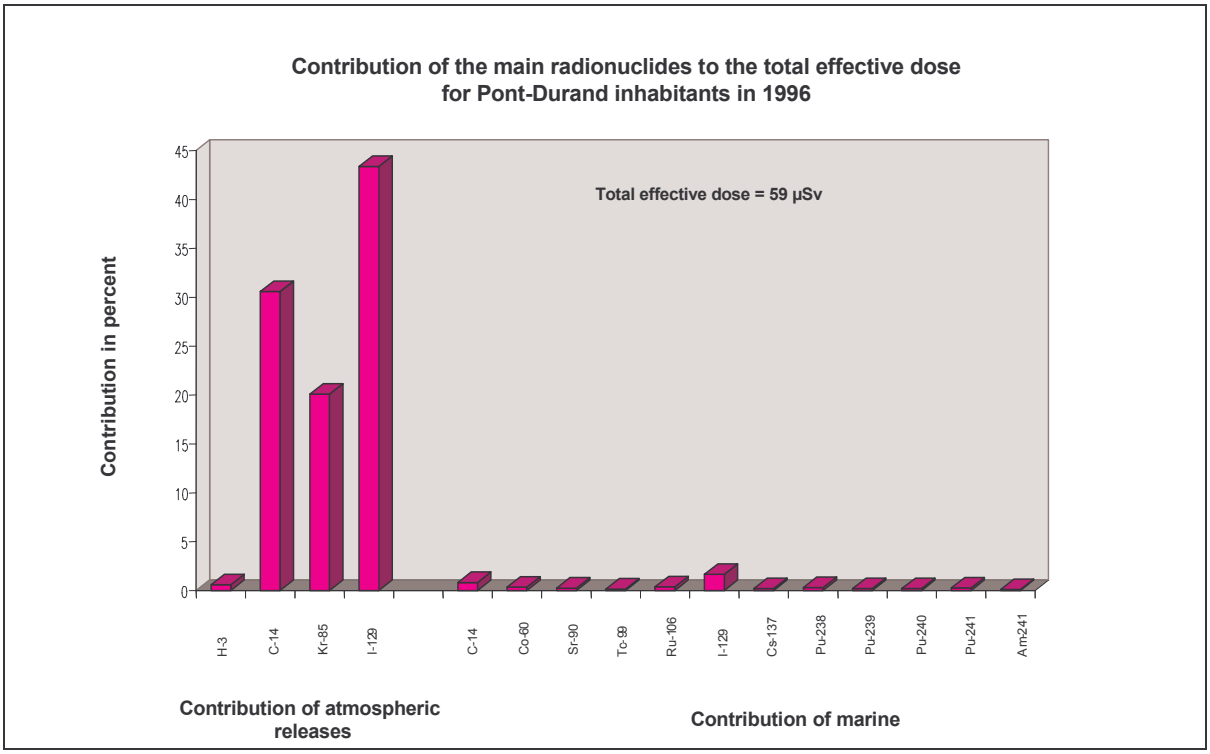


Figure 4.3.2.b: Contribution of the main radionuclides to the effective individual dose for Pont-Durand farmers in 1996

4.4. "Activities close to COGEMA sea release pipe" particular scenario

Releases of liquid effluents from the La Hague reprocessing plant pass through a five-kilometer-long release pipe, the end of which is about two kilometers from the coast at a depth of thirty meters. During low spring tides, a few meters of this pipe are emerged in the Moulinets Bay. Until summer 1997, a scale deposit on the inside of the pipe containing radionuclides created a dose rate in the immediate vicinity of the pipe. Descaling was carried out during the summer of 1997 in order to separate and retrieve this scale and therefore reduce the dose rate from the release pipe[67].

4.4.1. Frequency of exposure of the release pipe

The sea level does not depend on the tide coefficient alone. It is also strongly influenced by weather conditions, and particularly the wind strength and direction and atmospheric pressure. Under some weather conditions, the release pipe may be exposed when the tide coefficient is about 105 or more. GT4 analyzed tide coefficients extracted from the SHOM (Service Hydrographique et Océanographique de la Marine - Navy Hydrographic and Oceanographic Service) between 1994 and 1998, and estimated the average number of hours during which the pipe was exposed during the daytime to approximately 23 hours per year.

4.4.2. Irradiation due to the release pipe

Dose rate measurements were made in contact with and in the vicinity of the release pipe. These measurements were made when the pipe was emerged (measurements in air) and submerged (measurements in water). Table 4.4.2.A contains the results of these measurements.

Table 4.4.2.A: Results of dose rates measurements made by COGEMA around the release pipe in 1997 (in $\mu Sv.h^{-1}$)

MEASUREMENTS IN AIR[68]	
in contact with the pipe[69]	300-350
at 1 m	120
at 5 m	18
at 10 m	5
at 20 m	<1
at the bottom of the concrete block	1
on coflexip concrete posts	15
MEASUREMENTS IN WATER[70]	
at 20 cm	90
at 50 cm	5
at 70 cm	<1

[67] Globally, descaling operations reduced contamination in the pipe, but some isolated measurements still show dose rates of the order of a few hundred $\mu Sv.h^{-1}$ due to residual scale deposits.

[68] These measurements were made using a Scintomat.

[69] Measurements at the contact with the pipe were also made by the OPRI and the CRII-RAD. Measured dose rates are of the same order of magnitude as those in table 4.4.2.A.

[70] These measurements were made using a Télédetector.

4.4.3. Description of “Activities close to COGEMA release pipe ” particular scenarios

Table 4.4.3.A presents the populations and activities that could lead to external exposure.

Table 4.4.3.A: Characteristics of the “Activities close to COGEMA release pipe ” scenarios

CASE	POPULATION	LOCATION	DURATION
1	Fisherman or person walking close to the emerged pipe		10 minutes
2	Person walking close to the emerged pipe		30 minutes
3	Beach fishing fisherman	at the bottom of the block	15 minutes
		around the concrete posts	30 minutes
4	person walking on the customs trail	at the top of the block	
5	person walking on the “beach” (in the cove)	20 m from the emerged pipe	1 hour
6	diver (pipe submerged)	50 cm from the pipe	30 minutes

The customs trail is a relatively frequently used walking trail, but is far from the influence of the release pipe (case No. 4). The Moulinets Bay, where the release pipe is located is not easily accessible and the only way to reach it is to go down a steep path, off the customs trail. The few individuals who use this area regularly are local beach fishermen. The Moulinets Bay in itself is not even very good for this activity. Fishermen pass through it to fish further to the west near Cap Voidries, where most beach fishing is for abalones (molluscs).

4.4.4. Results

Table 4.4.4.A presents the effective doses associated with particular scenarios defined above.

Table 4.4.4.A: Effective doses associated with the "Activities close to COGEMA release pipe" scenarios

CASE	POPULATION	DOSE RATE in $\mu Sv.h^{-1}$	IMPACT in µSv	for a duration of
1	fisherman or person walking close to the emerged pipe	120	20	10 minutes
2	person walking close to the emerged pipe	15	7.5	30 minutes
3	fisherman (bottom of block)	1	2.75	15 minutes
	fisherman (concrete posts)	5		30 minutes
4	person walking on the customs trail	natural background noise (0.1 to 0.2 $\mu Sv.h^{-1}$)	no impact	
5	person walking on the “beach” (in the cove)	on average <1	<1	1 hour
6	diver (pipe submerged)	5	2.5	30 minutes

The dose rates used were dose rates measured in 1997. Since the pipe was replaced in 1980-1981, these values can be considered as being overestimates for the period from 1980 to 1997. Dose calculations were carried out for the six cases. If some groups of individuals carry out these activities more than once a year, doses should be multiplied by the frequency to obtain the received annual doses.

4.5. "Fishing near COGEMA La Hague reprocessing plants sea release pipe" particular scenario

4.5.1. Problem

The dosimetric impact related to exposure through the marine pathway for the cohort is determined by assuming a dilution factor of 0.76 Bq/m^3 per TBq released, estimated for the Goury area (the harbour of Goury is located 7 km from COGEMA release pipe). Furthermore, GT4 made a calculation for the group of fishermen in the Huquets area (at 1 km from the release pipe). This calculation was made using an average correction factor for the dilution factor (3.42 Bq/m^3 per TBq released).
However, the previous calculations could not deal with the radioecological situation in the few hectares located at the end of the pipe. Therefore it is still necessary to determine the influence of the "near field" (defined as the area within a radius of 300 m around the release pipe) on the marine fauna, and consequently its incidence in terms of effective dose received.

4.5.2. Description of " near field " scenario

The proposed methodology is as follows:

1. In 1997, the ACRO laboratory carried out analyses on eight samples of crustacean flesh taken from the "near field" by GREENPEACE [ACRO 1997a] [ACRO 1997b]. The OPRI made a measurements on a crab [OPRI 1997] at the same time. This measurement result is included.

2. Based on activities per unit mass measured for some radionuclides, the activity per unit volume of these radionuclides in "near field" water was determined using concentration factors established by GT3[71]. This operation was carried out for each quantified radionuclide and for each sample.

3. The ratio of these activities per unit volume to activities established in the Goury area for the cohort is used to establish an average correction factor for the dilution factor for each sample, using the average of the correction factors corresponding to each measured radionuclide.

4. This average correction factor applied to the activities per unit volume in the Goury area estimated in 1996 for radionuclides not measured by the ACRO and by the OPRI, is used to reconstruct activities per unit volume of "near field" water and to deduce activities per unit mass in crustaceans for all radionuclides in GT1 source term.

[71] Correction factors established from each measured radionuclide in the sample show good agreement with each other, since the ratios calculated at point 3 for the various radionuclides are similar (factor 1 to 7). This observation confirms GT3's choices in terms of values for concentration factors. However there is an exception, for ^{125}Sb, observed in each sample in which this radionuclide is present. A value of 300 $l.kg^{-1}$ (value close to the maximum value for the range provided by GT3 for this parameter) instead of 10 $l.kg^{-1}$ appears more appropriate having seen the results. This choice was used for subsequent calculations for the "near field" scenario.

5. The identical procedure is applied for the year 1985, for which liquid releases into the sea from COGEMA La Hague reprocessing plants were the highest.

6. Doses due to possible ingestion of a crab or a kg of crab flesh with the reconstructed activities per unit mass were then calculated for two age groups, namely children from 7 to 12 year old and adults[72].

4.5.3. Results

The results as effective doses engaged are given in table 4.5.3.A. All analyzed samples were included, including one sample for which activities were below the detection limit (partly due to insufficient flesh for this sample). Exposure levels in different samples are very variable. If these same samples had been taken from the "near field" in 1985, their consumption would have resulted in dose levels significantly higher than in 1996, above 1 mSv according to some assumptions. However, these assumptions should be considered with caution since the presence of marine fauna is very rare in the "near field" due to the high sea currents. Furthermore, mooring, dredging and trawling are prohibited in this area.

Above all, the distinction between the two years (1985 and 1996) reflects the quantitative difference between releases into the sea by COGEMA, which were about 20 times higher in 1985 than in 1996. But it also reflects the qualitative difference due to the composition of the releases. This explains the differences in results between two age groups:

- in 1996, the dose to 7 – 12 year old children was 60% higher than the dose to adults,
- in 1985, the same dose to 7 – 12 year old children was 116% higher than for adults.

A greater contribution to the dose was observed for some radionuclides (particularly ^{60}Co, ^{125}Sb, plutonium isotopes, ^{241}Am and ^{244}Cm) in 1985 than in 1996.

GT4 only studied the ingestion of crustaceans exposure pathway, since the only marine fauna samples available in the "near field" are crustaceans, particularly due to the fact that few marine animals can resist the high sea currents in this area.

Table 4.5.3.A: Effective doses in mSv due to different assumptions for the ingestion of crustaceans in the near field for 7-12 year old children and adults, in 1985 and 1996

	doses for 1 kg of crustaceans		**doses for an average sample**	
	1985	1996	1985	1996
7-12 years	0.354	0.014	0.080	0.003
adult	0.163	0.009	0.037	0.002

[72] Initially, two other assumptions for the consumption of "near field" crustaceans had been proposed by P. Barbey: consumption of their entire ration of crustaceans from the "near field", by an average adult and by a fisherman. Most members of GT4 considered these two assumptions to be unlikely, and therefore the corresponding doses were not calculated. P. Barbey admits that the assumption of a fisherman eating crustaceans exclusively from the "near field" is very unlikely, but he does not eliminate the possibility that an average adult could consume crustaceans originating exclusively from the "near field". M. Sené considers that the two assumptions for the consumption of "near field" crustaceans give approximate values of the variability of the dose as a function of some food and habit assumptions.

4.6. "Using water from the Sainte-Hélène river at Pont-Durand" particular scenario

4.6.1. Description of the "Using water from the Sainte-Hélène river" scenario

This scenario involves local use of water from the Sainte-Hélène river that could induce a large number of transfer pathways. The maximum water releases activity is measured at Pont-Durand, a point at which the river flow is low (of the order of 10 $l.s^{-1}$), so that it is difficult to draw off water for irrigation. Therefore, this calculation ignored the transfer of radionuclides through plants by irrigation water, and ingestion of Sainte-Hélène water by farmers[73] was also ignored. GT4 considered that the most realistic exposure pathway was transfer through animals drinking water containing suspended solids (SS) associated with radionuclides, and this is the pathway that they considered.

Animal food rations are as recommended by GT3 of the Nord-Cotentin Radioecology Group. Farmers rations are taken from the INSEE 1991 dietary survey for the agricultural population living in the Paris Basin ZEAT (Zone d'Etude d'Aménagement du Territoire - Regional Development Study Area) including the Nord-Cotentin [Bertrand 1993]. Total self-sufficiency is assumed for food products produced on the farm, in other words 100% of the dietary rations of man and animals are produced locally.

4.6.2. Activities in water in the Sainte-Hélène

The maximum values of measured tritium activities in water in the Saint-Hélène (annual averages) are found in samples taken in the Pont-Durand hamlet district, where there is a farm at the present time. The group of farmers considered in this particular scenario is at Pont-Durand. The year corresponding to the maximum value of annual averages of tritium is 1979, with a value of 8 330 $Bq.l^{-1}$ (11/11 significant values). Measurements (annual averages) of total β and total α for 1979 were not significant.

Therefore, the first calculation was for the year 1979 considering tritium releases only, and a second calculation presents the results for 1986, the only year in which at least ¾ of annual averages for total β and total α measurements were significant, in addition to tritiated releases.

Table 4.6.2.A: Activities measured in the Sainte-Hélène at Pont-Durand (ANDRA point R6)

Year	^{3}H ($Bq.l^{-1}$)	total β ($Bq.l^{-1}$)	total α ($Bq.l^{-1}$)
1979	8330	-	-
1986	1060	1.11	0.12

The total β activity is mainly due to ^{137}Cs (0.67 $Bq.l^{-1}$) and $^{106}RuRh$ (0.29 $Bq.l^{-1}$). For the α activity, the percentages of the activity measured on 20/10/86 due to ^{238}U, ^{235}U and ^{226}Ra (32%, 60% and 8% respectively) were used for this calculation.

4.6.3. Results

The total dose to farmers in this particular scenario was estimated at 10^{-2} mSv (10 µSv) in 1979 and 3.10^{-3} mSv (3 µSv) in 1986.

[73] The effective dose for an adult who would have drunk a liter of water from the Sainte-Hélène river once in 1979 would have been 0.15 µSv.

The main limitation to this calculation is the lack of any measurement results for tritium activity in the Sainte-Hélène before 1976 and for α and β activities before 1973. Furthermore, the distribution of the α activity is based only on one measurement result in 1986, at the Brasserie waterfall. However, the α activity only makes a very slight contribution to the dose due to the low transfers of actinides through animal products[74].

This particular scenario should be considered with the "Farmers living in Pont-Durand" particular scenario to take into account different exposure pathways that could be applicable to these farmers (exposure through releases into the atmosphere from the reprocessing plant and exposure through releases from the CM).

4.7. "Fishing in the Sainte-Hélène river at Pont-Durand" particular scenario

4.7.1. Situation of the local fishing activity

ANDRA had a study carried out to characterize fish populations in four rivers around the CM (the Sabine, Roteures (tributary of the Vallace), the Sainte-Hélène and the Grand Bel). This study is based on several information sources:

- investigation of the rivers,
- electrical fishing by ANDRA (1995) and the French Higher Fishing Council (CSP in 1989, 1990 and 1991),
- interviews with local fishermen.

These rivers are classified as first fishing category (predominant in salmonidae). However, eels were the only fish caught in 1989 and 1995 in the Sainte-Hélène (downriver), the Grand Bel and Roteures. The Sabine has a population of fario trout, as a result of new stocking. There is no fishing interest for the Grand Bel and Sainte-Hélène rivers, potential outlets from the CM, and fishing pressure is almost zero. The development of trout in these two rivers is limited firstly by their insufficient flows, and secondly by some pollution (occasional agricultural pollution, accidental chemical pollution in Roteures by a local manufacturer, etc.).

4.7.2. Description of the "Fishing in the Sainte-Hélène river" scenario

Despite the low fishing pressure, GT4 wanted to know what would be the accidental dose associated with consumption of a fish taken from the Sainte-Hélène. Table 4.7.2.A describes the assumptions about the time spent fishing and/or walking along the bank of the river and about fish consumption.

Table 4.7.2.A: Assumptions for the "Fishing in the Sainte-Hélène river" particular scenario

Time spent along the bank of the river	Fish consumption
1 h.year^{-1}	unit case 1 eel (100g)

Exposure pathways assumed for this particular scenario are ingestion of fish caught in the Pont-Durand district (which is upriver from the location at which the highest water activities per unit volume were detected) and external exposure to river sediments at the same location. Unit exposures (1 h.year^{-1}, 1 eel) are used for other particular scenarios (for example "Release pipe"). If some individuals spend more time or consume more fish, the doses will have to be multiplied in proportion to determine the received annual dose.

[74] In particular, GT4 verified that the activity levels of plutonium and americium isotopes that could be measured in Sainte-Hélène sediments in some years had a very low dosimetric impact.

The activity per unit mass of fish and sediments is estimated based on the activity of the water in Pont-Durand (see Paragraph 4.6.2.) in 1979 and 1986. Values of the transfer factor of radionuclides from water to fish and values of radionuclide distribution coefficients between water and sediments (K_D) are as recommended by the IAEA in accordance with GT3 recommendations, except for the K_D value for ^{137}Cs for which the value recommended by GT3 is 10 000 l.dw kg^{-1}.

4.7.3. Results

The dose corresponding to the ingestion of one eel in 1986 is about 2 µSv (due to ^{137}Cs). The contribution of α emitters is very low. The dose received by external exposure for one hour of exposure is 0.4 µSv in 1986.

4.8. "Playing at the mouth of the Sainte-Hélène" particular scenario

4.8.1. Description of the "Playing at the mouth of the Sainte-Hélène" scenario

It is assumed that a group of children (5 year old), are playing at the mouth of the Sainte-Hélène, and could accidentally swallow water and sediments and thus suffer external exposure. Values corresponding to bathing time, accidental water sediment ingestion rates are the values previously used by GT4 for children in the " 5 year old " age group in the cohort, namely 100 h.$year^{-1}$ bathing at the mouth of Sainte-Hélène, 0.1 l.$year^{-1}$ of river water and 2 g.$year^{-1}$ of sediments from Sainte-Hélène accidentally swallowed.

4.8.2. Activities of water in the Sainte-Hélène

The only available values (corresponding to ¾ of significant values) are given in table 4.8.2.A.

Table 4.8.2.A: Activities measured in water at the mouth of the Sainte-Hélène by the IPSN/LERFA

Year	^{3}H (Bq.l^{-1})	^{137}Cs (Bq.l^{-1})
1987	254*	0.155 (6/6 significant measurements)
1991	180 (2/2 significant measurements)	0.009 (8/8 significant measurements)

***: no tritium values are available at the mouth, therefore the value measured at point R6 (ANDRA measurement) was divided by 5 to take into account dilution between R6 and the mouth.**

As for the previous scenario, the activities per unit mass of sediments at the mouth of the Sainte-Hélène are deduced from the activity of the water using K_D values recommended by GT3.

4.8.3. Results

The effective dose to children for this particular scenario originates essentially from external exposure to ^{137}Cs in sediments and was estimated at about 0.5 µSv in 1991 and 10 µSv in 1987.

4.9. “Walking next to the CM fence" particular scenario

4.9.1. Description of the “Walking next to the CM fence” scenario

Considering the configuration of the CM installations, the only “public” walk possible in the recent past is along the east and north fences, since the west fence is at the boundary of COGEMA's installations.
This path is composed of three segments, namely the south-east, north-east and north segments. Thermoluminescent dosimeters are installed on each of these three segments. Values corresponding to the average given by the dosimeters in each of the segments are used for the calculation. Values of the dosimetric measurements used originate from measurements made by the ANDRA from 1985 to 1996 since the previous data are unusable (the dosimeter coding was changed and difficulties in identifying their locations). Dose rates used for an individual walking along this path are as recorded by dosimeters, without any other attenuation effect (for example due to distance). Dose rates measured by the ANDRA include the contribution of exposure from natural sources (cosmic and terrestrial radiation), for which the average estimated value is about 0.1 $\mu Gy.h^{-1}$.

The walking time is calculated based on the distance traveled: the north segment is about 200 m long, and each of the other two segments are twice this length. Based on a walking speed of 5 $km.h^{-1}$, the walking time for the north-east segment is 2.4 minutes, rounded to 3 minutes. The walking time for each of the other two segments is then 6 minutes, which gives a total walking time of 15 minutes which is realistic for this distance (1000 m).

4.9.2. Results

The maximum dose received for each walk is less than 0.5 µSv, and was applicable for November 1985. It should be noted that the dose rates at the fence have reduced very significantly with time: they are now less than 0.1 $\mu Gy.h^{-1}$ (100 $nGy.h^{-1}$) which should be compared with average dose rates measured in the region of between 70 and 110 $nGy.h^{-1}$.

The estimate of the dose associated with the “Walking next to the CM fence” particular scenario gives a value which is low compared with the background noise due to natural radioactivity. The calculation described is conservative, since the measurement results used are systematically the maximum values and no attenuating effect is considered. However, the calculation carried out is limited by the available data on which it could be based; no data before 1985 although dose rates measured at the fence have reduced since, and no data for some dosimeters, particularly in 1985.

4.10. Consumption of seaweed-based products

Since there is no available evidence to suggest that local populations consumed seaweed directly during the period from 1966 to 1996, GT4 considered that this particular exposure pathway was unrealistic. However, it wanted to study potential exposure pathways associated with the local industrial practice of extracting gelling agents from seaweed collected partly from beaches influenced by discharges into the sea from COGEMA La Hague reprocessing plants (*Chondrus cripus* and *Laminaria digitata*). A joint project was setup with the SKW Biosystèmes manufacturer operating the Carentan plant and an experimental plan defined. The objectives were to study the future of ^{3}H, ^{14}C and particularly ^{129}I, which are known particularly for their propensity of accumulating in seaweed, during the industrial processes, and to measure the concentration of the various detectable radionuclides in the three purified products originating from these processes and in manufacturing by-products. The method used is very similar to the previous experiments published in 1989 [Masson *et al* 1989]. Since the schedule for these experiments is not compatible with the Plenary Group's schedule, GT4 does not yet have any information more recent than what was published in 1989, which showed that:

- more than 93% of the initial radioactivity due to ^{99}Tc, ^{106}Ru and ^{60}Co is eliminated by the extraction process,
- the small traces of ^{137}Cs, ^{125}Sb, ^{110m}Ag and ^{54}Mn have disappeared in the final product,
- 56% of the ^{90}Sr is retained in one of the purified products (alginic acid produced from the oarweed).

This study concluded that there was a negligible dosimetric impact for populations consuming these products due to the large dilution of radionuclides from the raw material (seaweed) to man.

4.11. Transport of irradiated materials

The regulatory limits for radiation intensity (2 mSv.h^{-1} in contact with a package, and 0.1 mSv.h^{-1} at 1 meter in the general case [IAEA 1983]) confirm that transport of radioactive materials could be a non-negligible source of exposure. However, GT4 decided not to treat the transport of radioactive materials to and from COGEMA La Hague reprocessing plants as a particular exposure scenario since these exposure pathways are currently being analyzed in other Groups such as the “Spent fuel traffic” workgroup set up by the SNCF's CNHSCT (Conseil National Hygiène et Sécurité et des Conditions de Travail - National Health and Safety and Work Conditions Council). Two documents [OPRI/IPSN 1998] [IPSN/CEPN/GRS 1997] present available information about estimated doses to the public (railway workers being considered as members of the public, rather than as workers in the nuclear sector), and were distributed to members of the Plenary Group. In the OPRI/IPSN report, exposure levels of railway workers (apparently the members of the public most likely to be exposed since they work on or near to the packages) due to shipments vary between 1.8 µSv and 4.1 µSv depending on the actions being done (“operation”, “traction”, “rolling stock”). The report concludes that doses to railway workers under normal working conditions are very low, even if the same person repeats these actions several times during the year. However, the distributed documents do not answer all questions asked by some members of the Plenary Group such as exposure of the public on platforms in Valognes station or exposure of a car driver who follows or overtakes a package during road transport, but GT4 preferred that these questions should be dealt with by the specialized work organizations mentioned above.

4.12. Summary of the particular scenarios study

Table 4.12.A contains a summary of effective doses associated with particular scenarios.

Table 4.12.A: Summary of effective doses associated with particular scenarios

	Particular scenario description		Associated dose
adult living in the canton	1985 average scenario	/year	18 µSv
	1996 average scenario	/year	5 µSv
chronic scenarios	Fishermen in the Huquets area in 1985	/year	226 µSv
	Farmers in the Pont-Durand district 1996	/year	59 µSv
	Adult living in the 1500 m zone in 1996	/year	24 µSv
critical groups[75]	Fishermen in the Goury hamlet 1985	/year	41 µSv
	Adults living in Digulleville 1996	/year	6 µSv
occasional scenarios	Fishing close to the pipe	/occurrence	20 µSv
	Walking close to the pipe	/occurrence	7.5 µSv
	Fishing at the bottom of the concrete block and posts	/occurrence	2.75 µSv
	Walking in the Moulinets Bay	/occurrence	< 1 µSv
	Diving near the pipe	/occurrence	2.5 µSv
	Eating a crab (250 g) caught in the near field in 1985	/occurrence	313 µSv (7-12 year old)
	Using Sainte-Hélène water in 1979	/occurrence	10 µSv
	Using Sainte-Hélène water in 1986	/occurrence	3 µSv
	Fishing in Sainte-Hélène in 1979	/occurrence	0.015 µSv
	Fishing in Sainte-Hélène in 1986	/occurrence	2 µSv
	Playing at the mouth of the Sainte-Hélène in 1987	/occurrence	10 µSv
	Playing at the mouth of the Sainte-Hélène in 1991	/occurrence	0.5 µSv
	Walking close to the CM	/occurrence	0.5 µSv

The effective dose to the local population varied in time by about a factor of ten, mainly due to the variation in activities released by COGEMA.

Professional activity leading in particular to increased consumption of local food, and this activity being exercized in the areas most exposed to releases from COGEMA La Hague reprocessing plants (outside the near field) could have resulted in effective doses 10 times

[75] Reference groups were defined by COGEMA.

greater than the dose to the average person living in the Beaumont-Hague canton (chronic scenarios).

Particular habits (for example using water from the Sainte-Hélène river, presence on the bank of the Sainte-Hélène river or walking next to the CM fence) give dose increments less than or at most equal to the same order of magnitude as the effective dose associated with the average scenario (occasional scenarios), except for the "Fishing in the near field" scenario for which the dose increment could be much greater but this scenario is rare due to the ban on mooring and trawling in the near field and the very low presence of marine fauna in the near field due to the strong local currents.

Table 4.12.B contains a comparison of effective doses calculated for particular scenarios compared with results previously published by the "Souleau" Commission. Effective doses presented by the "Souleau" commission were the results of estimates made by operators - critical groups and the operators' dosimetric calculation model.

Table 4.12.B: Summary of effective doses associated with particular scenarios

	Particular scenario description		Associated dose
adult living in the canton	1985 average scenario	/year	18 µSv
	1996 average scenario	/year	4 µSv
chronic scenarios	Fishermen in the Huquets area 1985	/year	226 µSv
	Farmers living in Pont-Durand district 1996	/year	51 µSv
"Souleau" commission	Maximum theoretical evaluation[76] 1985	/year	112 µSv
	Maximum theoretical evaluation 1996	/year	23 µSv

5. CONCLUSIONS

Methodology

The methodology built up by GT4 to satisfy the two tasks of the Nord-Cotentin Radioecology Group is based on two approaches:

- Task 1: reconstruction of the cohort of 0 to 24 year old individuals in the Beaumont-Hague canton, and the estimate of doses to the red bone marrow received by these individuals due to all sources of exposure during the period from 1954 to 1996 in order to estimate the associated risk of leukemia during the period from 1978 to 1996,

- Task 2: search for particular scenarios corresponding to greater exposures due to locally higher exposure levels or particular habits of the local population.

The two methods were modeled in the same way in terms of estimating activities released by nuclear facilities in the Nord-Cotentin, dispersion and transfers of radionuclides through the environment. However, parameters characterizing the habit or geographic situation of inhabitants, and the calculated dosimetric indicators are specific to each of the two methods: annual doses to the red bone marrow for the cohort and effective doses engaged over the

[76] The maximum theoretical evaluation made by the « Souleau » commission is equal to the sum of dosimetric impacts for the various reference groups of operators and for the years considered.

life for particular scenarios. Collective doses and the risk of leukemia were quantified only for the first method (cohort study).

Limits

Activity released by the installations and the model for dispersion and transfers through the environment used by GT4 as input to the dosimetric model, were derived from work done by other groups (GT1 for released activities, GT2 for the results of measurements in the environment and GT3 for the best estimates of radionuclide concentrations in the environment). Therefore, dose and risk calculations combine limitations specific to GT4 and limitations in the work done by previous groups. It was impossible to take into account all these uncertainties.
Furthermore, particular difficulties were experienced with some specific points in GT4 tasks. The main difficulties were with the following points:

- modeling of exposure pathways associated with the sea spray (use of the TORIMA empirical model for the Nord-Cotentin specific situation, without prior validation),
- modeling of accidents (difficulties in calibrating the model used due to the lack of measurement results for many radionuclides),
- modeling of *in utero* exposure (temporary models while waiting for publication of the ICRP's work).

Additional difficulties related to GT4's reconstruction of doses and risks also occurred (lack of some data for the past, particularly concerning local habits and numbers of individuals).

Other sources of exposure (natural, medical, etc.) were dealt with in order to put exposure levels due to nuclear facilities in the Nord-Cotentin into perspective. This analysis demonstrated the weaknesses in available information about medical exposure and the large divergence of dosimetric models given in the literature for calculating the dose to the red bone marrow due to radon. Therefore, the study of these sources of exposure was less detailed and was used only to put the results related to local nuclear facilities into perspective.

The Group discussed all these difficulties mentioned, and they were resolved by general consensus, except for points for which some GT4 members expressed reservations as mentioned in this report.

Study of the 0-24 year old cohort

GT4 developed a model for estimating individual and collective doses in order to carry out all calculations necessary to reconstruct individual and collective doses to the red bone marrow, based on estimates of concentrations in the environment supplied by GT3. Model parameters concerning the number of individuals in the cohort, local habits as a function of age (dietary habit, self-consumption ratio, time spent in different activities) were defined by GT4 based on existing local bibliographic data, or based on assumptions for which a consensus could be found. Dose coefficients to the red bone marrow were reconstructed based on values provided by the NRPB and validated by the ICRP. Thus, individual and collective doses to the red bone marrow were calculated for all generations born between 1954 and 1996.

The collective dose to the red bone marrow during childhood (*ex utero)* due to routine releases from Nord-Cotentin nuclear facilities is 0.30 m.Sv for the entire cohort for the period from 1954 to 1996. There are also the contributions of the two COGEMA incidents/accidents, namely 0.04 m.Sv for the break in COGEMA release pipe (1979-1980) and 0.14 m.Sv for COGEMA silo fire (1981).

The collective dose to the red bone marrow during pregnancy (*in utero)* is only estimated for exposures due to routine releases from Nord-Cotentin nuclear facilities since a provisional model was selected while waiting for work done by the ICRP concerning modeling of exposure of the fetus. The contribution of the collective dose to the red bone marrow *in utero* is 0.02 m.Sv.

These exposure levels were put into perspective with doses to the red bone marrow due to all sources of exposure (natural, medical, fallout from atmospheric testing of nuclear weapons and the Chernobyl accident)[77]. The collective dose to the red bone marrow due to all sources of exposure is 322 m.Sv for the period from 1954 to 1996 including 74% due to natural exposure, 24% due to medical exposure, 2% due to fallout from tests and the Chernobyl accident, and 0.1% due to Nord-Cotentin nuclear facilities.

The final indicator for the evaluation of the risk of leukemia for the cohort is the calculated number of cases of leukemia, for comparison with the results of epidemiological studies available during the period from 1978 to 1996.
The risk of leukemia associated with exposure to ionizing radiation was estimated for young individuals from 0 to 24 year old who had lived in the Beaumont-Hague canton between 1978 and 1996. A cohort of 6656 individuals was reconstructed for this purpose, each individual being assumed to remain in the canton until his or her 25th birthday or until January 1 1997 (whichever is the first of these two dates). The total number of years of presence between 1978 and 1996 is 69308 person-years. The risk of leukemia is estimated by applying absolute risk models to calculated doses to the red bone marrow.

The results obtained are best estimates of the radiation-induced risk of leukemia within the cohort. These estimates were made as realistically as possible, but there is some uncertainty regarding these best estimates that could not be quantified. Furthermore, it should be noted that the method used assumes that any dose to the red bone marrow causes a risk of leukemia. Therefore, the results do not contain any information that could be useful in the discussion of the existing relation between exposure to ionizing radiation and the risk of leukemia. But assuming that there is such a relation, they provide quantitative information that can be used to determine the plausibility that the higher incidence observed in young people between 0-24 year old in the Beaumont-Hague canton between 1978 and 1996 could be explained by releases from Nord-Cotentin nuclear facilities.

The estimated number of radiation-induced cases in the population of 0-24 year old individuals in the Beaumont-Hague canton between 1978 and 1996 related to exposure due to routine releases from Nord-Cotentin nuclear facilities during childhood *(ex utero)* is 0.0009. This estimated number of cases increases to 0.0014 when taking into account exposure due to the accidents that occurred in 1979 (pipe break) and in 1981 (silo fire). Based on this annual estimate, the probability of occurrence of one radiation-induced case associated with exposure to routine releases from Nord-Cotentin nuclear facilities is equal to 1.4 per 1000. Therefore, it is very improbable that exposure due to local nuclear facilities could cause an observable increase in terms of incidence of leukemia.
The estimated number of radiation-induced cases in the 0-24 year old population in the Beaumont-Hague canton between 1978 and 1996, due to all sources of exposure during childhood *(ex utero)* is 0.835. 74% of this risk can be assigned to natural radioactivity and 24% to diagnosis medical exposure to ionizing radiation. It should be noted that these sources also exist across the country. Therefore the risk associated with exposure due to local nuclear facilities appears to be 500 times lower than the risk that can be assigned to other sources.
Taking into account the dose delivered *in utero* increases the number of cases that can be assigned to exposure due to routine releases from local nuclear facilities by about 33%.

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[77] No special study was carried out on the Casquets trench. However, measurement results used to validate models of transfers through the environment included the contribution from this source, if any.

The total number of cases that can be assigned to routine releases from local nuclear facilities is then 0.0012.
The results of estimates of the risk of leukemia obtained by the Nord-Cotentin Radioecology Group are consistent with the results of previous British radioecological studies.

Scenarios evaluated the impact of worse habits leading to higher doses, to determine the sensitivity on the individual risk. The habits considered are as identified in the case-control study by D. Pobel and J.F. Viel published in 1997 (time spent on the beach, consumption of fish, molluscs and local crustaceans).
Three scenarios were selected to determine the impact of some habits associated with this exposure pathway on the risk of leukemia:

- The "children spending time on local beaches during their childhood" scenario shows that even frequent visits to beaches (1h20 per day for the x5 scenario) throughout childhood does not significantly increase the risk of radiation-induced leukemia.
- The "mothers spending time on local beaches during pregnancy" scenario shows that even frequent visits to beaches (1h30 per day for the x5 scenario) during pregnancy does not significantly increase the risk of radiation-induced leukemia.
- In the "consumption of local fish and seafood" scenario, an individual who consumes a large quantity of local seafood (up to 590 g per day) would have his radiation-induced risk increased by about 73%, but this increase is essentially due to the ingestion of natural radionuclides (almost 100%).

Another factor that was associated with the risk of leukemia in the case-control study is the time spent living in a granite house, or a house built on granite. In their discussion, the authors suggested that this association could reflect a relation between the risk of leukemia and exposure to radon [Pobel and Viel 1997].
The "Living in a granite house" scenario shows a significant increase in the risk with the radon concentration level; living in a house with a radon concentration of 370 $Bq.m^{-3}$ and a five times higher terrestrial exposure (x5 scenario) increases the risk by almost 100% compared with the risk for a home in which there is an average concentration (74 $Bq.m^{-3}$). Half of this increase in the risk is due to the increase in terrestrial exposure and half is due to radon. However, this result does not demonstrate any cause and effect relation between exposure to radon and the risk of leukemia in children, and this association has not been established epidemiologically.

Particular scenarios

The “particular scenarios” approach identified average scenarios, chronic scenarios and occasional scenarios for which individual effective doses were quantified (see Table 4.12.A). The main conclusions are as follows:

- the effective dose to the local population changed in time by about one order of magnitude, mainly due to the change in activities released by COGEMA; exposure to routine releases from nuclear installations was greater in 1985 since releases into the sea were greatest during this period;
- a professional activity (agriculture or fishing) leading in particular to greater consumption of local food associated with carrying out this activity in the areas most highly exposed to releases from COGEMA La Hague reprocessing plants (outside the near field) resulted in effective doses ten times greater than those to the average person living in the Beaumont-Hague canton (chronic scenarios);
- particular habits (for example the use of water from the Sainte-Hélène river, being close to the Sainte-Hélène river or walking next to the CM fence) give dose increments not greater than twice the effective dose associated with the average scenario (occasional scenarios). The exception is “Fishing in the near field” for which the dose increment could be much

greater, but this habit is rare due to the prohibition on mooring and trawling in the near field and the very low presence of marine fauna in the near field due to the strong local currents.

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PART E

MAIN RESULTS

1. DOSIMETRIC RECONSTRUCTION AND EVALUATION OF RADIATION-INDUCED CASES OF LEUKEMIA (TASK 1)

1.1. General objective and methodology

The Group reconstructed doses to the red bone marrow (target organ for the radiation-induced risk of leukemia) received by the population of young people (0 - 24 year old) in the Canton of Beaumont-Hague during the period covered by the epidemiological studies. This retrospective reconstruction includes all exposure sources, and is used to estimate the number of leukemia that could theoretically be induced by radiation. It also enables a comparison of this number with the number actually observed for this same population.

The assumption made to calculate the risk of radiation-induced leukemia starting from the dose is that there is no threshold in the relation between dose and effect, in other words that a "low dose" is associated with a "low risk" rather than a zero risk. The models used are recognized internationally. The Group accepted this relation without making any critical analysis, although it is used within a dose range (of the order of 0.1 to 0.001 mSv for nuclear facilities), which is far outside the range for which it has actually been demonstrated[78].

Considering the assumption put forward by J.F Viel, the main effort was made on exposures due to releases from nuclear facilities, and particularly from COGEMA La Hague reprocessing plants.

Two complementary methodologies are used to evaluate the transfer of radionuclides contained in these releases to man:

- the first is to measure concentrations of radionuclides in the environment and consequently to estimate the impact on groups of population considering their geographic location and their use of this environment,
- the other consists of estimating the impact on these groups, knowing these releases, and making use of models representing mechanisms for the dispersion and reconcentration of radionuclides in the environment as far as man.

The Nord-Cotentin Radioecology Group uses the two complementary methodologies mentioned above by validating models by comparing their results with measurements in the environment.

Models validated in this way are used to evaluate contamination levels at all points in the environment, whereas the number of measurements is necessarily limited and expected values are frequently below the adopted measurement detection limits (these limits depend on the instruments and techniques used).

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[78] It is debatable whether or not the no-threshold risk model is applicable to environmental exposure cases. The data used for this model were derived from the epidemiological study of Hiroshima and Nagasaki survivors. In this case, firstly the dose was contracted within a small fraction of a second ("high dose rate"), and secondly a statistically significant increase in the various observed radiation-induced cancers was only observed for doses above the range of 50 to 200 millisieverts (mSv). No radiation-induced risk was demonstrated at doses below these ranges. However, the models used to estimate the risk due to *in utero* exposures are derived from epidemiological studies that have demonstrated a radiation-induced risk of leukemia associated with fetal doses starting from 10 mSv.

1.2. Summary of work on releases

The first objective was to reconstruct activities of radionuclides that are or could be present in liquid and gaseous releases in the various nuclear facilities located in the Nord-Cotentin region (COGEMA La Hague reprocessing plants, EDF's Flamanville electricity power station, ANDRA's "Centre Manche" shallow land disposal center, and the Navy's arsenal in Cherbourg Harbour).
The critical analysis of measured releases for which a regulatory declaration is made, is applicable to the following points:

- inventory of radionuclides, which should be as exhaustive as possible;
- consistency firstly between the "exhaustive" source thus defined and quantified when possible by calculation codes, and secondly the activity measured in the effluents at the release point by operators and declared within the framework of regulatory release procedures;
- reconstruction of radionuclide releases present but not measured in the past, or still not measured, either because the corresponding releases were not considered as being significant based on the operators' impact calculations, or due to limitations of analytic techniques. This reconstruction is made based on the identical physicochemical behavior of different isotopes of the same radionuclide, by defining chemical analogies between similar elements (in terms of the periodic classification table) and taking into account information available about impurities present in the material that give rise to activation products that may be released in the environment.

Operators' inventories only include measured activities. Therefore, they do not aim at exhaustiveness. Similarly, when a measurement is below the detection limit, they do not necessarily make low level measurements to search for the most precise measurable value. However, this type of information is necessary for a rigorous and precise evaluation of the radiological impact, even though *in fine* the radionuclides that were not included *a priori* in the evaluation apparently have relatively little effect in terms of dosimetric impact. This conclusion could only be reached after this analysis has been carried out. Furthermore, it was important to clearly identify the various radionuclides considered for the purposes of this study to evaluate the dose to the red bone marrow.

Essentially, the steps of the critical analysis mentioned above may be applied satisfactorily to COGEMA La Hague reprocessing plants for which it was possible to determine annual quantities of activity of the radionuclides present in the spent fuel at the time of their reprocessing, and which could therefore be released into the environment. The assessment is carried out by making use of standard calculation programs starting from the annual reprocessed tonnage and the characteristics of the spent fuel (nature, burn up and average cooling time).

As far as the two reactors at Flamanville Power Station are concerned and for nuclear reactors in general, the nature and activity of radionuclides present in the liquid and gaseous effluents depend on a large number of parameters. Examples of such parameters include the reactor operating mode, the rate of release of radionuclides from fuel element assemblies (micro-cracks, failure rate, etc.), the release of activation products from structural materials in cooling circuits and especially the treatment and management of liquid effluents before they are released into the sea, which have changed with time.

Verification means for facilities in Cherbourg arsenal are even more limited. Releases into the marine environment are much lower than releases from COGEMA La Hague reprocessing plants and their contribution to the added activity in the environment is very low.

Finally for ANDRA's CM, there is no simple relation between the radiological inventory of disposed waste and activity releases measured in the environment (particularly the Grand Bel and Sainte-Hélène rivers). This relation cannot be determined unless the history of the packages and the rates at which radioactive substances are transported in the subsoil (related to their solubility) are known.

Thus, the solution adopted for the two Flamanville power station reactors and the Cherbourg arsenal consists mainly of considering only the radionuclides measured by operators and included in their releases declaration (however carbon 14 and nickel 63 were added for Flamanville). The solution adopted for the CM was to consider only the main radionuclides measured in the environment by the various laboratories.

The conclusion about the work done on releases can be drawn up making a distinction between the different facilities. Special attention was paid to COGEMA La Hague reprocessing plants, due to the higher level of their releases compared with releases from other nuclear facilities (INB)[79] :

For COGEMA releases, a total number of 39 out of 75 radionuclides considered (52%) were added to the list of radionuclides supplied to the Group by COGEMA, and for which a measurement and an analytic identification had been made. These complements do not modify the orders of magnitude of the results supplied by the operator; however, they did help to define the composition of discharges in more detail and to give more exhaustive information about the composition of effluents which is necessary for a detailed dosimetric reconstruction.

Note the following points for the other industrial facilities:

- Liquid and gaseous releases from Flamanville Power Station were complemented by an evaluation of the activity of carbon 14 based on data in foreign literature; similarly, the activity of nickel 63 in liquid waste from the power station was determined starting from recent measurements made by the OPRI;
- For releases from the arsenal, the Ministry of Defense had provided the Group with results that were not available in the public domain in the past, in the form of a table of release measurements.

The results obtained do not cast doubt on data supplied by operators in terms of released activity, however, they did help to clarify the composition of releases necessary to make dosimetric impact calculations.

1.3. Summary of work on measurements

The objective was to collect and interpret the results of measurements made in the environment by about ten laboratories that regularly make radioactivity measurements in the region. The approach adopted consisted of carrying out the following in sequence:

- make an inventory of all samples and measurement types made starting from when the facilities were first put into service,
- standardize the presentation of measurement results and collect them in the form of tables and curves,
- interpret the results collected in this way.

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[79] No specific studies have been carried out on the Casquets trench in which radioactive waste was disposed of in the 1950s and 1960s. This trench is a potential source-term, although no effect on the marine environment has been detected since monitoring measurements were first made (middle of the 1960s).

It is clear that it is not sufficient to collect information; the variability of measurements within a single laboratory, and between different laboratories, have to be analyzed.

Factors influencing radioactivity levels in the environment, in space and over time and that could explain the observed differences, then need to be defined. For example, the sample taking period (before or after a release) is defined for a particular location. Thus, values used for comparison with the results of transfer models in the environment, and/or used directly for dosimetric reconstruction, can be validated.

The Group spared no efforts to be exhaustive for its inventory of samples and measurement types. On the other hand for the measurement results, it was decided to give priority to the information that is most relevant for the comparison with model results and for estimates of doses to populations, considering the large amount of data to be collected and verified within a limited time.

Therefore, the following selection criteria were applied:

- give priority to processing results for which several organizations took samples at the same location and at the same time, so that they can be compared with each other,

- give priority to indicators[80] for which long series of measurements are available in order to monitor variations of radioactivity with time, and for which existing sampling stations give the best coverage of the Nord-Cotentin area,

- emphasize points of specific interest case by case, for example some links in the food chain (milk), or the impact of a specific incident localized in time and space,

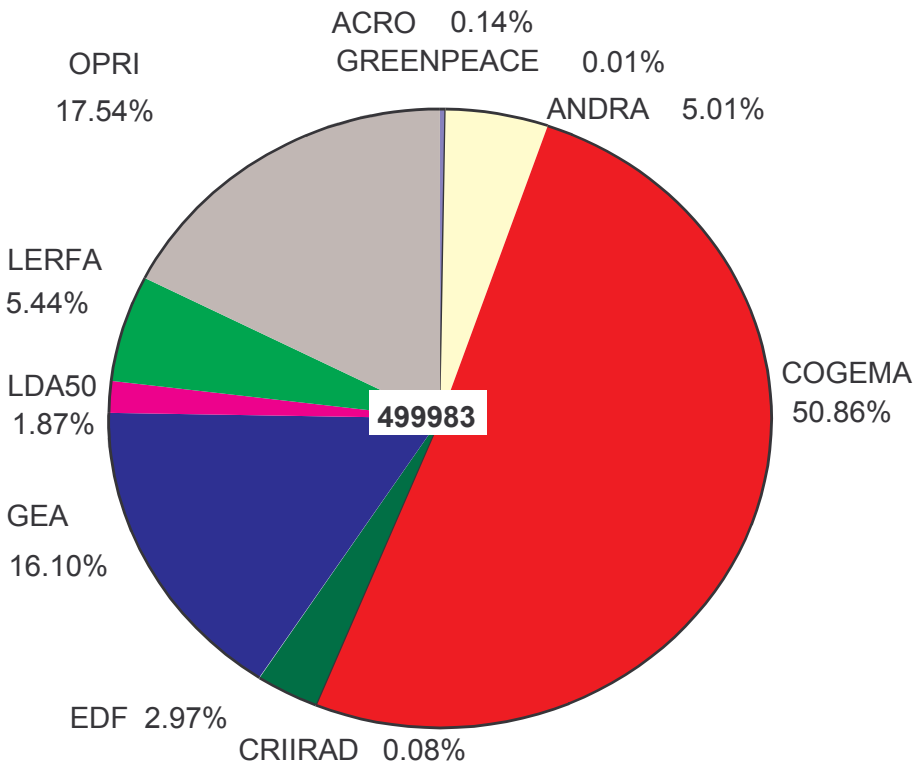
- give priority to results available in computer form so that they can be processed quickly,

- process environment data outside nuclear sites, for which the dispersion models that we want to validate are applicable.

Only results obtained after 1978 are used. A large amount of data were computerized starting from the end of the 1970s, and also the quality of the measurements increased. The end date of the period covered by the study is 1997, provided that measurement results for 1997 are available.

[80] The term "indicator" is used here in the sense of a sample type (sea water, sediment, an animal, a plant, etc.), for which a radioactivity measurement was made.

The total number of "determinations of concentrations of radionuclides or total activity" is equal to about 500,000[81], distributed as follows:



The critical review of results was followed by the creation of summary tables for each indicator or radionuclide, specifying the annual arithmetic mean used as a value for each organization and each location to represent average radioactivity levels in the environment, accompanied by the standard deviation, the maximum value of activity levels recorded during the year and the number of activity results exceeding the detection limit compared with the total number of measurements made during the year.

Sampling types, processing and radioactivity measurements of samples (and therefore detection limits) are adapted to the specific objectives of each laboratory (monitoring, expertise or research). This may make it difficult to compare results, particularly because detection limits are different depending on the objectives.

In summary, despite this diversity in procedures, all the work done on measurements in the environment has demonstrated that all results are generally consistent when all evaluation elements are considered, and participants have reached a consensus about the analysis of the variation of radioactivity levels detected in the environment in time and space.

This large scale review required a great amount of work. The collected data and the analysis results are available on a CD Rom[82].

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[81] This number is evaluated from the inventory and is approximate. It is underestimated particularly for gamma spectrometry analyses.

[82] This CD Rom can be obtained from GT2 organizer (see General appendices)

1.4. Summary of work on comparisons between models and measurements

The general objective of this work is to propose the most suitable models for evaluating the concentrations of radionuclides released through the environment by nuclear facilities in the Nord-Cotentin.

These models describe and quantify the various steps involved when a radionuclide passes from its release point through the various components of the environment to reach man:

- dispersion into the environment is modeled by a dilution factor for liquid releases into the sea or river, and by an atmospheric transfer coefficient for gaseous releases through the atmosphere,

- transfers to compartments in contact with man are modeled by radionuclide concentration factors in seafood and in river fish, and by distribution coefficient for sediments. For land compartments, and particularly for food, the model is much more highly developed and includes a large number of pathways.

Firstly, an inventory of existing models and their parameters (COGEMA, ANDRA, EDF, IPSN models and the European PC-CREAM model) was made. This comparison shows that the dispersion of measurement results compared with values predicted by the model is rarely greater than 10 in the marine environment or in the land environment. The Group considers that these differences are normal. They are partly due to the inherent nature of the models and the representativeness of the chosen parameters, and partly due to the inevitable fluctuation of the measurements in the environment used to build these models.

Furthermore, forecasts produced by models were systematically compared with the results of measurements actually made in the environment. This method allows adjustment of model parameters to local reality whenever possible, although this is rarely done in this type of work.

There is no doubt about the benefit of these comparisons in the marine environment, where a number of sufficiently sensitive measurements in the environment is available for many radionuclides. However in the terrestrial environment, the fewer number of measurements exceeding detection limits and the relative magnitude of the background noise made it impossible to carry out an equally extensive comparison between models and measurements. Therefore, priority should be given to making progress in this domain.

When long series of measurements exceeding detection limits (marine environment) were available to the Group, elements were provided to quantify the variability of the activities of radionuclides in the marine environment.

This exercise increased confidence in the model of the transfer of radionuclides into the marine environment, since the model could be adjusted over long measurement series available for some radionuclides. However on land, the smaller number of measurements exceeding detection limits or the relative magnitude of background noise, excluded the possibility of carrying out an equally extensive comparison between models and measurements.

1.5. Summary of work done on reconstruction of doses to populations and evaluation of the corresponding risks

The objective was to calculate doses to the red bone marrow received by young people between 0 and 24 year old in the canton of Beaumont-Hague due to nuclear industrial facilities in the region and due to other exposure sources.

The Group used a two-fold approach:

- evaluate the average dose to the red bone marrow received by the "cohort" considered and deduce the risk of leukemia from this dose; all exposure pathways for this population are studied,

- estimate the variability around the average dose to the red bone marrow obtained in this way, by studying particular behaviors that could lead to greater exposure ("cohort scenarios"); in particular, these are behaviors considered to be significant by epidemiological studies ("eating large quantities of seafood","frequent visits to the beach", etc.).

The first step was to "reconstruct" the cohort itself. The Group based its work on the birth registers and school attendance data for the canton of Beaumont-Hague. It also considered arrivals of children at the time of the "major construction site" during construction of COGEMA La Hague reprocessing plants, and death rates. The number of young people (0 - 24 year old) who had lived in the canton of Beaumont-Hague («cohort») during the period considered (1978-1996) is 6,656 individuals which is equivalent to an accumulated presence of the order of 70,000 individuals.years.

The second step was to calculate activities incorporated by the organism and external exposure starting from the activity concentrations in the environment and dose-relevant habits determined based on local inquiries (geographic location of the cohorts considered, use of the environment and consumption of food products by these same groups). Specific factors are applied to convert these activities into doses. The Group did not carry out a critical analysis on the use of these factors which are recommended by international organizations. The dose-relevant habits of individuals in the cohort, which were chosen to be as realistic as possible, correspond to average situations.

As mentioned above, calculated doses are doses to the red bone marrow (target organ for the risk of leukemia). All exposure pathways taken into account for each cohort were considered for routine releases, and for releases due to accidents and incidents. Doses were calculated since the beginning of releases from nuclear facilities (1966, the date on which releases started from COGEMA La Hague reprocessing plants). Doses for other sources of exposure to ionizing radiation (medical, natural, fallout from atmospheric tests of nuclear weapons and the Chernobyl accident), were calculated since 1954. Doses to the fetal red bone marrow during pregnancy (*in utero* exposure) were calculated only for routine releases from nuclear facilities.

The number of cases of leukemia that could theoretically be assigned to ionizing radiation (radiation-induced risk) is calculated in the final step of the estimate. This risk is calculated assuming that there is no threshold in the dose/effect relation.

The radiation-induced risk of leukemia was estimated over the period for which epidemiological data are available (1978-1996).

The results obtained are as follows:

- Collective doses

The collective dose due to routine releases from nuclear facilities in the Nord-Cotentin for the entire 0-24 year old cohort for the period from 1966 to 1996 is equal to 0.30 m.Sv. Figure 1 shows the contribution of radionuclides and exposure pathways.

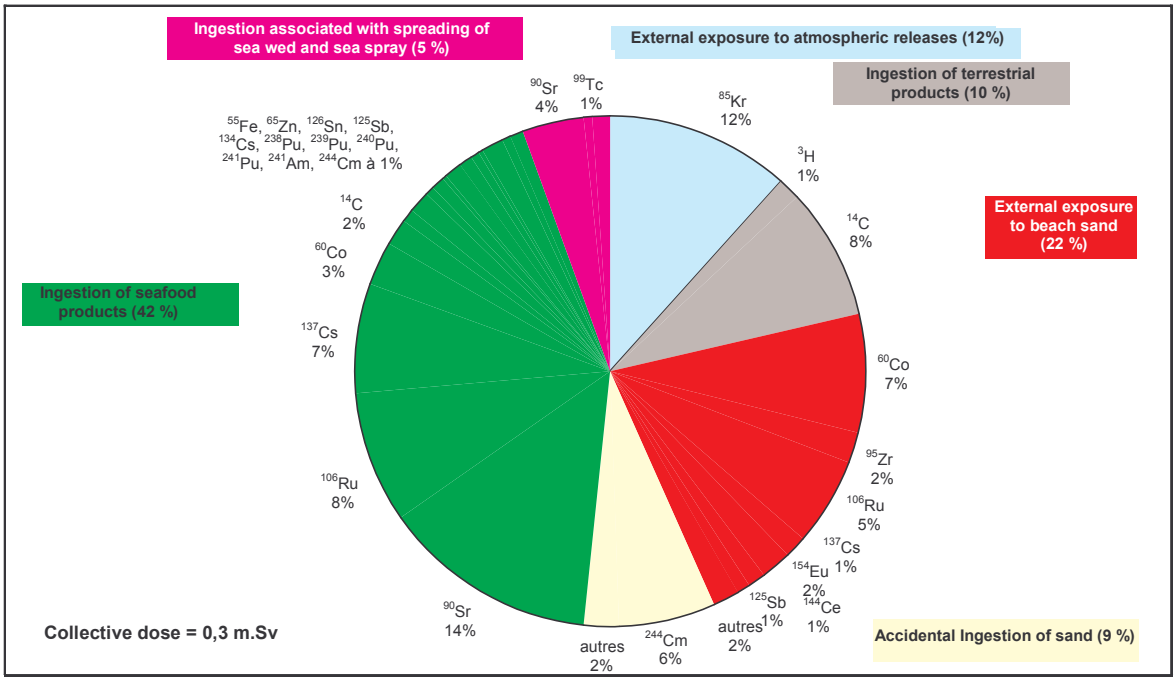

Figure 1 : Contribution of radionuclides and exposure pathways to the collective *ex utero* dose to the entire cohort over the period from 1966 to 1996 due to routine releases from nuclear facilities in the Nord-Cotentin.

The predominant exposure pathways for the dose are ingestion of seafood (42% mainly due to ^{90}Sr, ^{106}Ru, ^{137}Cs, ^{60}Co and ^{14}C) and external exposure to beach sand (22% mainly due to ^{60}Co, ^{106}Ru, ^{95}Zr and ^{154}Eu).

A bibliographic study was carried out to estimate the exposure of Nord-Cotentin populations to remote natural, medical and artificial exposures (Chernobyl accident, atmospheric testing of nuclear weapons).

The total collective dose to the red bone marrow of the young people cohort living in the Beaumont-Hague Canton for the period from 1954 to 1996 is equal to 322 m.Sv . The preponderant exposure source is natural exposure with a contribution of about 74%, namely 241 m.Sv. The main natural exposure pathway is ingestion of ^{210}Po (21% of the total collective dose), mainly through the ingestion of seafood. Medical exposure is a non-negligible source of exposure (24% of the total collective dose, namely 76 m.Sv). Exposure due to fallout from atmospheric testing of nuclear weapons and the Chernobyl accident contribute about 2% (5 m.Sv). Finally, routine releases from nuclear facilities in the Nord-Cotentin contribute less than 0.1% (0.30 m.Sv).

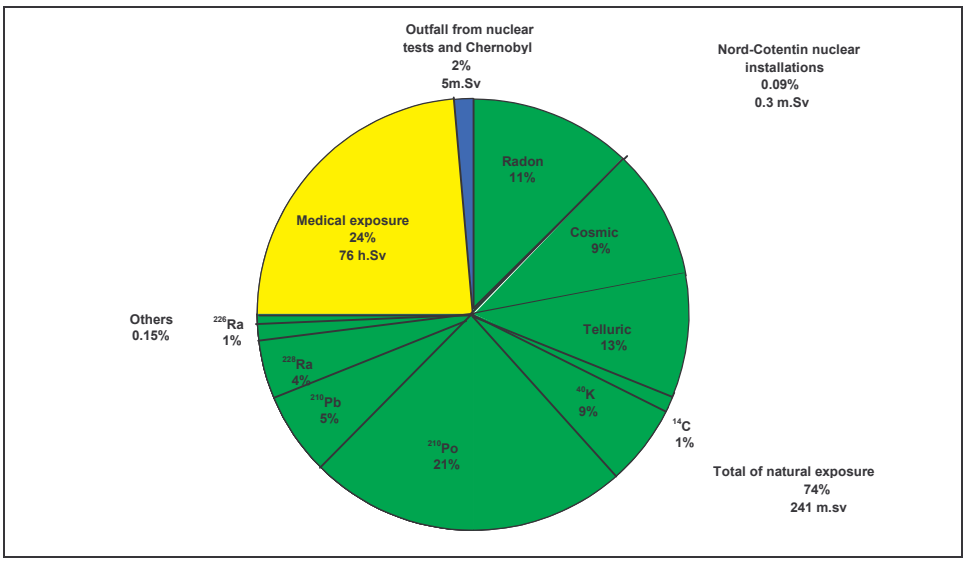

Figure 2: Contribution of various sources of exposure to the collective *ex utero* dose to the red bone marrow

Doses due to the two most significant accidents or incidents were also considered. The additional collective dose to the red bone marrow for the cohort due to the break in COGEMA's sea release pipe (1979-1980) was 0.004 m.Sv (to be compared with 0.30 m.Sv during normal operation). The additional collective dose to the red bone marrow for the cohort following COGEMA's silo fire (1981) was 0.14 m.Sv.

Finally, doses to the red bone marrow due to *in utero* exposure due to routine releases from local nuclear facilities were considered using two methods, while waiting for the publication of the IRPC[83] models. The overestimate approach gives a collective dose due to *in utero* exposure equal to 0.15 m.Sv. The more realistic approach gives a collective dose of 0.02 m.Sv.

- Risk

The final step in the radioecological evaluation starts from collective doses to the red bone marrow, and estimates the number of cases of leukemia that can theoretically be assigned to exposure to ionizing radiation of individuals in the 0 - 24 year old cohort who had lived in the canton of Beaumont-Hague.

This risk evaluation step involves the application of coefficients derived from the literature to define the relation between doses and the probability of occurrence of leukemia. It may also require an estimate of the "normal" incidence of leukemia in young people in France, depending on the method used.

Figure 3 shows the distribution of the number of cases of leukemia, in a similar manner to figure 1 that concerned doses.

Figure 4 shows the proportion associated with each exposure source. This figure should be compared with figure 2 that shows the proportion of the collective dose to the red bone marrow associated with each exposure source

[83] International Radiological Protection Commission

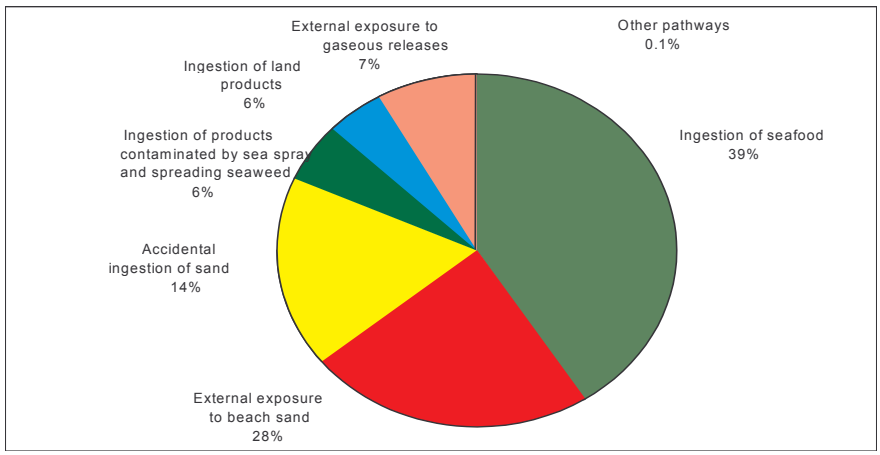

Figure 3: Distribution of *ex utero* cases of leukemia that can be theoretically assigned to routine releases from nuclear facilities in the Nord-Cotentin as a function of exposure pathways (0-24 year old cohort in the Canton of Beaumont-Hague, 1978-1996)

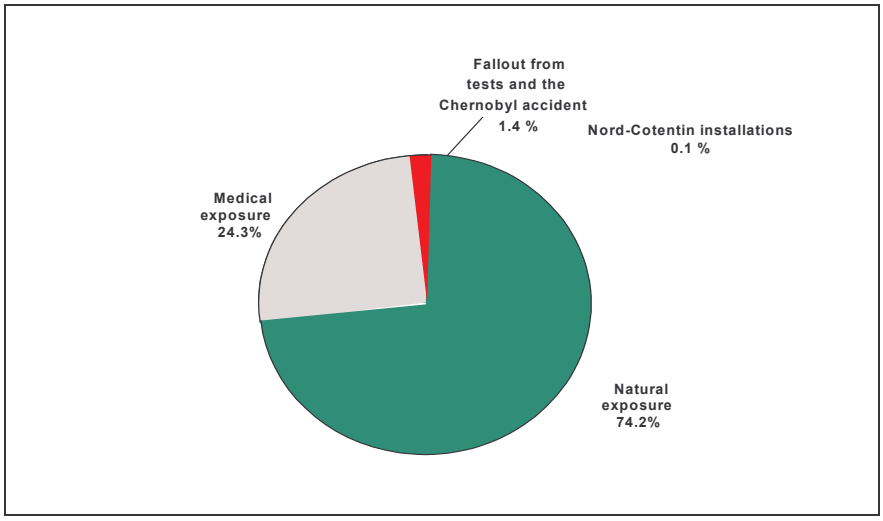

Figure 4: Distribution of radiation-induced cases of leukemia *(ex utero)* as a function of sources of exposure (0-24 year old cohort in the Beaumont-Hague Canton, 1978-1996)

1.6. Results and discussion of results

1.6.1 Results

Estimates of cases of leukemia that could theoretically be assigned to the various sources of exposure to ionizing radiation in young individuals from 0 to 24 year old for the Beaumont-Hague Canton over the 1978-1996 period, are broken down as follows:

Nuclear facilities	0.0014	(routine releases 0.0009*, accidental releases 0.0005)
Natural sources	0.62	
Medical sources	0.20	
Others	0.01	(fallout from nuclear tests, Chernobyl accident)
Giving a total (rounded)	0.83 cases	over a 19-year period

*The contribution of *in utero* exposure calculated only for routine releases from nuclear facilities is equal to 0.0003 cases, and is additional to this risk.

On the basis of the risk models used, the number of cases of leukemia that can be assigned to exposure to releases from the nuclear facilities for the "reconstructed cohort" of 6656 young individuals living in the Beaumont-Hague Canton is estimated at 0.0014 cases for the period from 1978 to 1996. The number of cases that can theoretically be assigned to the nuclear facilities thus represents about 0.2% of cases that can be assigned to all sources of exposure to ionizing radiation. Based on this estimate, the probability of occurrence of a radiation-induced case due to the nuclear facilities is of the order of 1 per thousand (apart from *in utero* exposure).

On the basis of the risk models used, the number of cases of leukemia that can be assigned to all exposure sources is 0.83, much of which is due to exposure to natural and medical sources (99%). It should be noted that the national population in general is exposed to these same sources.

1.6.2 Discussion of results

Epidemiological studies have shown that the total number of cases of leukemia expected in the Beaumont-Hague Canton from 1978 to 1996 would be of the order of 2 if the occurrence rate of this disease was the same as the value observed nationally. Four cases were observed. However, this difference is not statistically significant.

The reconstruction of exposures from the nuclear facilities by the Nord-Cotentin Radioecology Group, gave a calculated number of 0.0014 cases of radiation-induced leukemia during the 1978-1996 period. This number is low compared with the incidence of leukemia observed by the above mentioned recent epidemiological studies.

However, this result is the best estimate and it should be emphasized that at this stage the margins of uncertainty have not been quantified. In view of this, some members of the Group did not feel that at this stage they could conclude that it is unlikely that the releases from nuclear facilities contribute to the incidence of leukemia observed in the Canton of Beaumont-Hague.

The results obtained can be compared with those from similar studies carried out in the United Kingdom around the Dounreay and Sellafield reprocessing plants. The conclusion of the British studies was that the observed number of cases of leukemia cannot be explained by releases from the nuclear facilities.

Furthermore, scenarios were examined in order to determine the effect of habits leading to higher individual doses. The habits considered are described in the case control study of D. Pobel and J.F. Viel published in 1997 (time spent on the beach, consumption of local fish, shellfish and crustaceans). Even prolonged presence on the beaches (1h20 per day) did not significantly increase the radiation-induced risk from all sources. The risk to an individual who consumes a large quantity of local seafood (500 g per day) increases by a factor of about 2, but this increase is largely related to the ingestion of radionuclides of natural origin in seafood.

2. EVALUATION OF INDIVIDUAL DOSES TO THE MOST HIGHLY EXPOSED GROUPS (TASK 2)

2.1. Method

The method adopted for task 1 to evaluate the releases, to analyze measurements in the environment and to select models for radionuclide transfers through the environment, is also applicable to task 2.

However, different groups of population are considered. In this case, the objective is to identify groups or individuals likely to be the most highly exposed due to their geographic location or dose-relevant habits. It will be emphasized that a very broad interpretation is given to the mission letter since the Group did not restrict itself to exposure to releases from the COGEMA La Hague reprocessing plants, but it also considered particular exposure situations related to releases from the CM. Similarly, it made a distinction between "chronic" exposure situations expressed as an annual dose and "occasional" exposures expressed as a dose for an action or a situation lasting for a limited period.

Thus, about 15 different situations or scenarios were considered, including those used by COGEMA in its impact studies ("critical groups") which were examined and compared with an average theoretical scenario.

Calculated doses are doses to the entire body (also called "effective doses"), considered as a health detriment indicator and particularly risks of cancer to tissues and organs considered as being sensitive to radiation. Effective doses are calculated only for routine releases from nuclear facilities.

2.2. Results and discussion of results

The Nord-Cotentin Radioecology Group studied about fifteen particular scenarios, by considering different dose-relevant habits. The particular scenarios resulting in the highest effective doses (outside "near field"[84]) are compared with the critical groups used by COGEMA in its impact studies. The results are presented for the years during which the highest impacts occurred through marine and terrestrial pathways (outside "near field"):

	Individual dose (mSv/year)	
	1985	1996
COGEMA "critical groups"		
Fishermen of Goury	0.041	0.005
Inhabitants of Digulleville	0.014	0.008
Particular scenarios of the Radioecological Group		
Fishermen of Les Huquets	0.226	0.026
Farmers of Pont-Durand	0.053	0.059

These values should be compared with the limit for the public of 1 $mSv.year^{-1}$ (in fact a fraction of this value to take into account the possible contribution of other industrial sources), and, with the natural radioactivity of 2.4 $mSv.year^{-1}$.
The results obtained for the particular scenarios of fishermen of Huquets and farmers of the Pont-Durand district give values 5 to 7 times higher than the values obtained for the critical groups selected by COGEMA in its estimates for regulatory purposes of the impact of its releases, on the basis of the same methodology as the Nord-Cotentin Group. This is due to differences in choices regarding habits. These results may be considered as a sensitivity study of these factors.

[84] near field means within a radius of about 300 meters from the release point

Particular behaviors (occasional scenarios outside "near field") can result in increments to the effective dose that are less than or at most equal to the order of magnitude of the effective dose associated with the theoretical average scenario. Consumption of a crab caught in the "near field" (close to COGEMA sea release pipe) in 1985 resulted in an effective dose of several hundred µSv, but this scenario is rare since mooring and trawling in the "near field" are prohibited, and also because there is very little marine life in the area due to the strong local currents.

The following table summarizes all results for particular scenarios:

	Particular scenario description		Associated dose
individual living in the Canton	1985 average scenario	/year	18 µSv
	1996 average scenario	/year	5 µSv
chronic scenarios	Fishermen of Huquets in 1985	/year	226 µSv
	Farmers of Pont-Durand 1996	/year	59 µSv
	Adult living in the 1500 m zone in 1996	/year	24 µSv
critical groups	Fishermen of Goury 1985	/year	41 µSv
	Inhabitants of Digulleville 1996	/year	8 µSv
occasional scenarios	Fishing close to the pipe	/occurrence	20 µSv
	Walking close to the pipe	/occurrence	7.5 µSv
	Fishing at the bottom of the concrete block and posts	/occurrence	2.75 µSv
	Walking in the Moulinets Bay	/occurrence	< 1 µSv
	Diving near the pipe	/occurrence	2.5 µSv
	Eating a crab (250 g) caught in the near field in 1985	/occurrence	313 µSv (7-12 year old)
	Using Sainte-Hélène water in 1979	/occurrence	10 µSv
	Using Sainte-Hélène water in 1986	/occurrence	3 µSv
	Fishing in Sainte-Hélène in 1979	/occurrence	0.015 µSv
	Fishing in Sainte-Hélène in 1986	/occurrence	2 µSv
	Playing at the mouth of the Sainte-Hélène in 1987	/occurrence	10 µSv
	Playing at the mouth of the Sainte-Hélène in 1991	/occurrence	0.5 µSv
	Walking close to the CM	/occurrence	0.5 µSv

GENERAL APPENDICES

GENERAL APPENDICES

Appendix 1	Mission letters.
Appendix 2	Members of the Plenary Group and working groups.
Appendix 3	A through table of acronyms and abbreviations.
Appendix 4	Comments and reservations of the group or external associations.
Appendix 5	Websites
Appendix 6	Letters addressed to the President of the group from: - nuclear operators who contributed to determining the source term (GT1) - laboratory supervisors who contributed to preparing the inventory (GT2) confirm that they agree with the data presented.

APPENDIX I

La Ministre de l'Aménagement du Territoire et de l'Environnement

Le Secrétaire d'Etat à la Santé

Paris, August 25, 1997

Dear Madam,

Thank you for agreeing to act as President of the Radioecology Group that we decided to setup after seeing the recommendations of the "Scientific Committee for a new epidemiological study in the Nord-Cotentin", that was presided over by Professor Charles SOULEAU, at the request of our predecessors.

Your objectives will be to:

- prepare an inventory of liquid and gaseous radioactive releases from nuclear facilities in the Nord-Cotentin;
- produce a statement about monitoring of the radioactivity of the various media in the environment and products in the food chain;
- produce a statement of doses delivered to the exposed populations, including doses due to natural and medical exposure;
- estimate the risk associated with the received doses.

We are aware of the large amount of work necessary to complete this task, but in any case we would like to receive a progress report from your group within six months.

Mrs. Annie SUGIER
Nuclear Protection and Safety Institute
B.P. 6
92265 FONTENAY aux ROSES Cedex

Furthermore, in accordance with the report submitted to us by the "Scientific Committee for a new epidemiological study in the Nord-Cotentin" on July 1, please give priority to carrying out the following work:

- draw up a statement of the current state of knowledge about the behavior of radionuclides in the environment to verify estimates made by operators;
- write the necessary comparisons between measurements results and models for transfer into the environment;
- estimate the dose received by the exposed individuals, as realistically as possible.

We would like to receive a document from your group on these three items within four months.

The group composition as it was initially established will remain unchanged, and you can hold discussions with any person or organization that could contribute to your work.

Please inform us in good time if you consider that the composition of the group needs to be changed.

Best regards,

DOMINIQUE VOYNET **BERNARD KOUCHNER**

La Ministre de l'Aménagement du Territoire et de l'Environnement

Le Secrétaire d'Etat à la Santé

Paris, November 27, 1997

Subject: Nord-Cotentin Radioecology Group
Attachments: 1

Dear Madam Director,

In your October 1 letter, you informed us of the working method that you have chosen to complete the task that we assigned to the *Nord-Cotentin Radioecology Group*, of which you are the President. You also drew our attention to a proposal to widen the composition of the Group.

In our opinion this extension of the Group is desirable, provided that it does not reduce the capacity of the group to work productively.

We approve the proposal to widen the group as you expressed it (see Appendix 1). In our opinion, this proposal satisfies the request that we received from Mr. CAZENEUVE, President of the La Hague Special and Permanent Information Commission. We have noted the presence of three foreign organizations among the Plenary Group, which satisfies our desire for openness to the European scientific community.

Finally, we would like to remind you that the results of your work should be available in time to be taken into account in procedures to revise texts governing operation of COGEMA's La Hague plant in 1998.

Best regards,

Dominique VOYNET

Bernard KOUCHNER

Mrs. Annie SUGIER
Delegate Director for Protection
Nuclear Protection and Safety Institute
B.P. 6
92265 FONTENAY aux ROSES Cedex

APPENDIX 2

MEMBERS OF THE PLENARY GROUP OF NORD-COTENTIN

MEMBERS OF THE PLENARY GROUP			
Name	**Application**	**Name**	**Application**
Mrs. AMIARD-TRIQUET	CNRS	Mr. Le CORRE/Mr. GUILMIN*	EDF
Mr. AUVERLOT	ANDRA	Mrs. HERBELET	OPRI
Mr. BARBEY	ACRO	Mr. LAURENT	COGEMA
Mr. BARON	GEA	Mr. LORTHIOIR	IPSN
Mrs. BRETHEAU	IPSN	Mr. MURITH	OFSP
Mr. BURKART	BFS	Mr. PASQUIER	OPRI
Mr. LEDENVIC/Mr. CALMET*	IPSN	Mrs. ROMMENS	IPSN
Mr. CHAREYRON/Mr. DESBORDES*	CRII-RAD	Mrs. SENE	CSPI
Mr. CROUAIL	CEPN	Mrs. SUGIER (President)	IPSN
Mrs. SARFATI/Mrs. DECOBERT*	COGEMA	Mrs. VALENTIN-RANC	ANDRA
Mr. BEROUX/Mr. DELISLE*	EDF	Mr. WRIXON	NRPB
Mr. GERMAIN	IPSN	Mr. ZERBIB	CSPI
Mr. GOUMONDY	IPSN		

* Mr. CALMET replaced Mr. LEDENVIC starting from March 1999
* Mr. GUILMIN replaced Mr. LE CORRE starting from March 1999
* Mrs. DECOBERT replaced Mrs. SARFATI starting from October 1998
* Mr. DELISLE replaced Mr. BEROUX starting from October 1998
* Mr. DESBORDES replaced Mr. CHAREYRON starting from June 1999

MEMBERS OF GT1 GROUP			
Name	**Application**	**Name**	**Application**
Mrs. BAGANZ	COGEMA	Mr. LEBAR	COGEMA
Mr. BARBEY	ACRO	Mr. GOUMONDY (Secretary)	IPSN
Mr. BOURCIER	EDF	Mrs. ROMMENS	IPSN
Mr. DIANA	OPRI	Mrs. SENE	CSPI
Mr. DURET	ANDRA	Mr. ZERBIB (Chairman)	CSPI

MEMBERS OF GT2 GROUP			
Name	**Application**	**Name**	**Application**
Mr. AMIARD-TRIQUET	CNSR	Mrs. HERBELET	OPRI
Mr. BARON	GEA	Mr. KALIMBADJIAN	COGEMA
Mr. BEUTIER	NUSYS	Mr. KLEIN	ISTE
Mr. CHAREYRON	CRII-RAD	Mr. LE CORRE	EDF
Mr. CLAREBOUT	ACRO	Mr. MASSON	IPSN
Mr. DURET	ANDRA	Mr. PETRON	LDA
Mr. FIEVET	IPSN	Mr. PIGREE	ACRO
Mr. GERMAIN (Chairman - Secretary)	IPSN	Mrs. ROMMENS	IPSN
Mr. GUARY	CSPI	Mrs. SICLET	EDF

MEMBERS OF SUBGROUP 3			
Name	**Application**	**Name**	**Application**
Mrs. AMIARD	CNRS	Mr. DUBOIS	COGEMA
Mr. BAILLY DU BOIS	IPSN	Mrs. LECLERC-CESSAC	ANDRA
Mr. BOILLEY	ACRO	Mr. LENDENVIC	IPSN
Mr. BORDIER	COGEMA	Mrs. LISSORGUES	EDF
Mr. CALMET (Chairman - Secretary)	ISPSN	Mr. MARCHAND	EDF
Mrs. DELLERO	NUSYS	Mrs. MERLE-	IPSN
Mr. DESBORDES	CRII-RAD	SZEREMETA	IPSN
		Mrs. ROMMENS	EDF
		Mrs. SICLET	

MEMBERS OF SUBGROUP 4			
Name	**Application**	**Name**	**Application**
Mrs. BAGANZ	COGEMA	Mrs. HUBERT	EDF
M. BARBEY	ACRO	M. LAURIER	IPSN
M. BARON	GEA	M. LE BAR	COGEMA
Mrs. BRETHEAU (Chairman - Secretary)	IPSN	Mrs. LECLERC-CESSAC	ANDRA
		M. LENDENVIC	IPSN
Mrs. DELLERO	NUSYS	Mrs. LISSORGUES	EDF
M. DESBORDES	CRII-RAD	Mrs. MERLE-SZEREMETA	IPSN
Mrs. DOMBRY-RINGEARD	IPSN	Mrs. ROMMENS	IPSN
M. HARTMANN	EDF	Mrs. SENE	CSPI

APPENDIX 3

A THOROUGH TABLE OF ACRONYMS AND ABBREVIATIONS

ACRO	**A**ssociation pour le **C**ontrôle de la **R**adioactivité dans l'**O**uest
ANDRA	**A**gence **N**ationale pour la gestion des **D**échets **Ra**dioactifs
CNRS	**C**entre **N**ational de la **R**echerche **S**cientifique
CRII-RAD	**C**ommission de **R**echerche et d'**I**nformation **I**ndépendantes sur la **RAD**ioactivité
CSPI – CNAM – INTECHMER	**C**ommission **S**péciale et **P**ermanente d'**I**nformation près l'établissement de La Hague – **C**onservatoire **N**ational des **A**rts et **M**étiers – **IN**stitut des **TECH**niques de la **MER**
EDF – DSRE	**E**lectricité **D**e **F**rance – **D**épartement **S**écurité **R**adioprotection **E**nvironnement
EDF - DER	**E**lectricité **D**e **F**rance – **D**irection des **E**tudes et **R**echerches
GEA – MARINE NATIONALE	**G**roupe **E**tudes **A**tomiques – **Marine Nationale**
IPSN/LERFA	**I**nstitut de **P**rotection et de **S**ûreté **N**ucléaire/**L**aboratoire d'**E**tudes **R**adioécologiques de la **F**açade **A**tlantique
IPSN/DPHD	**I**nstitut de **P**rotection et de **S**ûreté **N**ucléaire/**D**épartement de **P**rotection de la santé de l'**H**omme et de **D**osimétrie
LDA 50	**L**aboratoire **D**épartemental d'**A**nalyses de la Manche
OPRI	**O**ffice de **P**rotection contre les **R**ayonnements **I**onisants

APPENDIX 4

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Work done by the Nord-Cotentin Radioecology Group ACRO Reservations and Comments

July 07 1999

The following text was presented at the last plenary meeting of the Nord-Cotentin Radioecology Group. The subjacent concepts for some of these reservations or comments were taken into account through amendments made to the draft "Summary note" discussed on July 07 this year, the final version of which was accepted by the ACRO representative.
However, we preferred to publish the text in full as an appendix to the summary document, to provide a clear statement of differences of opinion.

1 - The Nord-Cotentin Radioecology Group has worked for 2 years to attempt to retrospectively reconstruct radiation doses received by the La Hague population due to nuclear facilities in the Nord-Cotentin. One of its tasks (described in detail in the summary note) led the Group to calculate the risk of leukemia for young people between 0 and 24 year old during the period from 1978 to 1996.

2 - Two items are worth emphasizing, since they show the innovative aspect of the procedure originally required by the responsible Ministers and the President of the Group:
© this study would be carried out in detail, attempting to be exhaustive at all times
© despite initial reticence, non governemental laboratories would contribute to this work.

3 - The presence of non governemental laboratories must not conceal the significant imbalance between different groups of players in terms of equipment resources, human potential (volunteer work and its limits, etc.), evaluation tools and even experience in a field traditionally reserved for operators and government authorities. This is one of the reasons why non governemental laboratories must maintain their reserved attitude.

Reservations about the risk calculation:

4 - The results achieved by the Group can be very briefly summarized as two points:
© with the "cohort" approach, the calculated risk of leukemia due to nuclear facilities is between 0.0017 (absolute risk) and 0.0021 (relative risk)[85];
© some situations considered in the "special scenarios" approach resulted in actual doses of a few hundred µSv, or possibly of the order of one mSv.

[85] Figures taken from GT4 report (final version)

5 - Our main reservation applies to "realistic" procedure selected by the Group for the reconstruction of doses received by the cohort and the resulting risk. We continue to believe that in terms of radiation shielding, any evaluation of a health impact must be made conservatively since, in the absence of any precise knowledge of the uncertainty linked to the "realistic" calculation, the only way to bound the genuine value of the impact is to use the "overestimate" approach.

6 - It is probable that the European Directive was over-interpreted. As became clear many times in discussions within the Group, "*realism*" should apparently be understood as being somewhere between "*plausible*" and "*proven*". This essential difference may be illustrated by a specific example. The Group chose to assume that the consumption of molluscs by inhabitants of La Hague (North-West point) was produced in Saint Vaast la Hougue (East Coast). Why? Because there is no proof that production of molluscs in the La Hague region can satisfy consumption needs. Forget about *brelins noirs*, *brelins coques* (whelks), limpets that are collected by hand; forget about beds of abalones and scallops (see attachment) exploited by local fishermen and whelks and squids. However, these practices actually do exist and retrospectively, have provided a means of leisure in the region, and also a very useful complement for those on low incomes. This is not a minor detail, considering the contribution of the "marine ingestion" pathway to the dose.
In passing, and for the same reason, note that the "molluscs" ration for the 15-year-old age group is significantly underestimated (7 times less than for an adult!!).

7 - The comparison made by GT3 between environmental models and annual average measurements in the environment provided some confidence in the model of the future of marine releases, with the significant exception of a few radionuclides that are important in terms of dose (for example C14) and the near field. On the other hand, the validity limits of models normally used for atmospheric releases were determined based on Kr85 measurements, but these measurements did not provide a sufficient basis for proposing a completely validated alternative outside the validity limits of the model. The Group's choices were often arbitrary, since values derived from the literature were sometimes very highly dispersed. Therefore, the ACRO considers that it is not competent to make a judgment about air models and considers that the models used by the Group cannot be used as references in their current state.
Finally, note that flow models for contamination of ground water have not been studied.

8 - In conclusion, our main queries and the reason for our reservations, are illustrated by several facts:

8-1 - It is quite obvious that a large number of parameters are involved in the calculation of the dose and the associated risk, and that there is a margin of uncertainty for most of these parameters.

8-2 - This margin of uncertainty can be high (a factor of 10 or even more), particularly for parameters that have direct consequences in terms of dose.

8-3 - Despite a large amount of work done to model the exposure pathway to atmospheric releases, the Group is aware of weaknesses that exist in the method of calculating the impact on a terrestrial environment.

8-4 - *In utero* exposure could make a significant contribution to the risk through the dose delivered to the fetus. But here again, there is considerable uncertainty with the model; there is a factor of 10 between initial estimates (overestimate calculation) and current "realistic" corrections…

8-5 - Apart from these uncertainties, there are known and unknown omissions. Thus, the impact of sea spray is included for the ingestion pathway, but not for the inhalation pathway because there is no model. The dose received *in utero* due to accidents has not been calculated. Furthermore, the Group, in its very praiseworthy attempt to be exhaustive, has added almost forty radionuclides to those determined by the operators; however, there is no proof that there are no other unidentified radionuclides that could contribute to the dose. Finally, concerning reactors, the source term was assumed to be equal to zero for some radionuclides because they were "*below the detection limit*". However, considering the release flow, it is quite plausible that a real but unquantified activity could be omitted from the balance in terms of the annual cumulated value, due to the current checking methods.

The global uncertainty that accompanies the dose calculation and the associated risk is probably large (particularly in a "realistic" approach), but it was impossible to calculate it; thus, what reliable arguments do we have to confirm that we have not made a mistake by a factor of 30, in other words that the upper uncertainty margin is less than 30? If a factor of 30 is used, and considering a risk of 2.1 10^{-3} (relative), the probability that 1 case of leukemia could be explained by exposure to nuclear facilities becomes greater than 5%, and is no longer simply a question of chance.

Reservations on scenarios

9 - Although an overestimate procedure was used for the creation of special scenarios, selected exposure time or consumed quantity data are still low; each person should use values that appear must appropriate to him [see exposure time to the pipe, time spent near the ANDRA site, the quantity of molluscs caught in the near field, etc.]

10 - Nevertheless, for the state of the environment to the North of the CM, consumption of contaminated water and watering of gardens by this contaminated water[86] were excluded from the "realistic" option. Retrospectively, calculations were carried out during different years until 1979. If water sources (wells, wash houses, drinking troughs, etc.) at private individuals are still marked 20 years later, how is it possible to so confidently ignore these exposure pathways that even the operator took into account in the regulatory approach for his documents.

Special Reservations / Comments

11 - The presentation of results should clearly indicate the limits of our investigations. Firstly, the task of the Group was not to deal with all cancers (which could be a request or a question from local populations). Subsequently, the leukemia risk calculation only concerns a given period in life and a given population (end of the task following work done by J-F. Viel). In this sense, this limited evaluation alone could not translate the health impact of nuclear facilities in the Nord-Cotentin.

12 - The risk for cases of leukemia alone is deduced from the calculation of the collective dose for young people living in the canton of Beaumont-Hague. It should be emphasized that this is a partial collective dose considering the global influence of the facilities (to satisfy the "cohort" approach). The fraction of radioactivity consumed by populations other than those studied in the canton of Beaumont-Hague should be considered to arrive at a more complete estimate of the health impact[87], in order to determine the global collective dose (admittedly for a different purpose).

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[86] This choice explains most of the difference between the results presented here (10 µSv) and the results presented by the SOULEAU Committee (75 µSv).

[87] See the discussion above about mollusc beds, for which we emphasized local existence, but which were not used in food intakes since this production is supposed to be exported…

13 - Although the creation of risk models is outside the competence of the Group, a few points should be emphasized that tend towards a biased judgment, to say the least:

© The dose / effect relation is based mostly on studies of H-N survivors, for whom the exposure mode is relatively different from environmental exposure (strong acute dose versus weak chronic dose, etc.);

© For the risk calculation, other risk factors that could act in synergy are ignored; however, the multi-factorial approach now provides important input into understanding of the development of cancers.

14 - The representation as a percentage of all sources of radiation exposure emphasizes the importance of natural and medical sources compared with nuclear facilities. This method of representing radiation is questionable, considering the uncertainty about medical exposure (4 times greater in this study than in the English study). Due to the lack of any precise study, the committee selected the current estimate of the national average. The transposition to a more rural population, and also to young people only (who tend to make less use of medical facilities, etc.) and particularly for retrospective purposes (lack of examinations such as scans making a large contribution to the dose, etc.) probably tends to overestimate doses received by diagnostic examinations in this case.

15 - In conclusion, we consider it important that these reservations should emphasize uncertainties existing on the risk calculation and the limits of the exercise, in order to prevent making a permanent and final conclusion. The difficulty in establishing a cause-to-effect relation does not prove that this relation does not exist. However, this critical (self-critical) view must not conceal the importance of the work done during the last two years and its innovative aspects (in this respect, we fully agree with the comments expressed by the President of the Group). Finally, it is clear that a genuine debate has been setup between the various players and some of the proposals that we formulated have been accepted, either in the cohort approach, or in the scenarios approach.

Attachment

Although there are scallop beds near the La Hague coast, very few measurements were made on these indicators in the middle of the 1980s. For the molluscs category, most laboratories check limpets. However COGEMA SPR results include an analysis of scallops caught in Auderville in 1984. The following table (last column) shows the lag between this real activity in Auderville and the calculated activity in Barfleur, which was selected by the Group as the sampling location.

		Goury 1985	Goury 1985	Barfleur 1985	Auderville 1984	ratio
	F.C.	Act. ($Bq.m^{-3}$)	Act. ($Bq.kg^{-1}$)	Act. ($Bq.kg^{-1}$)	Act. ($Bq.kg^{-1}$)	Auderville / Barfleur
	molluscs	Sea water	molluscs	molluscs	Scallops	
^{54}Mn	10000	1.55E-01	1.55E+00	**7.75E-01**	**4.10E+00**	**5.3**
^{58}Co	2000	3.49E-01	6.98E-01	**3.49E-01**	**4.10E+00**	**11.7**
^{60}Co	2000	1.17E+01	2.34E+01	**1.17E+01**	**2.80E+01**	**2.4**
^{65}Zn	80000	9.30E-02	7.44E+00	**3.72E+00**	**1.40E+01**	**3.8**
^{106}RuRh	600	6.66E+02	4.00E+02	**2.00E+02**	**8.00E+02**	**4.0**
^{110m}Ag	40000	1.02E-02	4.08E-01	**2.04E-01**	**2.20E+01**	**107.8**
^{125}Sb	20	8.31E+01	1.66E+00	**8.31E-01**	**4.40E+00**	**5.3**
^{134}Cs	50	6.24E+00	3.12E-01	**1.56E-01**	**2.60E+00**	**16.7**
^{137}Cs+Ba	50	4.48E+01	2.24E+00	**1.12E+00**	**2.80E+01**	**25.0**
^{144}Ce+Pr	1500	3.32E+00	4.98E+00	**2.49E+00**	**2.40E+01**	**9.6**

A view from the Foreign Organization

The reports of an increase in incidence of leukemia amongst young individuals in the Nord-Cotentin clearly necessitated a thorough study of the radiological situation. Such studies are by no means straightforward. They require the input of professionals from a range of scientific disciplines such as reactor physics, radiochemistry, ecology, radiation dosimetry and radiation biology. Even then, the information available will inevitably be incomplete. Judgments will be required and any quantitative results will be subject to uncertainties. Nevertheless, in spite of their limitations, they facilitate understanding and are of considerable assistance to decision makers. They also help to provide and appropriate perspective for the public.

In the context of this particular study, we, as the three foreign organizations, wish to record that they regard the endeavours of the Nord-Cotentin Radioecology Group, which was set up by the Minister of Internal Development and Environment and the Secretary of State for Health as substantial. Although similar studies have been undertaken in other countries, we consider that this particular study has a number of unique features:

its attempt to be as exhaustive as possible in the development of information on the radioactive release, over a large number of years, from all the relevant nuclear sites in the area, and in reviewing the data on the levels of radioactivity in the environment; and its thoroughness in the review of the models of the behaviour of radionuclides in the environment to be used in the calculation of radiation dose.

The uniqueness of the composition of the Group also has to be recognised, comprising as it does, individuals from the various interested groups, viz, operators, regulators, and non governemental laboratories. Even we, as foreign organizations, found ourselves in the unique position of being able to assist in work that was very much a national matter. We greatly respect the openness of those who took the decision to invite us and the freedom that we were given to assist with the work. In particular, one us (Christophe Murith) provided assistance in the interpretation of measurements in the environment and undertook a series of measurements in the vicinity of the nuclear facilities; another (Werner Burkart) provided assistance with the modeling of the movement of radionuclides in the environment, radiation dosimetry and radiation biology; the third (Antony Wrixon) provided a link with the NRPB, a body that had undertaken a number of similar studies around nuclear facilities in the United Kingdom.

As observers of what was essentially a national matter, we also wish to note that we were very impressed by the way in which the various groups represented were able to work together under circumstances in which the debate was not far removed from public scrutiny. We would also wish to record that we were impressed by Mrs. Sugier's leadership of the Group; we consider that she led the Group in a most professional and sensitive way.

We consider that the final results of radiation doses and risks of radiation-induced leukemia to young individuals living in the Beaumont-Hague district are robust and should be seen as best estimates on the basis of present knowledge. These results indicate that nuclear facilities have contributed little to the radiological risk and would not lead to any observable increase in health effects. The group clearly recognised that results are subject to some uncertainty, and although attempts were made to reduce these to a minimum, they nevertheless remain. There may be some value in undertaking further specific studies to refine the knowledge of some of the parameters and the calculational models used. However, we believe that such further studies are unlikely to change dramatically the conclusions implicit in the results. In this context, we note that the UK studies were confronted with similar problems of uncertainty in their calculations of the risks of radiations-induced leukemia around nuclear facilities. These studies produced similar results to those in the present study, but no comprehensive uncertainty analysis was considered necessary.

On the other hand, we consider that the study clearly shows the significance of exposures from medical practices and natural sources of radiation. The calculations of exposures from these sources were based on much less information than those from the nuclear facilities. Furthermore, it is well know that both types of exposure vary considerably from one region to another and even within a region. We therefore consider that they both would undoubtedly be worthy of further investigation to determine their magnitude more precisely and eventually what be done to reduce them.

Finally, we note that the group identified a number of possible reference or critical groups. Such groups comprise those who are considered as receiving the highest exposures and are therefore of particular interest in the context of ensuring that members of the public are not exposed to excessive levels. Because the group identified a number of possible reference groups in addition to those already identified by the operators and the regulators, we would recommend that further work be done to determine more precisely what are the actual reference groups and to seek agreement on these with all concerned. This would necessitate studies of habits as well as measurements of radioactivity in the environment.

(ANGRY MOTHERS)

Thursday July 8 1999

Press release

Subject: "Summary of work done by the Nord-Cotentin Radioecology Group"

Finally, two years have now passed since our "for clear and objective information" manifesto. Fifty experts from various disciplines organized by a woman, Mrs. Annie Sugier, are reporting on their work, in an understandable and unbiased manner.

- Professor Spira's statement about the lack of leukemia among children between 0 and 25 year old in the Beaumont Hague canton from 1993 to 1996.

- the summary of the first work done by the Nord-Cotentin Radioecology Group "considering that it is improbable that a case of leukemia can be assigned to exposure due to nuclear facilities".

All this information reduces uncertainties and worries about leukemia for the "Mères en colère" association. This task only concerns leukemia.
The research and analyses should now be extended to include other cantons, other generations and other cancers, and should make a systematic search for health and impacts on the environment due to chemical and radioactive releases on micro-populations that could be affected by marine or atmospheric deposits. The rather positive prospects for leukemia as described by the Group coordinated by the IPSN in no way provide a guarantee to the "Mères en colère" Association that industrial or military radioactive and chemical releases are innocuous.

The Association has noted that there are still some uncertainties about the measurements.

- accidental releases are 2/3 as high as routine releases and demonstrate that there are some difficulties in controlling all sources considered (COGEMA, Andra plant, Flamanville power station, Cherbourg arsenal).

- the fact that the submarine deposit in the Casquets trench is not included in these sources (about 17,000 tonnes of waste) is another uncertainty remaining for the Nord-Cotentin population.

Concerning information, this study has shown that information is now accessible to the general public, and that it can be considered as being credible since it is produced by a group of experts from different backgrounds. This multi-disciplinary nature is an essential objectivity criterion for progress with work on health safety, and secondly it is a decisive communication act and will remain a positive consequence of Professor Viel's study published in February 1997.

APPENDIX 5

WEBSITES

Nord-Cotentin: www.environnement.gouv.fr

Acro: www.altern.org/acro

COGEMA: www.cogema.fr

GREENPEACE: www.greenpeace.fr

CSPI: www.mathilde.msh.unicaen.fr/andoc

French Parliament – Michel Rivasi report: www.assemblée-nationale.fr

CRII-RAD: www.criirad.com

Safety Authority: www.asn.gouv.fr

IPSN: www.ipsn.fr/nord-cotentin

APPENDIX 6