CORPORE, a tool for interpreting whole body monitoring results

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Abstract

In long-term contaminated territories, the interpretation of whole body monitoring results is not straightforward. In these territories, years after an accident, the ingestion of contaminated foodstuffs becomes the preponderant root of exposure. However, the individual ingestion profiles are multiple and complex, and it is generally difficult to check that the actual doses received by individuals comply with the long-term dose objective stated by the ICRP for existing exposure situations (1 mSv/y). In this context, the challenge is to identify, together with the exposed people, the food products that are the main sources of their contamination in order to find options to reducing their individual doses ALARA.

Within the ETHOS and CORE projects implemented in Belarusian villages contaminated by the Chernobyl accident, a software prototype, named CORPORE, was developed by CEPN, with the support of the Norwegian Radiation Protection Authority (NRPA). This tool provides a quick and simple interpretation of the whole body measurements of the inhabitants. Actually, from the results of the whole body measurement and according to the age of the person, it is possible to assess the quantity of radioactivity ingested daily (Bq/d) through food assuming averaged diets and/or specific ingestion profiles: the model was developed to address both a daily mean ingestion and episodic ingestions (e.g. much higher contamination ingested only once or twice between two consecutive whole body measurement campaigns).

This tool was used by local health professionals to develop a practical radiation protection culture among the population. Thus, in territories contaminated by the Chernobyl accident where the highest doses are now received due to a seasonal consumption of mushrooms, berries or game meat, CORPORE helped health professionals and radiametrists in discussing with and informing people about the radiological risks they are exposed to. In Norway, where the Sami people is also still facing to the management of the Chernobyl accident consequences – the reindeer meat being the main source of its contamination – the tool was used by NRPA at the occasion of periodic whole body measurement campaigns, to try to find rooms for manoeuvre with the people, case by case, for reducing their internal doses.

There is no doubt that in Japan, after the Fukushima accident, the people that have not been evacuated or those that will come back home in the future will have a similar questioning.

Context

After any event that result in radiological consequences, the long-lasting contamination of the environment upsets all dimensions of the living conditions of people inhabiting in the affected territory: the health conditions, the social life, the priorities of the education system, the ethical and aesthetical aspects as well as the conditions for producing and distributing foodstuffs or other goods. This context induces large concerns, worries and questioning among the population and most of the time, severe psychological, health and societal consequences. Everyone is affected by such a situation: inhabitants who have, at all times, to take care of the contamination that has crept into their daily life, authorities who have to set up strategies for recovery, experts who need to evaluate the effectiveness of these strategies, and all other professionals who have to adapt their working conditions and practices to cope with a destabilized environment.

The local health professionals and more generally, all those who usually are considered as local experts, are overwhelmed with questions from their patients and co-citizens, who wish to be reassured or at least informed about the risks they are facing to. Regarding their exposures to radiations, they would like to understand and to know better when they are receiving doses, from which pathways (irradiation, ingestion, inhalation, etc.), if they are themselves contaminated, if the radioactivity has or will have an impact on their health or that of their relatives, why they are more exposed than the neighbours, etc. Regarding the contamination of the environment, the people would like to understand how and how long their living areas are contaminated, how this will evolve, and how it can be assessed. One of their major concerns deals with the contamination of foodstuff, feedstuff and other consumer goods, especially what levels are considered hazardous or harmful to health.

Local health professionals have not a lot of information that can help them in evaluating the actual individual risks due to radiation exposure. Taking into account the fact that, years after an accident, the predominant pathway in contaminated areas is generally through ingestion, the measurement of the internal contamination is often the only one indicator that they can used. Moreover, the organization of frequent measurement campaigns that can help to be more precise in the dose assessment, is quite difficult and expensive; health authorities can also promote the installation of whole body counters at the local level (e.g. in hospitals) but physicians are not often familiar with these equipments and need specific training.

In any case, the interpretation of whole body monitoring results is not straightforward: the individual ingestion profiles are multiple and complex, and it is generally difficult to calculate an individual dose, and to verify that it complies with the long-term dose objective stated by the national authorities for emergency and then, existing exposure situations (ICRP recommends to set a reference level in the range of 1-20 mSv/year with a long-term objective of less than 1 mSv/year).

In this context, the challenge for local professionals is more to identify together with the exposed people, individual behaviours and food products in the diet that are the main sources of contamination, than to perform a precise dose assessment. A better understanding of the contamination profiles helps for finding options and self-help protection actions that will reduce individual exposures as low as reasonably achievable (ALARA).

The CORPORE model

As an attempt to answer these legitimate questions of people living in a contaminated area, and to provide a technical support to local health professionals, a software prototype, named CORPORE, was developed by the Nuclear Protection Evaluation Center (CEPN), with the support of the Norwegian Radiation Protection Authority (NRPA). This tool provides a quick and simple interpretation of the whole body measurements of the people. Actually, from the results of the whole body measurement and according to the age of the person, it is possible to assess the quantity of radioactivity ingested daily (Bq/day) through food assuming averaged diets and/or specific ingestion profiles: the model was developed to address both a daily mean ingestion and episodic ingestions (e.g. highly contaminated products ingested only once or twice between two consecutive whole body measurement campaigns).

CORPORE was developed in the post-Chernobyl context, two decades after the catastrophe: at that moment, the main contributor to the dose was ^{137}Cs. This is the main reason why the tool currently considers the ^{137}Cs contamination only.

In the CORPORE tool, for a unique ingestion $Q(t_0)$ at time t_0, the organism contamination at time $t_0 + t$ is defined as follows:

$$A(t_0 + t) = Q(t_0) \cdot r(t) = Q(t_0) \cdot \sum_{i=1}^{3} A_i \cdot e^{-\lambda_i \cdot t}$$

Where
r(t): Retention function of caesium,
$Q(t_0)$: Ingested activity at time t_0 (Bq),
A_i: Initial fraction (t_0) in the three compartments of the considered organism,
λ_i: Abatement constant of caesium, taking into account radioactive and biologic periods (in days^{-1}).

The retention function of caesium is described by the sum of three exponential terms, each term corresponds to a compartment of the body where the caesium is eliminated more or less quickly. This retention function is described in the ICRP 56 publication (ICRP, 1989).

$$r(t) = a_1 e^{-0,693t/T_1} + a_2 e^{-0,693t/T_2} + a_3 e^{-0,693t/T_3}$$

Where $a_1+a_2+a_3 = 1$ and T_1, T_2 and T_3 are biological half-times of Cs-137 in the three compartments (see table 2 hereafter)

The first compartment is a compartment where the caesium is eliminated very quickly, it corresponds to the urinary excretion of caesium in the first days after the ingestion. The second compartment is a long-life component, it corresponds to the progressive urinary excretion of caesium. The third compartment is a very long-life component, it corresponds as well to the progressive urinary excretion of caesium. This compartment was added in 2000 following studies on the victims of the Goiânia accident (Brazil, 1987). This compartment does not have a significant role.

Table 2. Biokinetics data for caesium-137 (ICRP 56)

	Whole body					
Age	a_1	a_2	a_3	T1	T2	T3
5 year-old	0,45	0,55	0,001	9,1	30	400
10 year-old	0,30	0,70	0,001	5,8	50	400
15 year-old	0,13	0,87	0,001	2,2	93	400
Adult	0,10	0,90	0,001	2	110	500

As an example, the table 3 presents the case of a person who ingests 100 Bq of caesium.

Table 3. Example of application: elimination of caesium for a person who ingests 100 Bq at time t_0

Age	5 years	10 years	15 years	Adult
t_0	100	100	100	100
t_0 + 1day	96	97	97	97
t_0 + 2d	92	93	93	95
t_0 + 3d	88	89	91	93
t_0 + 4d	84	86	89	91
t_0 + 5d	81	83	87	90
t_0 + 10d	66	71	82	85
t_0 + 15d	54	63	79	82
t_0 + 20d	45	57	76	79
t_0 + 30d	33	48	71	74
	Bio decay: about 4% per day	Bio decay: about 3,5% per day	Bio decay: about 2% per day	Bio decay: about 1,5% per day

Another example is given by figure 2 hereafter. This figure shows the level of total radioactivity of the body following a single intake of 10,000 Bq of caesium-137 by individuals at different ages. This figure shows very clearly the differences of speed of removal of the ^{137}Cs incorporated in the body depending on the age: for children less than 5 years, there is only approximately 5% of the caesium remaining after a hundred days, whereas for adults, it is necessary to wait 4,5 times much longer (more than one year) to obtain a similar reduction of the ^{137}Cs body content.

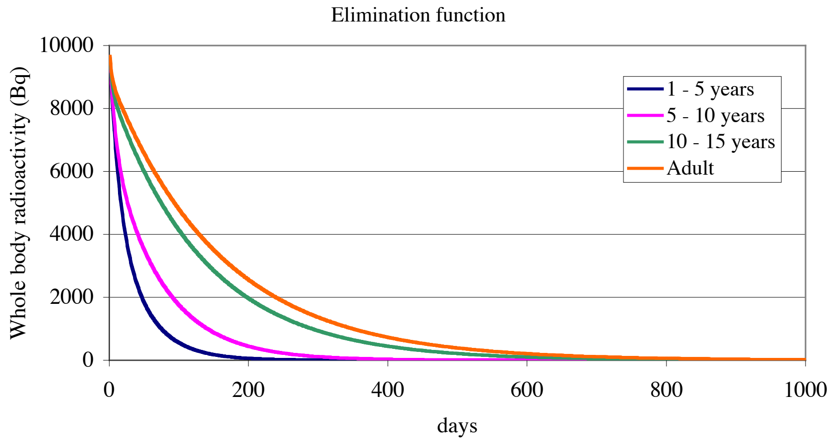


Figure 2. Evolution of the whole body radioactivity following a single intake of 10,000 Bq of ^{137}Cs

Episodic vs. chronic ingestion profiles

The CORPORE tool takes both into account the chronic ingestion and the episodic ingestion of contaminated products.

The average ingestion means calculated between two whole body monitoring measurements give the chronic quantity of radioactivity incorporated, considering that this quantity stays constant. It means that the chronic ingestion is a good criteria if the food diet has few variations. To determine the average chronic ingestion, the first step consists in identifying the 'everyday consumed' products (water, milk, meat, vegetables, etc.) and measure their activities. According to the results obtained:

- These products explain the level of radioactivity ingested every day,
- These products only partially contribute to the radioactivity ingested.

In the second case, it is necessary to take into account the specific products that are consumed episodically and are sometimes highly contaminated (berries, mushrooms, etc.). In this perspective, it is very important to have a good dialogue with the concerned person so as to identify the products and carry out, if possible, measurements of these products.

If ingestion/inhalation of radioactivity is continuous, the radioactive burden of the body will increase gradually until it reaches an equilibrium state (balance between the incorporated radioactivity and that eliminated), as shown hereafter by Figure 3.

The equilibrium state is reached at the end of a time period that depends on the age of the person considered. At the equilibrium state, the relationship is linear, i.e. the whole body contamination is directly proportional to the incorporation rate. However, individual differences are observed, depending on the metabolism, the potassium content of the body, the weight of the person, muscle mass, etc.

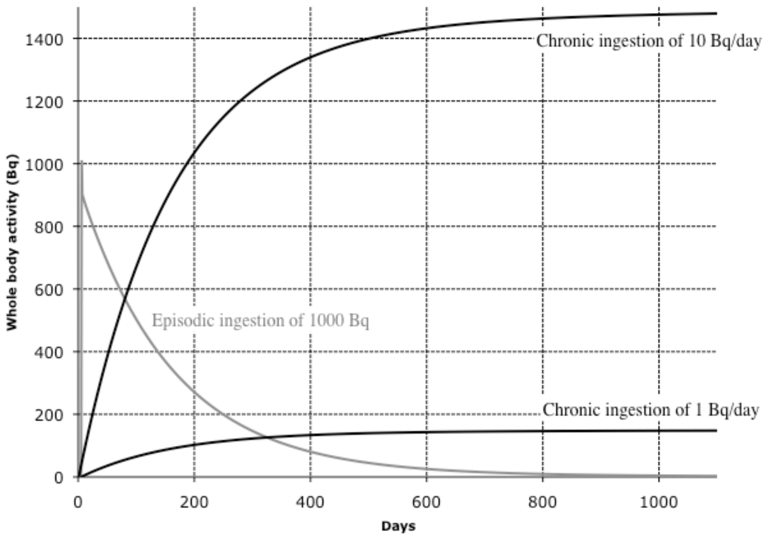


Figure 3. Different types of ingestion modes

Whole body monitoring measurement frequency

In order to evaluate the radioactivity ingested daily between two whole body monitoring measurements, it is needed to have in mind that the caesium could be incorporated according to different hypotheses of incorporation, for instance:

- The day before the whole body contamination measurement,
- Continuously and constantly during all the period (between two measurements),
- The first day of the considered period (i.e. the day after the penultimate measurement).

In addition to these three situations, a lot of other possibilities do exist. The number of possibilities could increase or decrease according to the time between each whole body measurement campaign. The uncertainties linked to the estimation of ingested contamination (in Bq) could be estimated. For example, for a young child (1-5 years), the factor of uncertainty linked to the estimation of ingested contamination could reach 100 if the period between the measurements is around 6 months!

In order to reduce the uncertainties, the number of optimal measurement campaigns, according to the age, has been determine as follows:

Table 4. Optimal frequency of whole body contamination measurements for different categories of ages for ^{137}Cs

Age	**Optimal frequency of whole body contamination measurements**
5 year old	12 times a year
10 year old	6 times a year
15 year old	3 times a year
Adult	2,5 times a year

Functionalities of the CORPORE tool

The CORPORE software prototype has been developed in Microsoft Access 2007 environment (running on Windows 2000, XP, Vista or Windows 7 operating systems). All necessary data are stored in a relational database structure giving the possibility of numerous calculations. Furthermore, functions allow importing and exporting data sets to insure interoperability with other software.

The CORPORE application is structured in two modules. The first module deals with all the personal data of the measured person. The following information are gathered: name, date of birth, address, gender, weight, results of measurements. During the conception of the software, it was emphasized that the measured person should not be asked too many questions and not be submitted to a “scientific investigation”.

Once the results of the whole body measurements are entered in the software (expressed in becquerels), the software calculates automatically the result in Bq per kg. The calculation is based on the ICRP biokinetics model for caesium in humans (ICRP 56, 1989). The software also provides the corresponding amount of radioactivity ingested in Bq per day that could lead to the observed results: for this calculation, it assumes a chronic ingestion profile during the period between the last two measurements or an equilibrium state for the person if there is no other measurement result available (Fig. 1).

Once these results obtained, they are compared with all the results stored in the software: for instance, with the previous measurements of the person or with the results of the village. Graphs are generated automatically (Figure 4). Thus, this first module allows initiating the dialogue with the measured person and evaluating his/her radiological situation (improvement of the results if he/she is frequently measured, comparison with the average situation in his/her town/village etc.).

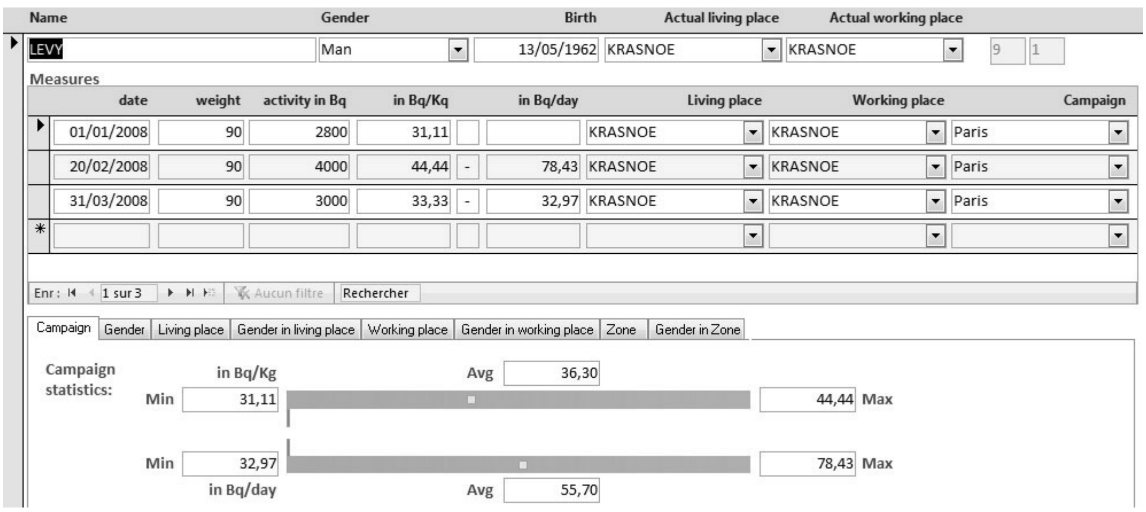


Figure 4. Illustration of the first module

The second module addresses the interpretation of individual measurements. It is based on typical ingestion libraries (average diet, average contamination of foodstuffs) that can be modified according to case specific information. The operator should also proceed by iterative steps. If the default profile does not allow interpreting the observed result, he could discuss with the person to adapt his/her ingestion profile (modification on the average contamination of the products or of the consumed quantities, etc.). Episodic ingestions could also be considered.

The second module is based on tables and graphs that allow to follow this iterative process (Figure 5). In a first step, the graph allows to evaluate the difference between the calculated amount of radioactivity ingested every day and the value corresponding to the chosen default profile. In a second step, when the operator enters new values in the chronic ingestion profiles of the person, it is possible to observe if the two values are getting closer. Finally, assuming episodic ingestions can allow finding the exact profile of contamination of the person.

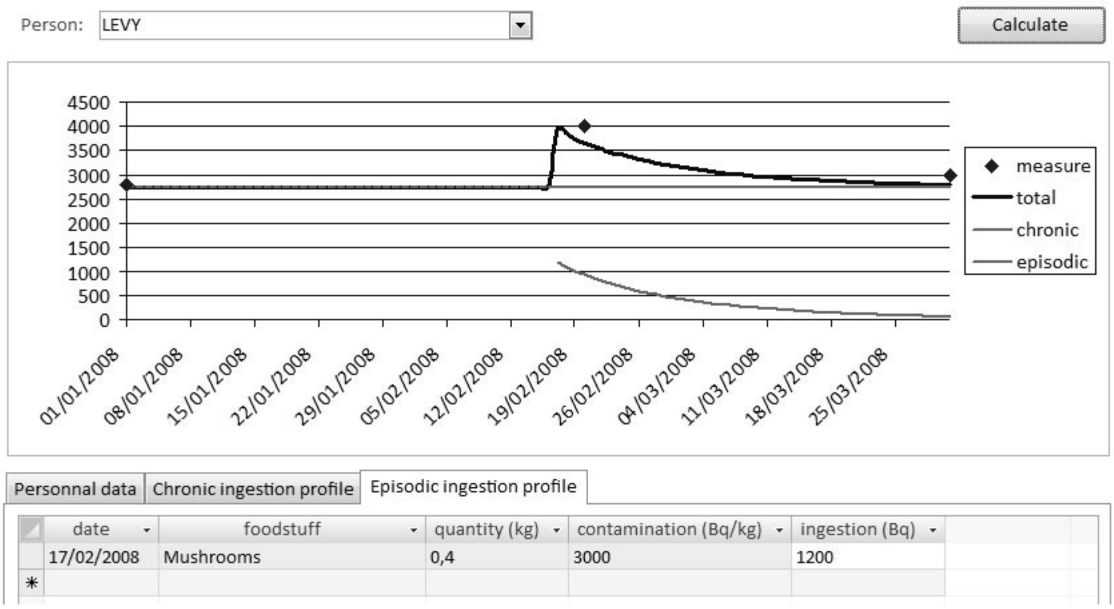


Figure 5. Illustration of the second module

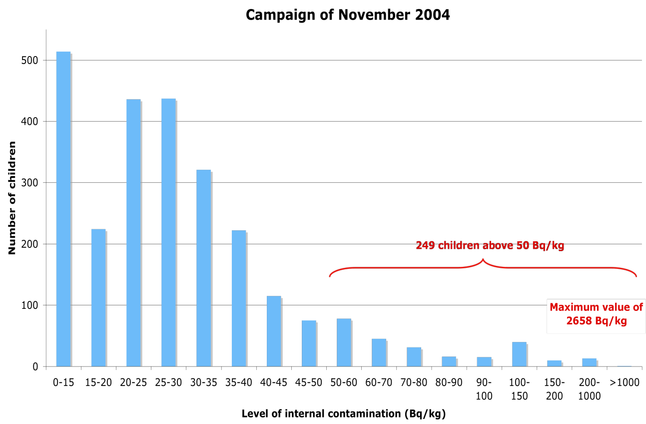
<u>Use of the CORPORE tool</u>

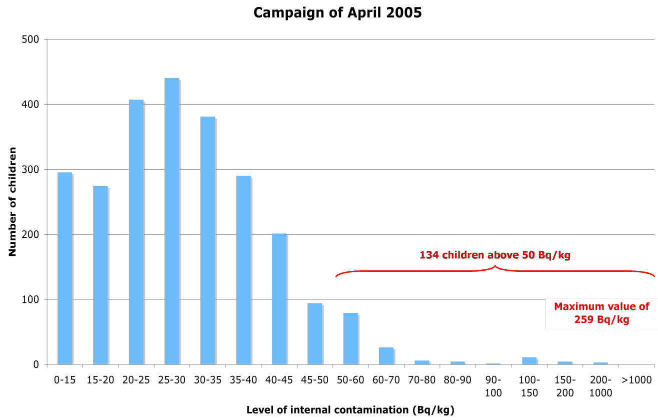
CORPORE was initially used in Belarus in the post-Chernobyl accident context. Between 2004 and 2009, several whole body monitoring campaigns had been carried out in the schools and kindergartens within the CORE - "Cooperation for Rehabilitation" - Programme implemented in Belarus (Stolyn, Bragin, Chechersk, etc.). CORPORE was used all along the projects to help local health professionals to interpret the whole body contamination measurements.

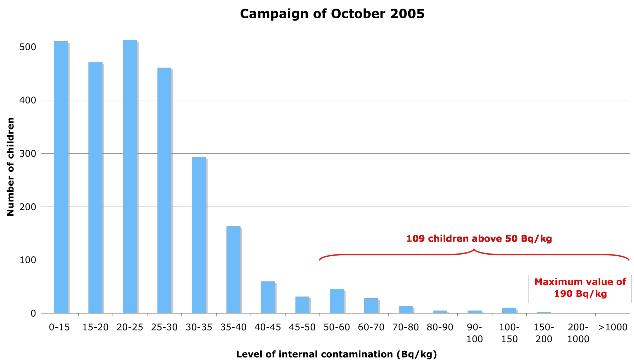
In Belarus, it is well known by radiological protection experts that the most sensitive foodstuffs are dairy products and meat; the contamination levels of these products directly depend on the level of contamination of winter fodder and Summer pastures. Mushrooms, berries or game meat are often the main sources of the highest levels of internal contamination, especially during Autumn (i.e. due to episodic ingestions). Nevertheless, daily ingestion of smaller quantities of caesium (e.g. in milk and vegetables) could also explain some of the highest whole body monitoring results (i.e. through a chronic consumption of contaminated foodstuff).

But, knowing that, how to respond correctly to people who care for their children's health? How to explain properly why, from one measurement campaign to the next, the individual contamination has decreased or increased? How to calculate the effective dose received by a child between two measurement campaigns? What can be said to the parents in order to help them in improving the situation of the most exposed children? All these questions remained more or less unanswered.

The following figures and Table 1 show real distributions of internal contamination of 2,500 children living in a contaminated area, 18-20 years after the Chernobyl accident.







Thanks to a better understanding by local health professionals of the caesium incorporation and biological elimination profiles, coupled with an improvement of the radiological protection culture of the children and their parents, the maximum internal contamination observed in the Bragin district has fallen more than tenfold (from 2670 Bq/kg to 260 Bq/kg) in one year (September 2004-October 2005). The results of the measurement campaign performed in Fall 2005 showed that the number of children whose level of contamination was between 50 and 70 Bq/kg had slightly decreased. More than 95% of children of the district had a level of contamination below 50 Bq/kg (75% below 30 Bq/kg) after the campaign of measurements performed in October 2005. However, this encouraging macro-analyse hid individual worrying situations: several children stayed at internal contamination levels above 50 Bq/kg; in some cases, it was even observed an increase between two measurement campaigns. The efforts of local health professionals focused on these children and their parents. In 2006, two new whole body contamination measurements campaigns were launched.

Table 1: Internal contamination of children living in the Bragin district, Belarus. 2004-2006

Whole body contamination measurement campaign	No. of children	Averaged whole body contamination (Bq/kg)	Maximum whole body contamination (Bq/kg)	No. of contaminations > 50 Bq/kg	No. of contaminations > 100 Bq/kg
April 2004	*2 056*	*27*	***2 056***	*78*	*17*
Nov. 2004	2 592	32	**2 658**	249	64
April 2005	2 526	29	**259**	134	18
Oct. 2005	2 612	24	**190**	109	12
May 2006	2 530	25	**168**	50	4
Sept. 2006	2 486	31	982	242	43

It can also be noted that there was no evidence of decrease in mean whole body contamination (equal to about 30 Bq/kg), a level that is quite inevitable when people live in an environment where most of the foodstuff are slightly contaminated (chronic contamination situation). Unfortunately, in 2006, despite the improvement of the radiological protection culture in families, all indicators (averaged contamination, maximum contamination, number of children above trigger levels, etc) increased again. Discussions with concerned families, together with the use of CORPORE models, allowed to understand and explain this bad trend: it was an exceptional year for mushroom picking and consumption (episodic contamination situation)… Spectrometric measurements made on mushrooms indicated very high levels of contamination in different areas: until 100,000 Bq/kg, 20 years after the accident!

In the same spirit, one year after the Fukushima accident, the Japanese families begin to have the same questioning about the internal contamination of the children. It is observed that the external doserates have drastically decreased (although localized hotspots above 4µSv/h still remain). Thus, for the people who have not been evacuated or those who would like to come back living in evacuated areas, the assessment of internal exposures becomes the main concern.

The establishment of a deep dialogue between the families and the local health professionals is the only way to interpret properly the whole body contamination measurements and, to identify the causes and roots of the observed levels of exposure. Especially, a discussion with the families about their dietary habits is needed in order to find products that are likely to be the main contributors to internal exposures (through chronic and/or episodic ingestions of contaminated foodstuff).

Conclusion

The CORPORE tool has primary been developed to serve as a support for the dialogue between the measured person and the health professional performing the measurement. The main objective is first to identify progressively, through questions and answers, the main sources of contamination of the interviewees and secondly to determine the various options for reduction of the internal exposure. CORPORE has not been developed as a dose assessment tool but as a dialogue tool that enable to assess the quantity of radioactivity ingested daily (Bq/d) through food assuming averaged diets and/or specific ingestion profiles.

The software can also constitute a useful database: it allows storing information on people affected by the accident (whole body measurements) and a set of environmental data (measurements of contaminated foodstuffs, etc.). Moreover, the statistical power of the software can be highlighted: indeed, it offers opportunities to aggregate stored data according to different criteria. This tool can also be used by local health professionals to support and develop a practical radiation protection culture among the population.

In territories contaminated by the Chernobyl accident where the highest doses are now received due to a seasonal consumption of mushrooms, berries or game meat, CORPORE helped health professionals and radiametrists in discussing with and informing people about the radiological risks they are exposed to. Similarly, in Norway where the Sami people is also still facing to the management of the Chernobyl accident consequences – the reindeer meat being the main source of its contamination – the tool was used by NRPA at the occasion of periodic whole body measurement campaigns, to try to find rooms for maneuver with the people, case by case, for reducing their internal doses. In the vicinity of Fukushima, first contacts have been taken with a computer science university, in order to envisage the development of the CORPORE software in Japanese, taking into account specific contributions to internal contamination (e.g. presence of Cs-134).

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