Guidance on Practical Radiation Protection for People Living in Long-Term Contaminated Territories

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"Strategies and Guidance for establishing a practical radiation protection culture in Europe in case of long-term radioactive contamination after a nuclear accident"

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# TABLE OF CONTENTS

1. **Introduction** ......................................................... 5

2. **General questions** .................................................. 6
   2.1 Is the environment contaminated? ................................ 6
   2.2 How am I exposed? ................................................ 7
   2.3 How to know if I am irradiated? ................................ 8
   2.4 Are food products radioactive? .................................. 8
   2.5 How to know if my foodstuffs are contaminated? .............. 9
   2.6 How am I contaminated? .......................................... 9
   2.7 How to know whether I am contaminated? ....................... 10
   2.8 Who can explain to me the radiological situation, answer my questions and propose possible actions? .................. 10

3. **Who can answer?** .................................................. 11
   3.1 The health professionals ............................................ 11
       3.1.1 Listen to and help people to understand the situation ... 11
       3.1.2 Answer the questions posed .................................. 12
       3.1.3 Propose actions in specific circumstances .................. 12
       3.1.4 Propose possible actions ..................................... 13
   3.2 The specialists of measurements .................................. 13
       3.2.1 Immediate communication of the result of any measurement 13
       3.2.2 Public information ............................................. 14
       3.2.3 Alert .......................................................... 14
       3.2.4 Transfer of the information to the stakeholder advisory board 14
   3.3 The local stakeholder advisory board ............................. 14
       3.3.1 Statistical analysis of the measurement data ............... 15
       3.3.2 Ensure the proper functioning of the system .............. 15

4. **How to monitor the situation?** ..................................... 16
   4.1 External radiation ................................................... 16
       4.1.1 What kind of device should be used? ......................... 16
       4.1.2 Where to get a dosimeter? ................................... 17
   4.2 Foodstuffs contamination ........................................... 17
       4.2.1 With what kind of device? .................................... 17
       4.2.2 Where to make a measurement? ............................... 18
   4.3 Body contamination ................................................ 18
       4.3.1 With what kind of device? .................................... 19
       4.3.2 Where to make a measurement? ............................... 19

5. **How to interpret results of measurements?** ......................... 20
   5.1 External dose rates ................................................ 20
       5.1.1 First stage: collection of external dose rate data .......... 20
       5.1.2 Second stage: calculation of dose from external irradiation 21
   5.2 Foodstuffs contamination .......................................... 22
   5.3 Whole body measurements .......................................... 23
       5.3.1 First stage: collection of whole body measurement data .... 24
       5.3.2 Second stage: historical reconstruction of the ingestion of radioactive elements ................................................. 24
       5.3.3 Third stage: comparison with foodstuffs measurements .... 25
   5.4 Comparison tools ................................................... 27
       5.4.1 Reference situations ............................................ 27
6. How to improve the radiological situation? 37
   6.1 Options to reduce one’s own external exposure 37
   6.2 Options for the household 37
      6.2.1 What can I do at home? 37
      6.2.2 What can I do in the garden? 38
      6.2.3 What can I do in the allotment and vegetable gardens? 39
      6.2.4 What can I do with contaminated waste? 39
      6.2.5 What can I collect (or eat) from the countryside and the forest? 39
   6.3 Options for health professionals & the local stakeholder advisory board 41
      6.3.1 Provision of advice/information/guidance to the public 41
      6.3.2 Provision of counting/monitoring equipment 42

7. Technical sheets on radioactivity 43
   7.1 Description 43
   7.2 Units 44
   7.3 Uptake in the body 45
   7.4 Health effects 46

Glossary 49
This document presents basic principles for a handbook on Practical Radiation Protection. It provides general guidance on how to measure radiations and how to behave in a situation of long-term contamination. It gives information relating to radioactivity and exposure routes of persons. It explains how to measure this radioactivity in the environment and in the body, and particularly how to interpret the data from these measurements in order to implement protective actions fitting with the encountered individual situation. It also presents the main principles of a system of radiation monitoring and protection. This system was elaborated from that developed within the framework of the ETHOS project in Belarus and was completed according to the questions and concerns of the four stakeholder panels.

An accident can result from different types of scenarios, leading to different levels of contamination, more or less important in duration and extension. Besides, it concerns the whole population (public, authorities, experts and health professionals) and may affect every dimension of life.

The handbook does not aim at covering such a complexity.

First, it is addressed mainly to the population and health professionals. Nevertheless, it can serve all other professional bodies, that may be directly requested in case of contamination of the environment, particularly for educational purposes for example.

Secondly, it is not exhaustive. It is mainly adapted to a rural area and refers only to caesium-137. It is explained by the fact that the document had been elaborated from the experience of Belarus after the Chernobyl accident and that, in this rural country, the caesium-137 is still the major contributor to radiological exposures. However, in most of the post-accidental situations, it is likely that ways of life of rural populations will be the most disrupted.

The document aims at raising people’s awareness on new risks and behaviours linked with radioactivity. The methodology and the principles presented in this document can be further adapted to any other situation of various origin.

As said before, this document had been realised in co-operation with four groups of stakeholders. It was elaborated to provide elements of answers and guidance on their questions and preoccupations regarding the exposures to radioactivity in the environment, its effects on the health and the means to keep vigilant.
2. General questions

In case of a radiological accident, the whole population will be confronted to new problems and new preoccupations. Each individual will have questions regarding radioactivity and its effects on the health:

- How is the environment contaminated? How am I exposed, and at which moments particularly?
- Am I contaminated myself?
- How and where can I measure the radioactive contamination?

Moreover, everyone will wonder how to face this new situation and who can help him:

- What can I do concretely, by myself, or with the help from somebody else:
  - To protect myself and to avoid future exposures?
  - To mitigate, as far as possible, the consequences of past exposures?
- Who can explain the radiological situation to me, answer my questions, propose possible actions to improve the situation and help me in this way?

2.1 Is the environment contaminated?

From a personal point of view, the environment relates, first of all, to the places where we spend time with our family and then corresponds to the nature around us.

- The house,
- The garden,
- The work places,
- The school,
- The public places,
- The places of leisure activities, holidays.

The environment (houses, rivers, forests…) is contaminated if radionuclides have been deposited on it, and remain present. The radionuclides deposited on the ground can go further into the soil or fixed on dust particles, be transported by wind and water and thus come into plants and animals. The duration of the contamination depends on the radionuclides that have been deposited. For instance, in case of a contamination with caesium, the radioactivity disappears only after more than 300 years.
Radioactive elements (deposited into our environment or contained in our foodstuffs) emit radiations that can be dangerous for people.

2.2 How am I exposed?

As just said before, in the event of a release of radioactivity into the environment, radionuclides may be widely dispersed leading to the contamination of a variety of materials. Radionuclides released into the atmosphere would be moved around by the wind and deposited on the ground. With regards to aquatic environments, radionuclides would be dispersed due to general water movements/tidal currents and sedimentation processes. Consequently, radionuclides may find their way into terrestrial and aquatic environments leading to the irradiation of people and foodstuffs.

Humans may be exposed to radioactive elements via two main routes:

1. external exposure to contamination, radionuclides deposited into the environment emit radiations that reach people,
2. intake via consumption or inhalation of contaminated material (foodstuffs, dust particles, water).

The relative importance of these exposure routes depends on the radionuclide, the nature of the surface onto which deposition occurs and local conditions.

The most important contributors to human exposure are the radionuclides which are potentially environmentally mobile. For caesium both external irradiation and internal irradiation (following ingestion) can be important exposure routes.

Ingestion of radionuclides in foods can be an important contributor to the total dose received by an individual or a population group. The foodstuffs of most concern in the event of an accident involving radioactivity vary with time and with the radionuclide. For most people, the major foodstuffs contributing to dose will be those which have the highest concentrations of the radionuclides and/or which are eaten in large quantities. For example, although consumed in relatively small quantities, wild mushrooms and berries and freshwater fish are known to most readily concentrate radioactivity (particularly caesium-137). Furthermore, if deposited onto pasture, radioactive elements can be easily transferred to cow milk, which is regularly consumed by both adults and children. Other important
foodstuffs can include meat and vegetables. Certain groups may be exposed to higher doses than others due to their dietary, social and other habits.

2.3 How to know if I am irradiated?

Radioactive elements deposited on our environment can become a source of external exposure (through their radiations). To be well protected, as radioactivity is invisible and silent, it is possible to detect radiations and to measure them wherever you are.

The quantity of radiations is measured by means of small detectors, which are called dosimeters. You can use the dosimeter yourself in all places where you have doubts on the state of radiological cleanliness (your house, your garden...). The presence of external radiations in the place where you are located is translated by a number that is directly given by the detector [see p.17, 4.2.1].

*Measurement of external radiation in a garden with an electronic dosimeter (Photo ETHOS, Belarus)*

Note that in the absence of “accidental” contamination of the environment, a “background radiation” can be measured anywhere. This background radiation is composed of the naturally occurring radioactivity coming from minerals and cosmic radiation, and the man-made radioactivity coming from nuclear weapon tests and nuclear industries [see p.27, 5.4.1].

2.4 Are food products radioactive?

Natural radioactivity in food:

Naturally radioactive materials in the earth’s crust are taken up by plants and animals and become dissolved in water. Therefore, everything we eat and drink is slightly radioactive although the resulting radiation dose is weak [see p.27, 5.4.1].
Radiological incident:

In case of a radiological accident, radioactive elements can be transferred to foodstuffs. Every foodstuff can be contaminated. Nevertheless, some of them are known to concentrate more radioactivity than others. For instance, mushrooms, game and berries are often very contaminated products.

In the European Union, in case of an accident, authorities have planned to introduce Food Intervention Levels to prevent the consumption of contaminated products.

These regulations specify maximum activity concentrations (see p.30, 5.4.2) allowed in marketed foods. Thus, the public is protected from exposure to potentially contaminated food by the regulations restricting the movement, supply or sale of certain foods, or food products from within a designated area. For example, supermarkets, shops and markets selling or supplying food for human or animal consumption will be subject to these restrictions.

These regulations would concern marketed foodstuffs. As far as private productions are concerned, authorities would have to provide information to make members of the public sensitive to the necessity to measure the contamination of their own produce from an allotment or private garden or of free foods from the wild.

2.5 How to know if my foodstuffs are contaminated?

The equipment needed to measure the level of contamination in foods is more complicated than that used for measuring the external radiation. The measurement, therefore, has to be made by a trained person: “the foodstuffs monitoring operator” [see p.13, 3.2]. The volume of food needed for a measurement is about one litre. The measurement takes about thirty minutes [see p.17, 4.2].

At any time, a “background contamination” can be measured in any products. For example today, regarding caesium-137, this background contamination is mainly due to fallout from Chernobyl and from past nuclear weapons testing [see p.27, 5.4.1].

2.6 How am I contaminated?

Radionuclides can be transferred in our organism by inhalation or by ingestion of contaminated food. It causes then an internal irradiation of our body.

Depending on the chemical properties of the radionuclides concerned, the body absorbs more or less the radioactivity ingested or inhaled in air. Moreover, the radioactivity is gradually eliminated, it depends on the characteristics of the radionuclide. It can be a slow process taking months or years [see annex p.45]. Nevertheless, if one ingests products containing radioactivity daily, the contamination of the body will continuously increase up to an equilibrium level (balance between ingestion and elimination). One can measure the radioactivity eventually contained in the body at any time.
2.7 How to know whether I am contaminated?

The whole body measurement must also be performed by a specialist, the “whole body monitoring operator”, because it involves sophisticated tools [see p.13, 3.2]. There are various types of devices that allow measuring the whole-body contamination. The measurement usually takes from 10 to 20 minutes depending on the device used and the expected sensitivity of the results [see p. 19, 4.3].

Only a limited number of radionuclides can be detected directly in the body. Again, a “background contamination” can be always measured in the body. Thus 10 000 Bq of potassium-40 are naturally present in the body (elimination being compensated by input from foodstuffs). Regarding caesium-137, a residual contamination is due to fallout from Chernobyl and from past nuclear weapons testing [see p.27, 5.4.1].

2.8 Who can explain to me the radiological situation, answer my questions and propose possible actions?

There are many people who are able to respond to questions related to radioactivity.

The health professionals are particularly important in answering questions for the family [see p.11, 3.1]. They can assess the individual’s situation and propose certain corrective actions or complementary measurements. Furthermore, they should have an understanding of the mechanisms of exposure, individual reference values and statistical data at the local, regional or national levels on radiation-induced health effects.

The specialists of measurements are also important persons [see p.13, 3.2]. They can explain what the results of measurements mean and compare your situation to the situation of the village for instance. In this way, they can alert you in case of a critical situation.

An essential element for the exchange of information and to facilitate the dialogue between a person and the specialists is an individual booklet or “family passport” on the radiological situation that could contain all of the necessary information to estimate and understand the radiological situation and the exposure of the person [see p.36, 5.5.3].

Answers can also be obtained in local centres of information, named here “local stakeholder advisory board” which have the role of collecting data from all professionals (health area and measurements) [see p.14, 3.3].
3. Who can answer?

3.1 The health professionals

The health professionals are all persons playing a role in the prevention, survey and health protection. After a radiological accident or an event leading to a contamination of the environment, the role of these persons will change due to the need to answer questions related to radioactivity. They will become the first point of contact for many people with regard to their health concerns and to elements of radiological protection. They will:

- Listen to and help people to express their concerns regarding the radioactivity,
- Answer the questions posed,
- Alert in case of a critical situation,
- Propose possible actions and advice, including guiding the family towards where to go and how to obtain complementary measurements.

The health professionals are not limited to physicians but also include staff of hospitals, nurses, pharmacists, psychologists, as well as school doctors and company doctors.

3.1.1 Listen to and help people to understand the situation

Based on available information, the health professionals should be in a position to open a dialogue with the person concerned. They should get, through an individual booklet or family passport [see p.36, 5.5.3], information about the radiological situation of the person concerned to help him:

- To interpret the radiological data and to put them into perspective with available reference levels [see p.27, 5.4],
- To express their concerns or questions about problems connected with the radioactivity,
- To propose a medical consultation adapted to the situation.
3.1.2 Answer the questions posed

Many questions can be tackled by the health professionals, through illustrating the answers with personalised information:

- Basic knowledge concerning the radioactivity, the mechanisms of transfer in the environment and the exposure routes of the persons [see annex p.43, 7.1],
- Links between radioactivity and health; uncertainties and attitudes of precaution [see annex p.45, 7.3],
- The various types of measurements, their utility [see p.16, 4],
- Indications on how to gradually interpret the results of measurements by oneself, or with the help from skilled people [see p.on page 20, 5].

3.1.3 Propose actions in specific circumstances

The health professionals should be able to obtain information that allows them to identify critical situations from the results of the various types of measurements. Thus they can alert the person if:

- The environment is abnormally contaminated in certain places. The health professionals estimate with the person the time spent in these places and possibly ask for additional measurements to be carried out [see p.20, 5.1]. However, the time spent at such locations should be reduced before getting confirmation from additional measurements.

- There are abnormally high whole body measurement results: questions should then be asked about the quality of the food available to the family:
  - If the results of measurements of food products are satisfactory, then it is necessary to check for other possible ways of contamination (e.g. during a stay in another more contaminated recreation area or the exceptional consumption of a very contaminated product, …),
  - If the results of measurements of food products reveal high levels of contamination: were these food products exceptionally transported from a more contaminated zone? Or if need be, make additional measurements but, in the meantime, reduce as much as possible the consumption of these products.
3.1.4 Propose possible actions

By avoiding systematic “prohibitions” but proposing suitable actions according to the particular situation, for example:

- To propose “cleaning” where it seems relevant,
- To reduce the time spent in the contaminated places,
- To substitute other foods for those most contaminated, respecting the need for nutritional balance and food preferences,
- To propose food preparation techniques and cooking recipes [see p.37, 6.2.1]

The health professionals also have to help the people to recognise the most “useful” measurements for an effective and personalized follow-up of the radiological situation:

- Prescription of specific measurements.

3.2 The specialists of measurements

These are people in charge of measuring the contamination of foodstuffs and of the human body, and who are able to inform people about the contamination of the environment at the local level. At the local level and at the proximity of the population, these functions are relatively new and will have to be further concretely defined. They should assure a service of measurement and advice for the local population, and for the whole society through the stakeholder advisory board.

In reality, this professional category implies two distinct functions: on the one hand, those people who measure the human body contamination and on the other hand, those people who measure the radioactivity in food products at the request of the local population and the health professionals.

They would also be responsible for providing some guidance on measuring the contamination of the environment and actually measuring these in public places.

3.2.1 Immediate communication of the result of any measurement

The foodstuffs and whole body monitoring operators are responsible for providing results directly to the concerned person as soon as possible after the measurement, in form of a personalised sheet, or record in the individual radiation protection booklet [see p.36, 5.5.3].
3.2.2 Public information

The specialists of measurements are responsible for informing people. This can be done through public notices, brochures and posters that describe the radiological situation of the village. For instance, mean values of contamination can be provided for each kind of foodstuffs as well as the maximum and the minimum values. In the same way, the mean value for the body contamination can be given and a graph can be drawn to describe the situation of the village. A map could be done as well to identify the most contaminated places in the village. These posters and these brochures could be found in city halls, doctors’ offices, hospitals, schools etc.

3.2.3 Alert

The foodstuffs and whole body monitoring operators are entitled to alert the person coming for a measurement of a critical situation. In that case, they may direct this person towards the health professionals.

3.2.4 Transfer of the information to the stakeholder advisory board

The measurement data must be passed on periodically (e.g. monthly) to the stakeholder advisory board. It is also important for the foodstuffs and whole body monitoring operators to be given the necessary information back from the stakeholder advisory board to enable them to have a wider view of the situation. However, they will not necessarily have all of the information to obtain a complete picture at the local, regional or national levels. They may also have to direct people towards other sources of information (i.e. the health professionals, the stakeholder advisory board).

3.3 The local stakeholder advisory board

The local stakeholder advisory board is constituted with persons from a wide range of skills at the local level (village, quarter). It can rely on existing bodies or structures, or stand on its own. Its functions are:

- To collate the data on the local radiological situation,
- To give feedback information in an easily understandable and practically useful way for the interested parties,
- To enhance the coordination of measurements and health professionals actions,
- To provide a clear and coherent picture of the local situation.
Concretely, this body will collect data on the radiological situation from the different measurement sources (contamination of the environment, radiological quality of foodstuffs, whole body measurements). It will carry out statistical analyses of the data at local level, from which it will develop useful reference situations to help in the interpretation of the data by the various interested parties. Its work will not be limited to purely technical matters. It will work with the administrations (local, regional and national government) and with the interested professionals. It should involve representatives from the administrations, local elected representatives and non-governmental organisations to facilitate the exchange of information about the radiological situation for the whole society and hence improve the strategies for all interested parties.

3.3.1 Statistical analysis of the measurement data

The local stakeholder advisory board should:

- Collect all measurement data (external dose rates, contamination of food products and body) available from the population, the foodstuffs and whole body monitoring operators, and possibly from other sources of information,
- Analyse these data to produce an understandable and useful statistical set of information for the health professionals (and for other interested parties),
- Diffuse clear and understandable information in public places by distributing posters and brochures and through media (radio, newspapers, mail boxes). For instance, maps of contamination of forests, a list of the most contaminated products, advice on the right behaviour can be distributed.
- Actualise data,
- Constitute reference situations,
- Pass on these scientific results (periodically) to health professionals and to other concerned parties, at the local, regional and national levels.

3.3.2 Ensure the proper functioning of the system

The stakeholder advisory board is also in charge of regulating the measurement system. It ensures the availability, the reliability (quality assurance) and the plurality of the sources of measurements (appropriate training of professionals in charge of measurements, calibration and maintenance of the equipment, etc.). Furthermore, it ensures that the system is adapted according to social demand and according to the evolution of the legal and regulatory frameworks in place.
4. How to monitor the situation?

4.1 External radiation

The external radiation can be evaluated through “external dose rate measurements”. Indeed, external doses rates can indicate the radiological situation and its time evolution. The higher the external dose rate, the more the place is irradiated.

These measurements of external dose rates must be performed by specialists if the contamination is high (high risk of exposure) or if precise results are required. In that case, the equipment and procedures are specific. Nonetheless, the population may also perform measurements, with simpler equipment and after appropriate training. Such measurements can be performed indoors (at home, at the workplace) or outdoors (in the garden, in recreational areas), simply to check the rates regularly or when questions arise, and to have a better idea of the places where people use to spend time and where the external dose rates may be higher than elsewhere.

4.1.1 What kind of device should be used?

Nowadays, the measurement of the external dose rates can be carried out in a relatively easy way by means of “pocket” electronic dosimeters.

The external dose rate is an indicator of the “cleanliness” of the places of life. The presence of radioactivity at certain places is associated with a higher external dose rate at these places.
How to monitor the situation?

4.1.2 Where to get a dosimeter?

Dosimeters can be given to the population or be put at the disposal of the population at different places: at the local radiological measurement point nearest to the place of residence of the interested person, at the health professionals (doctors, pharmacy), etc.

Contact point: As far as Western Europe countries are concerned, it seems that the city hall would be appropriate.

4.2 Foodstuffs contamination

The measurement of contamination in foodstuff provides information on the radiological situation and how it is changing over time. It allows foodstuffs to be classified according to their contamination level and contributes to the interpretation of body measurements.

4.2.1 With what kind of device?

The measurement of the foodstuff contamination is performed using detectors integrated into a bowl which contains the products to be measured. The bowl is surrounded with lead shielding to prevent interference from the external background irradiation.
This equipment can allow to measure the contamination of the soil. We can put some ground inside and thus know the contamination of his/her garden.

Foodstuffs control equipment in Belarus

Equipped vehicle in France

The volume of food required for a measurement varies from half a litre to a litre. The measurement takes approximately half an hour, time which is necessary for the equipment “to count” the radioactivity with sufficient accuracy.

The final result of the measurement is then generally expressed in becquerels per kilogramme (Bq/kg) for solid products or in becquerels per litre (Bq/L) for liquids (see units in annex p.44, 7.2).

4.2.2 Where to make a measurement?

These measurements require specific equipment and skilled operators. This could be performed by the foodstuffs monitoring operator closest to the place of residence of the interested person.

Contact point: As far as Western Europe countries are concerned, it seems that the city hall could orientate the citizens towards the foodstuffs monitoring points (city hall, pharmacy, veterinary, agro-industrial facilities (co-ops), etc.).

4.3 Body contamination

The measurements of body contamination provide information on the radiological situation and its time evolution. It allows a better health protection follow-up of people living in contaminated territories and contributes to a better detection and prevention of the possible health effects.

Furthermore, the total contamination also reflects the previous ingestion or inhalation “recent past” of the considered person. For example, by comparing the body measurements with foodstuffs measurements, it is possible to detect critical individual situations and to point out some dietary habits that can be modified in order to reduce the exposure by ingestion.
4.3.1 With what kind of device?

The whole body measurement is performed by means of dosimeters integrated into a structure surrounding more or less the body. It can be for example a closed cabinet (in which the person can stand or lie), or more simply an equipped seat installed inside a room or loaded on a vehicle. The structure contains several sensors protected by shielding against external background irradiation.

![Whole body counter « cabinet » for vertical standing measurements](image1)

![« Equipped seat » loaded on a vehicle in France](image2)

The measurement takes a minimum of about ten minutes. The results are generally expressed in becquerel or in Bq/kg (see units in annex p.44, 7.2).

4.3.2 Where to make a measurement?

Whole body measurements require specific equipment and skilled operators. They must be performed by the whole body monitoring point closest to the place of residence of the interested person.

Contact point: As far as Western Europe countries are concerned, it seems that the city hall could orientate the citizens towards the whole body monitoring points (public or private hospitals and mobile units).

**Inclusive system for radiation monitoring**

The capacity of providing all the different types of radiological measurements presented above relies on a system of radiation monitoring of a relatively new kind: an inclusive system, i.e. not only single “official” laboratories, but a network system having the capacity of being piloted at the local level, and involving different independent information sources which would be at the service of local populations.

For quality assurance purpose, a certification system would be required for each of the different independent sources, at the national and even international levels. This certification would include the calibration of the equipment, the training of professionals for measurement and the protocols for measurements, the latter including not only the measurement but also the presentation of the results in a convenient form for local officials and people involved.
5. How to interpret results of measurements?

5.1 External dose rates

External dose rates measurements inform about the present “instantaneous” radiological exposure of a person. A measurement at a given time does not allow informing about the past exposure. Unless one could use and report the results from a dosimeter continuously, the only way to know about the dose from external irradiation over a given time period is to estimate the dose, by multiplying the external dose rate (in microsievert/hour-see annex) by the time spent (in hour), assuming that the dose rate has remained constant during the whole considered time period.

5.1.1 First stage: collection of external dose rate data

A minimum of parameter values is required to be able to calculate approximately the exposure from external irradiation [see Radiation monitoring p.16].

- The results of external dose rates at the place the person is supposed to be exposed (in microsievert/h, μSv/h),
- The time spent by the person at this place (in h/day).

In the example below, the column [Time spent] was added to the results of external dose rates

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Place</th>
<th>Estimated time spent (in h/d)</th>
<th>Measured external dose rate (in μSv/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/12/2001</td>
<td>Living room</td>
<td>2</td>
<td>0,12</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Bedroom</td>
<td>9</td>
<td>0,06</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Living room (fire place)</td>
<td>1</td>
<td>0,28</td>
</tr>
<tr>
<td>15/07/2002</td>
<td>Garden</td>
<td>2</td>
<td>0,18</td>
</tr>
</tbody>
</table>
5.1.2 Second stage: calculation of dose from external irradiation

The dose from external irradiation is calculated by multiplying the external dose rate (in $\mu$Sv/h) by the time spent (in h). If one person is exposed at different places, the resulting total dose is obtained by adding all contributions from each different place. For chronic exposures (repeated all along the year) it may be useful to calculated the total resulting dose and express it in “annual equivalent”, i.e. by multiplying for example the daily dose by the number of days of exposure.

How to evaluate one’s own external exposure?

The external exposure depends on:
- The dose rate measured in the considered place (microsievert/hour),
- The time spent by the person in this place (hour/year).

It can be calculated by multiplying the dose rate per the time spent.

Example 1:
In a bedroom, on the bed, the measured external dose rate is 0,08 $\mu$Sv/h. A person spends an average of 2900 h/year at that place.
The external exposure is $0,08 \mu$Sv/h x 2900 h/y = 232 $\mu$Sv/year = 0,23 mSv/year.

Example 2:
In an armchair close to a fireplace, the measured external dose rate is 0,50 $\mu$Sv/h. A person spends an average of 400 h/year.
The external exposure is $0,50 \mu$Sv/h x 400 h/y = 200 $\mu$Sv/year = 0,2 mSv/year.

Both examples given above show that it is important to look both at the external dose rate and at the time spent. In example 2, the external dose rate is much higher than in example 1, but it corresponds to a place where we spend less time. The resulting external exposure is of the same order of magnitude.
In the example below, the annual dose was calculated assuming that the exposure was repeated daily over the year (365 days)

<table>
<thead>
<tr>
<th>Name</th>
<th>Address:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of measurement</td>
<td>Place</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Living room</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Bedroom</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Living room (fire place)</td>
</tr>
<tr>
<td>15/07/2002</td>
<td>Garden</td>
</tr>
</tbody>
</table>

Total annual equivalent = 1,42 µSv/d * 365d/y = 518 µSv/y (0,52 mSv/y)

5.2 Foodstuffs contamination

What is relevant, for internal contamination, is the total quantity of radioactivity inhaled or ingested over time.

For ingestion, this quantity depends on:

- The quantity of radioactivity in the consumed foodstuffs (Becquerel/Litre or Becquerel/kg),
- The quantity of foodstuffs consumed by the person considered (kg or L),
- The possible inadvertent ingestion of soil or dust.

For inhalation, this quantity depends on:

- The quantity of radioactivity in the air (Becquerel/m³ of air),
- The volume inhaled by the person considered during the exposure time (function of the respiratory rate in m³/s).

How to evaluate one’s own internal exposure?

This is determined by calculating the quantities of ingested radioactivity. This is done by multiplying the amount of radioactivity in food products by the consumed quantities.

These “ingested becquerels” are then converted into dose by multiplying the calculated quantities of radioactivity by a specific dose coefficient depending on the radionuclide concerned (here caesium-137). These coefficients are called ingestion dose coefficients. They depend on the age of the person. For ingestion, they are taken from: INTERNATIONAL COMMISSION ON RADIATION PROTECTION, Age-dependent doses to members of the public from intake of radionuclides: Part 5, Compilation of ingestion and inhalation dose coefficients, Publication 72, Annals of the ICRP, 1995.
### 5.3 Whole body measurements

The whole body contamination measurement gives information about "the radiological state" of the person at a precise moment. This measurement reflects however the "radiological past" of this person as regards his ingestion of radioactive elements, because it takes a certain time for these elements to fix in the body and then to be eliminated from it.

Whole body measurements together with dietary histories and information about level of contamination in food can be used to reconstruct a "theoretical history" of the incorporation of radioactive elements (by ingestion or by inhalation).

Then, it is often possible to identify the food products which are at the origin of the contamination of the concerned person and to evaluate whether or not improving actions should be implemented.

Measurements of whole body contamination only provide estimations of the quantity of ingested radioactivity. Indeed, the professional of measurements can only give an interval (minimum-maximum) in which the right value of ingested radioactivity is. The closer the measurements are, the more the situation can be properly evaluated. Nevertheless, as measurements are very expensive, they cannot be repeated every week, a compromise has to be found.
5.3.1 First stage: collection of whole body measurement data

A minimum of parameter values is required to be able to reconstruct approximately "the history" of the ingestion.

- The whole body measurement (in Becquerel or Becquerel/kg),
- The date of the measurements,
- The age and weight of the person.

Note that a single measurement is not valuable for further interpretation in terms of ingestion or dose calculation unless direct information is available on the time profile of intake.

Example: a person (child) has performed four whole body measurements between 1997 and 1998. Results are reported below in the following table. A column [Number of days] was added, indicating the duration (in days) of each period between measurements.

Age of the person: 9 years
(Radionuclide caesium-137)

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Result (in Bq)</th>
<th>No of days of the period</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/10/97</td>
<td>4 320</td>
<td>61</td>
</tr>
<tr>
<td>15/12/97</td>
<td>5 360</td>
<td>95</td>
</tr>
<tr>
<td>20/3/98</td>
<td>3 800</td>
<td>57</td>
</tr>
<tr>
<td>16/5/98</td>
<td>6 220</td>
<td></td>
</tr>
</tbody>
</table>

5.3.2 Second stage: historical reconstruction of the ingestion of radioactive elements

This reconstruction can be conducted with the help of measurement professionals or health professionals. The objective is to calculate the amount of radioactivity which had to be ingested through foodstuffs during the different periods between body measurements, that can lead to the observed results. This is a theoretical reconstitution that can be further refined if the interested person can provide more detailed individual data on his/her diet and on the foodstuffs contamination.

Results of such a reconstitution are given in the following table for the example above.
The column [Min-Max range] was added, that indicates that the reconstitution is only an approximation. The level of uncertainty (i.e. a wide Min-Max range) increases as the interval between body measurements increases.

<table>
<thead>
<tr>
<th>Date of measure</th>
<th>Result (Bq)</th>
<th>Nb days of the period</th>
<th>Calculated Mean ingestion (Bq)</th>
<th>Min-Max range (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/10/97</td>
<td>4 320</td>
<td>61</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15/12/97</td>
<td>5 360</td>
<td>91</td>
<td>6 100</td>
<td>3 729-11 839</td>
</tr>
<tr>
<td>20/03/98</td>
<td>3 800</td>
<td>57</td>
<td>7 600</td>
<td>2 734-12 518</td>
</tr>
<tr>
<td>16/05/98</td>
<td>6 220</td>
<td></td>
<td>6 840</td>
<td>5 036-14 076</td>
</tr>
</tbody>
</table>

Calculation of the ingestion starting from the results of whole body measurements

These calculations can be performed into different ways, depending on the available tools. Schematically, one can use either pre-calculated values (Tables) or simplified calculation software.

In both cases, it is important to collect both the value one is looking for (the quantity of $^{137}$Cs ingested a day) and information about the precision of this "theoretical" value: its uncertainty interval. For this purpose, three values are looked for:

- A mean value, calculated by assuming a continuous and constant daily ingestion over all the period of time separating whole body measurements,
- A minimum value, calculated by assuming that the ingestion is made in the single day just before the considered body measurement (at the end of the considered period),
- A maximum value, calculated by assuming that the ingestion is made in the single day just after the previous body measurement (at the beginning of the considered period).

They give the correspondence between the quantity of $^{137}$Cs as measured in the body and the quantity ingested during the whole period preceding the measurement; they are given for four age groups. The confidence intervals (Min-Max range) are indicated corresponding to the optimum frequency of body measurements, i.e. the frequency of body measurements which minimises the uncertainty on the interpretation of the results in terms of ingestion profiles.

5.3.3 Third stage: comparison with foodstuffs measurements

The previously reconstructed values of ingestion must be compared with direct measurements of foodstuffs consumed by the person considered. If such measurements do not exist, it is advisable to obtain information from the nearest measuring point.

The table below provides data on several foodstuffs contamination corresponding to the person considered in the example already discussed.
How to interpret results of measurements?

It is then possible to look for one or several foodstuffs which are likely to be the main contributor(s) to the value of ingestion previously estimated, taking into account the dietary habits of the person. It is advisable to look first at the products which are consumed regularly (daily) and to evaluate to what extent these “common” foodstuffs can contribute on their own to the reconstructed "theoretical" ingestion.

**Reminder:** over the period from 20/03/98 until 16/05/98 (57 days), the reconstructed "theoretical" mean ingestion is 6,840 Bq (120 Bq/day in average).

In this example, it seems that the milk can, if consumed daily, represent an important part of the ingested radioactivity (4,674 Bq in average over a total of 6,840, i.e. about 70%).

Then, it is advisable to look at the products which are consumed only occasionally but which can, due to their relatively high level of contamination, also contribute to the reconstructed ingestion.

**In the example below, the total quantity of radioactivity ingested in a meal of wild boar and bilberries is calculated.**

<table>
<thead>
<tr>
<th>Product</th>
<th>Quantity regularly consumed (kg/day)</th>
<th>Measured contamination (Bq/L or Bq/kg)</th>
<th>Contribution of the product to ingestion of contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk</td>
<td>0,5</td>
<td>98-230</td>
<td>49-115 Bq/day (average 82 Bq/day) or 2,793-6,555 Bq (average 4,674 Bq)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Quantity once consumed (kg)</th>
<th>Measured contamination (Bq/L or Bq/kg)</th>
<th>Contribution of the product (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bilberries</td>
<td>0,150</td>
<td>3,223</td>
<td>483</td>
</tr>
<tr>
<td>Boar</td>
<td>0,200</td>
<td>8,415</td>
<td>1,683</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>2,166</strong></td>
</tr>
</tbody>
</table>

We can see from this calculation that a single meal of wild boar and bilberries, consumed the day before the body measurement, additionally to the daily consumption of milk, can explain the level of contamination of the person.
How to interpret results of measurements?

This example shows that the method is very iterative and requires a dialogue between the individual concerned and the health professionals. It appears that the "wild" products – although more contaminated – do not systematically contribute to the contamination of the people. It is essential to first focus on regularly consumed foodstuffs, and at a later stage, on other products consumed more occasionally but that could be a significant part of the intake.

Such a process shows that professionals of measurements will be efficient only if they receive extra training to gain expertise and radiation protection knowledge. They will have for instance to understand the common routes of contamination.

5.4 Comparison tools

To have control on the radiological risks in a contaminated environment, it is important to have elements to evaluate one’s own situation:

- Compared with other situations (or reference situations, including background for example),
- Compared with regulatory limits.

5.4.1 Reference situations

Human activities, independently from any accidental event leading to a contamination of the environment, may be a source of radiological exposure, either by external irradiation (external dose rates) or by internal contamination (inhalation and ingestion of radioactivity from air and foodstuffs).

Global doses

The figures below present varying exposure situations in France, UK and Germany.
Exposure situation in France

Exposure situation in UK

Exposure situation in Germany
Note that the different contributions must be added to calculate the total resulting dose for a given person. Thus, the exposure from cosmic radiations must be added to the one coming from earth rocks, to the one resulting from medical radiological acts or nuclear industry activities, etc. The resulting total dose is estimated to 3 millisievert/y for example in average in France.

**Foodstuffs contamination**

In France a review of recent caesium-137 measurements (2002-2003) in food products provides the following orders of magnitude (i.e. values which are highly probably measured throughout the country, the existence of some sparse “hot spots” with higher values not being excluded): milk less than 0.1 Bq/L, fruits less than 0.1 Bq/kg, mushrooms 10-160 Bq/kg.

For Germany (Bavaria), recent measurements (2003-2004) are presented in the Table below.

<table>
<thead>
<tr>
<th>Product</th>
<th>No of measurements</th>
<th>Contamination $^{137}$Cs (Bq/L or kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>Milk</td>
<td>139</td>
<td>0,07</td>
</tr>
<tr>
<td>Pork</td>
<td>10</td>
<td>0,16</td>
</tr>
<tr>
<td>Beef</td>
<td>10</td>
<td>0,11</td>
</tr>
<tr>
<td>Deer</td>
<td>16</td>
<td>0,29</td>
</tr>
<tr>
<td>Wild boar</td>
<td>20</td>
<td>1,44</td>
</tr>
<tr>
<td>Root vegetables</td>
<td>11</td>
<td>0,14</td>
</tr>
<tr>
<td>Leafy vegetables</td>
<td>25</td>
<td>0,09</td>
</tr>
<tr>
<td>Bilberries</td>
<td>3</td>
<td>0,37</td>
</tr>
<tr>
<td>Lowbush cranberries</td>
<td>1</td>
<td>8,24</td>
</tr>
<tr>
<td>Potatoes</td>
<td>26</td>
<td>0,13</td>
</tr>
<tr>
<td>Bay boletus (cepe)</td>
<td>13</td>
<td>52,7</td>
</tr>
<tr>
<td>Yellow boletus</td>
<td>6</td>
<td>8,97</td>
</tr>
</tbody>
</table>

*Sampling from 13.07.03 – 13.07.04, Bavaria, Bayerisches Landesamt für Umweltschutz (LfU)*

**Body contamination**

As far as body contamination is concerned, in France too, a continuous survey of a group from the general population (not particularly exposed due to their professional activity) shows that the level of contamination does not usually exceed 50 Bq (whole body). It is considered to be the most probable value that could be observed throughout the country. A few higher values associated with very typical local dietary habits have been measured in the late 90’s in the Vosges (a person for whom several hundreds of Bq of $^{137}$Cs were measured).
**Specific reference scales**

**External irradiation**

The Figure below presents a scale of radiation dose established in Belarus territories contaminated by the Chernobyl accident. The different levels which are reported on this scale were discussed and defined with the local population, taking into account the local situation (according to the measured external dose rates in houses, in gardens and in the environment, at school, in public places, etc.) as well as other reference situations (for example the levels reported in France) and finally the regulatory limits applied at a national and international levels.

**Internal contamination through foodstuffs ingestion**

The Figure below presents a scale of internal contamination levels established in Belarus territories contaminated by the Chernobyl accident. The different levels which are reported on this scale were discussed and defined with the local population, taking into account the local situation (according to the measured foodstuffs contamination at the village scale, coming from the private and public production) as well as other reference situations (for example the levels reported in France) and finally the objectives fixed at the national level by the health authorities, notably in terms of total contamination of caesium-137 in the body.
5.4.2 Regulatory limits

Regulatory limits are established at national and international levels. These limits provide maximum permitted annual doses for the public (any person who is not exposed to ionising radiation due to his professional activity, like nuclear workers for example). These limits apply to any source of exposure, coming in addition to the background already mentioned above.

Today, the dose limit fixed by the regulation is 1 millisievert/year for the public\(^5\).

Concerning foodstuffs, permitted concentration limits relating to the consumption of food products following an accidental contamination are fixed in the European Council Directive 87/395/4 EURATOM. These limits were established following the Chernobyl accident, with the major objective of tackling situation of a comparable scale.

Permitted concentration limits are given in the table below for five food categories, and considering four groups of radionuclides.

For concentrated or dried food products, the limit applies to the reconstituted product as ready for consumption.

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Baby foods(^a)</th>
<th>Dairy produce</th>
<th>Minor foods(^b)</th>
<th>Other foods</th>
<th>Liquid foods(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isotopes of strontium (incl. (^{90})Sr)</td>
<td>75</td>
<td>125</td>
<td>7 500</td>
<td>750</td>
<td>125</td>
</tr>
<tr>
<td>Isotopes of iodine (incl. (^{131})I)</td>
<td>150</td>
<td>500</td>
<td>20 000</td>
<td>2 000</td>
<td>500</td>
</tr>
<tr>
<td>Alpha-emitting isotopes of plutonium and transplutonium elements</td>
<td>1</td>
<td>20</td>
<td>800</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>All other radionuclides of half-life greater than 10 days, (incl. (^{134})Cs and (^{137})Cs)(^d)</td>
<td>400</td>
<td>1 000</td>
<td>12 500</td>
<td>1 250</td>
<td>1 000</td>
</tr>
</tbody>
</table>

\(^a\) Baby foods are defined as those foodstuffs intended for the feeding of infants during the first four to six months of life, which meet, in themselves, the nutritional requirements of this category of person and are put up for retail sale in packages which are clearly identified and labelled “food preparation for infants”.

\(^b\) Minor foods correspond to foods products entering in the composition of foodstuffs but in lower quantities: spices, herbs, cocoa, coffee, etc.

\(^c\) Liquid foods: values applicable to tap water, according to the decision of each State Member.

\(^d\) Carbon-14, tritium and potassium-40 excepted.
The table is above all useful in case of short-term contamination. In case of long-term contamination, public health authorities would have to implement another system more adapted to the radiological situation. For instance, following the Chernobyl accident, Norwegians have implemented a system that allows to consume contaminated foodstuffs if it is done in controlled and small quantities. In fact, their system is based not only on the contamination of foodstuffs but also on the particular consumption of each individual. In Belarus, in the same way, the limits of contamination of mushrooms and berries have been adapted according to the quantity consumed by people.

5.5 Data management

Results from radiological measurements can allow people to understand their own radiation exposure risks and whether to take protective actions.

Thus it seems important that radiological measurements, whatever these measurements (external dose rates, foodstuffs contamination, body contamination), can be made relevant and returned as soon as possible to the interested person [see p.36, 5.5.3]. It is also important to aggregate these data for statistical purposes. Finally, it is important to present these data in a form that is understandable (and consequently more useful for further action) by all stakeholders, even those who are not expert in radiation protection related fields.

5.5.1 Retention and communication of individual results

The results of radiological measurements (external dose rates, contamination of foodstuffs and body contamination) are some of the elements that characterise an individual’s situation and that of the family at any time. It is important that this information can be kept personally by them [see p.36, 5.5.3]. In particular, it may be useful for people if they have future health concerns.

External dose rates

For external dose rates, the information can be kept in a simple way because the measurements can be performed directly by the householder. Thus he can keep a simple plan of his environment (house, garden, workroom) on which external dose rates can be reported in various places.

<table>
<thead>
<tr>
<th>Name</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMITH J.R.</td>
<td>Garden street 24, Whiteley</td>
</tr>
<tr>
<td>Date of measurement</td>
<td>Place</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Living room</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Bedroom (child1)</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Living room (fire place)</td>
</tr>
<tr>
<td>15/07/2002</td>
<td>Garden</td>
</tr>
</tbody>
</table>
The reports would also mention information on the background radiation, obtained from historical measurements at the same place or from other comparable reference situations.

**Foodstuffs contamination**

For measurements in foodstuffs, it is advisable to provide an individual result sheet, which is directly returned to the concerned person by the foodstuffs monitoring operator. This result sheet may contain the most recent results together with a summary of the previous results and a comparison with information from a wider area (comparison with the levels of radioactivity in products produced regionally for example).

<table>
<thead>
<tr>
<th>Name</th>
<th>Address:</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMITH J.R.</td>
<td>Garden street 24, Whiteley</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Product</th>
<th>Measured contamination (in Bq/L or Bq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/12/2001</td>
<td>Carrots</td>
<td>23</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Potatoes</td>
<td>12</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Strawberries (from garden)</td>
<td>&lt;10</td>
</tr>
<tr>
<td>10/12/2001</td>
<td>Blackberries</td>
<td>234</td>
</tr>
<tr>
<td>15/07/2002</td>
<td>Pork meat</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

**Body measurements**

For whole body measurements, it is again advisable to provide an individual result sheet, returned directly to the concerned person after the measurement, which in a similar way as for foodstuffs, summarises the previous results and a possible comparison with information from a wider area.

<table>
<thead>
<tr>
<th>Name</th>
<th>Address:</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMITH N.</td>
<td>Garden street 24, Whiteley</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date of measurement</th>
<th>Weight of the person (kg)</th>
<th>Age</th>
<th>Measured contamination in Bq</th>
</tr>
</thead>
<tbody>
<tr>
<td>15/10/97</td>
<td>35</td>
<td>8</td>
<td>4 320</td>
</tr>
<tr>
<td>15/12/97</td>
<td>36</td>
<td>8</td>
<td>5 360</td>
</tr>
<tr>
<td>20/3/98</td>
<td>35</td>
<td>9</td>
<td>3 800</td>
</tr>
<tr>
<td>16/5/98</td>
<td>35</td>
<td>9</td>
<td>6 220</td>
</tr>
</tbody>
</table>

**5.5.2 Synthesis and use in a statistical approach**

The results of measurements such as those described above can also be used to present the radiological situation for a wider area. The objective here would not be to present a statistical analysis of the results in an exhaustive way such as for scientific research purposes. Instead the aim should be to identify methods to analyse and display the information that will be useful, for the population and for
the people responsible at the local and national levels; the results of the ETHOS project in Belarus will be useful here.

**External dose rates**

The results from individual measurements of external dose rates can be aggregated on a local level (village, city), or a regional level to give an overall picture of the radiological quality of the environment. This could lead for example to a cartographic representation, which then allows every family to assess their own situation in relation to that in the immediate vicinity.

**Foodstuffs contamination**

In a similar way, the contamination levels in foodstuffs at an individual level can be aggregated into a local level (village, city) or a regional level, by grouping for example foods by categories, from the more contaminated to the less contaminated. It can also lead to a sort of map of the radiological quality of foodstuffs which allows every person to assess their own situation in relation to their close geographic environment.

Note that in the EU most food is obtained from sources well away from the local area. So it can be important to distinguish between the food bought in supermarkets, in local markets and that locally obtained.

**Map of radiological quality of foodstuffs at a village scale over 2000-2001 period (source ETHOS, Belarus)**

<table>
<thead>
<tr>
<th>Product</th>
<th>No of measurements</th>
<th>Contamination $^{137}$Cs (Bq/kg)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Known to concentrate radioactivity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Milk</td>
<td>322</td>
<td>0</td>
<td>466</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Dried mushrooms</td>
<td>4</td>
<td>1 800</td>
<td>36 222</td>
<td>12 016</td>
<td></td>
</tr>
<tr>
<td>Fresh mushrooms</td>
<td>20</td>
<td>36</td>
<td>1,160</td>
<td>411</td>
<td></td>
</tr>
<tr>
<td>Bilberries</td>
<td>13</td>
<td>98</td>
<td>375</td>
<td>223</td>
<td></td>
</tr>
<tr>
<td>Cranberries</td>
<td>11</td>
<td>30</td>
<td>1 617</td>
<td>293</td>
<td></td>
</tr>
<tr>
<td><strong>Less sensitive</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrots</td>
<td>6</td>
<td>0</td>
<td>37</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Meat</td>
<td>1</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td>52</td>
<td>0</td>
<td>43</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

**Body measurements**

As far as body measurements are concerned a statistical approach at a village or regional scale would allow a global picture of the radiological situation to be obtained and could contribute to the health or epidemiological follow-up of the population.

The following map is an example of what it is possible to do. It brings together data of the contamination of children in several districts of Belarus.
Synthesis

**Presentation of the results in a statistical perspective**

<table>
<thead>
<tr>
<th>Type of measurement</th>
<th>Benefits expected from the statistical approach</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At an individual level</td>
<td>At the community level</td>
</tr>
<tr>
<td>External dose rates</td>
<td>To assess one’s situation in the context of neighbouring and comparable situations</td>
<td>Indicator of the radiological quality of a territory</td>
</tr>
<tr>
<td></td>
<td>Follow the time-evolution</td>
<td></td>
</tr>
<tr>
<td>Foodstuffs</td>
<td>To assess one’s situation in the context of neighbouring and comparable situations</td>
<td>Indicator of the radiological quality of a territory</td>
</tr>
<tr>
<td></td>
<td>Follow the time-evolution</td>
<td></td>
</tr>
<tr>
<td>Body</td>
<td>To assess one’s situation in the context of neighbouring and comparable situations</td>
<td>Indicator of the radiological quality of a territory</td>
</tr>
</tbody>
</table>
5.5.3 Individual booklet or family passport

Each person should have all his measurements results in an individual booklet. This would allow a quantitative assessment of the available information. Such a booklet can be used to evaluate the evolution of the radiological situation over time and to compare all the data (for instance whole body measurements with measurements of foodstuffs). It is important that the individual himself fills in the booklet.

<table>
<thead>
<tr>
<th>Date</th>
<th>Whole body</th>
<th>Foodstuffs</th>
<th>Ambient dose rates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Type of measurements</td>
<td>Indoors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Market products</td>
<td>Self-produced or gathered products</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meat</td>
<td>Eggs</td>
</tr>
<tr>
<td></td>
<td>Bq</td>
<td>Bq/kg</td>
<td>Bq/kg</td>
</tr>
<tr>
<td>15/10/03</td>
<td>4320</td>
<td>98</td>
<td>&gt;10</td>
</tr>
<tr>
<td>24/10/03</td>
<td>3200</td>
<td>&gt;10</td>
<td>23</td>
</tr>
<tr>
<td>12/12/03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/01/04</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. How to improve the radiological situation?

In case of long-term contamination of the environment, different protective and prevention actions are implemented directly by the public authorities in the concerned sectors.

Public authorities may also put at the disposal of the population other additional means, that can be implemented at an individual level by each person. Radiometers, foodstuffs and body monitors are an example of such initiatives.

Finally, some “know-how” or “good practice” can also be developed by each individual, on the basis of his/her knowledge about the situation and practical means that are beforehand at his/her disposal.

The list of improvement options proposed below is not exhaustive. It is based on proposals of the Belarus and English panels.

6.1 Options to reduce one’s own external exposure

The individual external exposure can be reduced:

- By reducing the time spent in a place where the dose rate is high,
- By reducing the exposure rate itself (shielding, decontamination through appropriate cleaning),
- By increasing the distance from the source of radiation.

6.2 Options for the household

6.2.1 What can I do at home?

1. Clean indoor surfaces,
2. Process and store foodstuffs prior to consumption.
1) **Clean indoor surfaces**

If deposition to the area occurs particularly without rainfall, indoor contamination may be significant, especially during the initial stages of contamination. Later on, the dust brought on the soles of shoes or on the clothes, or even by air masses, can be a source of contamination indoors. It is of importance not to let dust accumulate in places where persons may spend time, or may be in contact.

2) **Process and store food prior to consumption**

Processing and storage of some home-grown or self-gathered wild foods may achieve reductions in the activity concentration in the edible parts to less than intervention limits. Methods for processing and storing may include blanching, marinating, deep freezing, drying and making jams, chutneys and preserves. Blanching can remove activity incorporated within the food. For example 50% of radiocaesium contamination is removed during blanching or boiling. Meat and fish can be marinated in NaCl brine with reductions of up to 80% and 50% respectively for radiocaesium.

6.2.2 **What can I do in the garden?**

1. Dig/plough the garden,
2. Use contaminated wood and resulting fire ash carefully.

1) **Dig/plough the garden**

Radioactive caesium deposited onto soil could remain in the top few centimetres of the soil profile for many years (particularly in clays and brown earths). Inverting this layer of contamination to a deeper position within the soil profile provides significant shielding against external irradiation.

**What do I need to do?**

Dig the top layer of the soil to a depth of ca. 30 cm attempting to take the turf to the bottom of this vertical profile. Garden soils may be tilled by petrol-driven rotovators or dug with a spade. By diluting the contamination within the top 20 cm of soil, the radionuclide uptake by the roots of some plant species will also be reduced.

2) **Use contaminated wood and resulting fire ash carefully**

Frequently burning contaminated wood in domestic ovens may lead to a gradual increase in the concentration of caesium-137 in ash compared to normal firewood.

**What do I need to do?**

If used as a fertiliser in the garden, the contamination from the ash may be transferred to crops/fruit/vegetables grown in the fertilised soil. Otherwise, prefer an alternative fertiliser for the garden. At best, combine mineral fertilisers (with potassium or phosphates) with usual organic ones.
6.2.3 What can I do in the allotment and vegetable gardens?

Contamination in the soil can easily be transferred to the food being grown in it. Thus, in kitchen gardens and allotments, topsoil can be removed by spade and relocated to an area of the garden not used for food production e.g. a flower bed. Occasionally topsoil could be completely removed from gardens, although this generates a lot of waste soil.

Removal or relocation of soil should be carried out as soon as possible. Local authorities may transport contaminated topsoil to landfill sites but due to volumes that would be involved, this would not be common practice.

6.2.4 What can I do with contaminated waste?

Contaminated waste could arise (solid and/or liquid) from:
- Allotment/kitchen gardens (e.g. produce unsuitable for consumption),
- Garden waste (e.g. leaves, grass cuttings etc),
- Kitchen waste (e.g. peelings, outer leaves) due to food preparation techniques.

Household refuse is normally sent to landfill or is incinerated. Organic waste from gardens is often collected separately and sent to composting facilities. However, it can be mixed with other refuse and disposed of to landfill or incineration.

In the event of an accident, all refuse could be contaminated, particularly garden waste. The management of this waste will be controlled by the authorities and a special collection may be arranged. Garden waste may be segregated from household waste, if this is not normal practice.

A monitoring scheme may be set up to determine the most appropriate disposal route for contaminated waste. The waste may still be sent to landfill or incinerator plants depending on the levels of contamination and whether these plants are licensed to accept contaminated waste. Small quantities of contaminated liquids (e.g. milk from livestock) may be disposed of at dairy effluent or sewage treatment plants. Vegetable waste may be kept for composting either in situ or at commercial facilities. The high moisture content and readily putrescible nature of some food residuals mean that waste treatment cannot be delayed.

6.2.5 What can I collect (or eat) from the countryside and the forest?

It is possible that some areas normally used for the collection of free foods may have restricted access. Furthermore, game hunting and fishing may be restricted to certain times within the hunting/fishing seasons when activity concentrations are reduced.
Mushrooms

Do not pick mushrooms in areas contaminated by caesium-137 at levels above 74,000 Bq/m². Is it recommended to check periodically the contamination of mushrooms even in low contaminated territories.

To decrease the contamination, mushrooms should be cleaned and cooked in brine with a little of vinegar or citric acid. Then, they can be dried.

According to their capacity to retain caesium-137, 4 groups of mushrooms are distinguished:

1. Accumulating mushrooms (>1000 Bq/kg): bay boletus (Xerocomus badius), Paxillus involutus, yellow boletus (Suillus luteus), Agaricus amarus, Rozites caperatus;
2. Mushrooms with a high uptake of radionuclides (between 400 and 1000 Bq/kg): delicious milk cap (Lactarius torminosus), Russula, Tricholoma flavovirens, chanterelle (Cantharellus cibarius);
3. Mushrooms with a mean uptake of radionuclides (between 65 and 350 Bq/kg): king boletus or cepe (Boletus edulis), birch boletus (Leccinum scabrum), horn of plenty (Craterellus cornucopioides);
4. Mushrooms with a weak uptake of radionuclides (<60 Bq/kg): parasol mushroom (Lepiota procera), honey mushroom (Armillaria mellea), puffball (Licoperdon perlatum), morel (Morchella), shaggy mane (Coprinus comatus), cultivated mushrooms, oyster mushrooms.
Hats of mushrooms are known to concentrate more radioactivity than their feet.

**Berries**

Do not pick berries in forests contaminated by caesium-137 at levels above 74,000 Bq/m². Is it recommended to check periodically the contamination of berries picked in forests where the contamination level is between 37,000 and 74,000 Bq/m².

In forests with a contamination level less than 37,000 Bq/m², it is advised to measure blackberries, strawberries and raspberries. Blueberries and cranberries have to be measured compulsorily.

Under the same conditions, caesium-137 is twice or threefold more concentrated in blueberries than in strawberries or raspberries.

Jam or compote making does not decrease the contamination.

### 6.3 Options for health professionals & the local stakeholder advisory board

#### 6.3.1 Provision of advice/information/guidance to the public

To provide general advice/information/guidance on:

- Council Food Intervention Limits. Reassurance that marketed foodstuffs bought from supermarkets would be suitable for consumption and fall within limits set by Government legislation. Ways to restrict dietary radionuclide intake from self-gathered wild foods (i.e. mushroom and berries), home-grown foods (i.e. fruit and vegetables) and private water supplies, water butts. Advice may vary from suggestions as to which foodstuffs can be eaten without restrictions, which would be suitable to eat occasionally, and which should be avoided completely.

- Improvement options suggested for households including when it is 'safe' to implement the options and when it would be reasonable to cease taking action.

- Other improvement might be carried out to decontaminate areas such as roads, schools and other public areas, by authorities.

The advice could be communicated in the media (i.e. newspapers, Internet) and as specially produced leaflets.
6.3.2 Provision of counting / monitoring equipment

To provide the public with personal access to equipment or facilities for screening home-grown or self-gathered foodstuffs for radioactivity content. Monitoring facilities can include loan or donation of Geiger counters or electronic dosimeters, with suitable training, to enable personal monitoring of external dose rates, or access to independent monitoring services. Local measurement stations for determination of radionuclide content in foodstuffs (particularly self-gathered) and/or whole body monitoring should be made available.
7. Technical sheets on radioactivity

7.1 Description

All matter is composed of a multitude of atoms of different types. Some can be in an unstable state. When they are unstable, they are called radioactive, because they are subject to a spontaneous physical transformation (change of state or disintegration), which produces radiation and/or particles. The speed (or rate) of disintegration can be variable.

Some atoms reach a stable state after their disintegration; they are no longer radioactive. In other cases, the disintegration process produces new atoms which are themselves unstable. As a consequence, these new atoms are again subject to a new disintegration, and thus to another emission of radiation or particles, etc.

Radioactive decay

The disintegration process occurs with time, depending on the degree of instability of each kind of atom. Some atoms quickly disintegrate: we speak of "short-lived" radionuclides. On the contrary some atoms take millions of years before disintegrating. We speak of "long-lived" radionuclides. In the middle, all situations may be encountered in the nature...

The disintegration process occurs with time and can not be accelerated. It depends of the degree of instability of the radionuclide. As time goes by, the number of radionuclides diminishes, so does the radioactivity. An atom "lifetime" is characterised by its "half-life", it corresponds to the time period needed for half of the initial atoms from a considered amount of matter to disappear (by disintegration).

Different types of radioactive emissions

The radiation or particles emitted within a disintegration process differ, according to the atoms:

- Alpha emission (\(\alpha\)) corresponds to the emission of a particle (matter); more precisely, it deals with a helium nucleus (two protons and two neutrons),
- Neutron emission corresponds to the emission of particles (matter),
- Beta radiation (\(\beta\)) corresponds to the emission of a charged particle (matter); more precisely it deals with an electron,
- Gamma radiation (\(\gamma\)) corresponds to an electromagnetic wave (like visible light and X-rays).
7.2 Units

Three units are used for radioactivity:

- The becquerel (Bq) is used to quantify the activity of a radioactive source; it corresponds to one disintegration per second. Multiple units are frequently used:
  - the kilobecquerel (kBq) = 1 000 Bq,
  - the megabecquerel (MBq) = 1 million Bq (10⁶ Bq),
  - the gigabecquerel (GBq) = 1 billion Bq (10⁹ Bq),
  - the terabecquerel (TBq) = 1 trillion Bq (10¹² Bq).

- The sievert (Sv) is used to quantify the biological effect of the radiation on the exposed individual, depending on the nature of the radiation and on the exposed organs. Multiple units are also commonly used:
  - the millisievert (mSv) = 0.001 Sv,
  - the microsievert (µSv) = 0.001 mSv or 0.000001 Sv.

Some radionuclides and their characteristics

Radionuclides present since the Earth’s origin

About twenty of “primordial” elements remain present in the nature, i.e. unstable atoms originated from the formation of the Earth, and which radioactive decay is so long that all of them have not been disintegrated yet. In particular it is the case of potassium-40 (⁴⁰K), radioactive daughter products of uranium-238 (²³⁸U), of thorium-232 (²³²Th) and of uranium-235 (²³⁵U).

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half life</th>
</tr>
</thead>
<tbody>
<tr>
<td>potassium-40 (⁴⁰K)</td>
<td>1,29 billions years</td>
</tr>
<tr>
<td>uranium-238 (²³⁸U)</td>
<td>4,5 billions years</td>
</tr>
<tr>
<td>thorium-232 (²³²Th)</td>
<td>14 billions years</td>
</tr>
<tr>
<td>uranium-235 (²³⁵U)</td>
<td>0,7 billion years</td>
</tr>
</tbody>
</table>

These radionuclides are found in the soil, in water, in the air, in plants and in living organisms, including humans.

Radionuclides continuously produced by cosmic radiation

Cosmic radiation continuously produces radionuclides, in the air and in Earth’s crust. In particular it is the case of carbon-14 (¹⁴C), tritium (¹H), chlorine-36 (³⁶Cl), beryllium-10 (¹⁰Be), silicon-32 (³²Si).

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half life</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon-14 (¹⁴C)</td>
<td>6 000 years</td>
</tr>
<tr>
<td>tritium (¹H)</td>
<td>13 years</td>
</tr>
<tr>
<td>beryllium-10 (¹⁰Be)</td>
<td>2,7 millions years</td>
</tr>
<tr>
<td>silicon-32 (³²Si)</td>
<td>650 years</td>
</tr>
<tr>
<td>chlorine-36 (³⁶Cl)</td>
<td>310 000 years</td>
</tr>
</tbody>
</table>
Radionuclides originated from human activity

Different human activities lead to the formation of radionuclides, so-called “anthropogenic”. Since the beginning of the 20th century, short-lived radionuclides have been used in medical applications. Nuclear fusion or nuclear fission energy produces a multitude of radionuclides of varying half-lives. Nuclear weapons tests have widespread large amounts of radionuclides in the environment in the second half of the 20th century as well as accidental events in nuclear power plants (Kyshtim accident-1957, Three Miles Island-1979, Chernobyl-1986) but also in hospitals, research centres, ...

In particular, it is the case of iodine-131 ($^{131}\text{I}$), iodine-129 ($^{129}\text{I}$), caesium-137 ($^{137}\text{Cs}$), cobalt-60 ($^{60}\text{Co}$), strontium-90 ($^{90}\text{Sr}$) and many more...

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>iodine-129 ($^{129}\text{I}$)</td>
<td>17 millions years</td>
</tr>
<tr>
<td>iodine-131 ($^{131}\text{I}$)</td>
<td>8 days</td>
</tr>
<tr>
<td>caesium-137 ($^{137}\text{Cs}$)</td>
<td>30 years</td>
</tr>
<tr>
<td>cobalt-60 ($^{60}\text{Co}$)</td>
<td>5 years</td>
</tr>
<tr>
<td>strontium-90 ($^{90}\text{Sr}$)</td>
<td>28.5 years</td>
</tr>
</tbody>
</table>

These radionuclides are found in the soil, in water, in the air, in plants and in living organisms, including humans.

7.3 Uptake in the body

The body absorbs radioactive elements via the lungs/gut, skin and wounds. They are then eliminated by bio-chemical/physiological processes depending on the chemical nature of the radionuclide.

Figure below shows the level of total radioactivity of the body following a single intake of 10 000 Becquerels of caesium-137 by individuals at different ages. This figure shows very clearly the differences of speed of removal of the $^{137}\text{Cs}$ 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 $^{137}\text{Cs}$ body content.

![Evolution of the whole body radioactivity following a single intake of 10,000 Bq of $^{137}\text{Cs}$](image)

*Evolution of the whole body radioactivity following a single intake of 10,000 Bq of $^{137}\text{Cs}$ (From: Institut de Protection et de Sûreté Nucléaire, Le césium de l’environnement à l’Homme, Collection IPSN, EDP Sciences 2000).*
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).

The figure presented below shows the level of radioactivity of the whole body for a continuous and constant incorporation of 1 Becquerel per day. It shows that an equilibrium state is reached at the end of a time period that depends on the age of the person considered. Note that the relationship is linear, i.e. the whole body contamination is directly proportional to the incorporation rate. Also note that individual differences are observed, depending on the metabolism, the potassium content of the body, the weight of the person, muscle mass, etc., the values provided below correspond to reference persons.

Progressive body accumulation of caesium associated with a continuous and constant incorporation of 1 Bq per day and corresponding whole body contents at the equilibrium state

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**Caesium retention in the body**

The caesium which enters the body through ingestion is quickly absorbed at the gastro-intestinal tract and then passes in the blood, and further into target organs. *From: Institut de Protection et de Sûreté Nucléaire, Le césium de l’environnement à l’Homme, Collection IPSN, EDP Sciences 2000.*

The movement of caesium in the body can be predicted from detailed statistical models. *From: Age-dependent doses to members of the public from intake of radionuclides: Part 1, Publication 56, International Commission on Radiological Protection, Annals of the ICRP, vol.20, No.2 (1989).*

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**7.4 Health effects**

Radiation can damage living tissue in the human body. The body attempts to repair the damage but sometimes the damage is too severe or too widespread, or mistakes are made in the natural repair process.

Radiation can affect the body in a number of ways and the adverse health consequences of exposure may not be seen for many years. The adverse effects can range from mild effects, such as skin burns, to serious effects, such as cancer and death, depending on the amount of radiation absorbed by the body, the type of radiation, the exposure route and the duration of exposure. Very acute exposures to radiation may cause death within a few days or months. Exposure to lower
doses of radiation may lead to an increased risk of developing cancer or other adverse health effects.

Ionising radiation may damage cells in the living material through which it propagates. If cellular damage occurs and is not adequately repaired, the cell may not survive, reproduce or perform its normal function. Alternatively, it may result in a viable but modified cell, which may go on to become cancerous if it is a somatic cell, or lead to inherited disease if it is a germ cell.

In general, the health effects of ionising radiation depend on the dose received and are divided into stochastic effects (genetic risks in offspring, somatic effects - cancer), and deterministic effects.

### Tissue reactions

Associated with high-dose acute exposure (mostly >0.1 Gray), these effects are called "deterministic" because they always appear following the exposure (within days - prodromal syndrome, gastrointestinal syndrome, central nervous system syndrome - or weeks - haematopoietic syndrome, pulmonary syndrome). Note that most of the deterministic effects do not appear in long-term situations of exposures. In some particular case however, certain deterministic effects like cataracts or hypothyroidism manifest only over periods of years or more. The seriousness of deterministic effects depends directly on the received dose with a threshold dose below which the effect is not observed (see following Table). From Little M.P., Risks associated with ionising radiation, British Medical Bulletin, n°68, pp 259-275, 2003.

If the damage to cells cannot be repaired by internal mechanisms, they lead to the cellular death, and in doing so, provoke side effects on tissues and organs. Depending on the affected tissues, symptoms can be for example skin burns (a symptom which was observed the same year as the discovery of ionising radiation, in 1895), temporary infertility, effects on the central nervous system, the digestive system or the system of production of white corpuscles. When tissues are not affected too much, these effects are reversible and would heal. However, in case of very high exposures, too many cells are destroyed, leading to the complete destruction of tissues or irradiated organs. Burns can then require the amputation of a limb; the effects on the vital systems can lead to the death of the victim.

In the particular case of a foetus exposed in uterus, an exposure can cause the death of the embryo or cause further malformations.

The followings values are given for an adult.

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Organ</th>
<th>Threshold dose (in Gray)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mortality</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone marrow syndrome</td>
<td>Bone marrow</td>
<td>1.5</td>
</tr>
<tr>
<td>Pneumonitis</td>
<td>Lung</td>
<td>5.5</td>
</tr>
<tr>
<td>Gastrointestinal syndrome</td>
<td>Colon (internal dose)</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Small intestine (external dose)</td>
<td>9.8</td>
</tr>
<tr>
<td>Embryonic/fetal death</td>
<td>Fetus</td>
<td></td>
</tr>
<tr>
<td>1-18 days of pregnancy</td>
<td></td>
<td>0.12</td>
</tr>
<tr>
<td>18-150 days of pregnancy</td>
<td></td>
<td>0.37</td>
</tr>
<tr>
<td>&gt;150 days of pregnancy</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td><strong>Morbidity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prodromal effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Vomiting</td>
<td>Digestive tract</td>
<td>0.49</td>
</tr>
<tr>
<td>- Diarrhoea</td>
<td>Digestive tract</td>
<td>0.55</td>
</tr>
<tr>
<td>Lung fibrosis</td>
<td>Lung</td>
<td>2.7</td>
</tr>
<tr>
<td>Skin burns</td>
<td>Skin</td>
<td>8.6</td>
</tr>
<tr>
<td>Hypothyroidism</td>
<td>Thyroid</td>
<td>2.3</td>
</tr>
<tr>
<td>Thyroiditis</td>
<td>Thyroid</td>
<td>140</td>
</tr>
<tr>
<td>Cataracts</td>
<td>Eye lens</td>
<td>1.3</td>
</tr>
<tr>
<td>Suppression of ovulation</td>
<td>Ovary</td>
<td>0.85</td>
</tr>
<tr>
<td>Suppression of sperm count</td>
<td>Testes</td>
<td>0.46</td>
</tr>
</tbody>
</table>
**Stochastic effects**

At all levels of exposure, effects can appear long time after exposure. For both somatic (cancers) and genetic heritable effects the probability of appearance, but not their severity, is taken to depend on the radiation dose; this is why they are called "stochastic" (or unpredictable). The dose-response may be non-linear, as for deterministic effects. However, in contrast to the situation for deterministic effects, for most stochastic effects it is generally accepted that at sufficiently low doses there is a non-zero linear component to the dose-response i.e. there is no threshold.

In cases where irradiation causes small amounts of damage, then the cells can repair themselves. The cells are then able to survive and reproduce. However, genetic damage (DNA change) may have occurred which persists when the cell reproduces. Such damage is the origin of cancers and leukaemia that may arise years after the radiation exposure. They can also lead to damage to offspring if reproductive cells (ovum, sperm cells, etc.) are damaged.

The way to evaluate the individual probability of developing stochastic effects after an exposure to ionising radiation has been scientifically investigated since the beginning of the 20th century through two complementary disciplines: epidemiology and radiobiology. Epidemiology is the study of disease in populations. Disease rates in exposed and unexposed populations can be compared using standard statistical methods (for example the surviving populations of Hiroshima and Nagasaki who were exposed to the atomic bombs have been, and are still, the main source of data on the stochastic effects of radiation). Whereas radiobiology consists of experimental research in laboratories, to study the interaction of radiation with living cells in order to determine the mechanisms of all biological responses at the microscopic (cell) level. Results from both these types of study are used to define a "dose-risk" relationship and provide a quantification of the individual risk associated with radiation at any non-null exposure level.

The International Commission for Radiation Protection (ICRP) defines the individual risk in its Publication n°60 (in 1991) as follows: the probability of a person of dying from a cancer increases by 5% for a received dose of 1 Sievert (1 Sv) cumulated over the whole life. This is an additional risk to be compared with the 25% probability (in our western societies) of dying from a “natural” cancer. It means that a person who has received a lifetime (70 years) dose of 1 Sv has a probability of dying from a cancer which increases from 25 to 30%.

Similarly, an additional annual exposure of 1 mSv/year would increase the individual risk of fatal cancer over the lifetime (70 years) from 25% to 25.035%.

This linear dose-risk relationship with no threshold has served as a basis for the precautionary approach against the stochastic effects of ionising radiation since the 1950s.
Background Radiation: Radiation from cosmic sources, naturally occurring radioactive materials, including radon and global fallout as it exists in the environment from the testing of nuclear explosive devices. The typically quoted average individual exposure from background radiation is 3.6 millisievert per year.

Becquerel (Bq): The unit of radioactive decay equal to one disintegration per second. 37 000 000 000 becquerels = 1 curie (Ci).

Chronic exposure: Exposure that occurs over an extended period of time or a significant fraction of the animal’s or person’s lifetime. This may be continuous or given in multiple small fractions.

Contamination, radioactive: Deposition of radioactive material in any place where it may harm persons, environment or equipment.

Curie (Ci): One of the units used to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 000 000 000 disintegrations per second (Becquerels), which is approximately the activity of 1 gram of radium. It is named for Marie and Pierre Curie, who discovered radium in 1898.

Decay, radioactive: The decrease in the amount of any radioactive material with the passage of time due to the spontaneous emission from the atomic nuclei of particles, often accompanied by radiation.

Deterministic effect: Or non stochastic effect. An effect that can be related directly to the dose received. The effect is more severe with a higher dose, i.e. it gets worse as dose increases. It typically has a threshold, below which the effect will not occur. A skin burn from radiation is a deterministic effect.

Dose: The absorbed dose, given in gray (Gy) represents the energy absorbed from the radiation in a gram of any material. Furthermore, the biological dose or dose equivalent, given in sievert (Sv), is a measurement of biological damage to a living tissue from the radiation exposure.

Dose rate: The ionizing radiation dose delivered per time unit. For example, sievert per hour (Sv/hr).

Dose, external radiation: The dose from sources of radiation located outside the body.

Dose, internal radiation: The dose to organs of the body from radioactive materials deposited and retained inside the body.

Exposure: Being exposed to ionizing radiation or to radioactive material.
**Gray (Gy):** The international system (SI) unit of absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One gray is equal to one joule of energy deposited in one kilogram of a material. The unit gray can be used for any type of radiation, but it does not describe the biological effects of the different radiations. Absorbed dose is often expressed in terms of hundredths of a gray, or centi-grays.

**Radiation (ionizing radiation):** Alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. Radiation does not include non-ionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light.

**Radioactivity:** The spontaneous emission of radiation from the nucleus of an unstable atom. Measured in units of becquerels or disintegrations per second.

**Radionuclide:** An unstable element that decays or disintegrates spontaneously, emitting radiation. Approximately 5,000 natural and artificial radionuclides have been identified.

**Sievert (Sv):** The international system (SI) unit for dose equivalent. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in term of thousandths of a sievert, or milli-sievert. To determine equivalent dose (Sv), the absorbed dose (Gy) is multiplied by a quality factor (Q) that is unique to the type of incident radiation.

**Stochastic effect:** An effect that occurs on a random basis with its effect being independent of the size of dose. The effect typically has no threshold and is based on probabilities, with the chances seeing the effect increasing with dose. Cancer is a stochastic effect.

**Whole-body counter:** A device used to identify and measure the radiological burden in human beings and animals. It uses heavy shielding to keep out existing background radiation and ultra sensitive radiation detectors and electronic counting equipment.