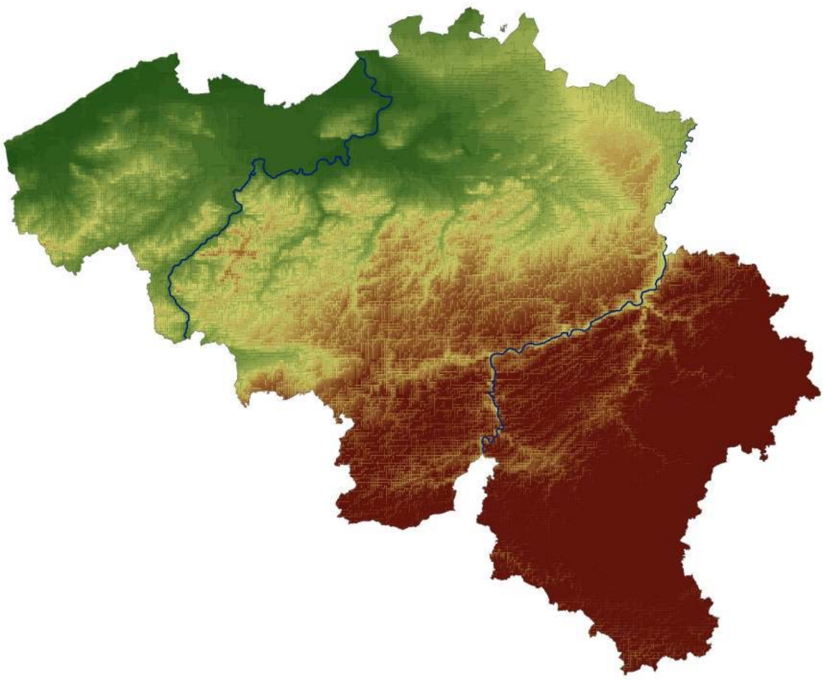
FANC
federal agency for nuclear control

SURVEILLANCE OF THE TERRITORY & NATURAL RADIATION SERVICE

Radiological Monitoring in Belgium

Summary report 2018



- October 2019 -

Federal Agency for Nuclear Control

Health and Environment Department

Territorial Monitoring & Natural Radiation Service

Territorial Radiological Monitoring Unit

Ravensteinstreet, 36. B-1000 Brussels - Belgium
Website: http://www.fanc.fgov.be

Email: info@fanc.fgov.be

Authors:

Lionel SOMBRE, PhD, responsible for the Territorial Radiological Monitoring

Tel.: +32 2 289 21 54 – Fax: +32 2 289 21 52
Email: lionel.sombre@fanc.fgov.be

Jurgen CLAES, MSc. Eng., Environmental Radioactivity Expert – Radiological Monitoring
Tel. : +32 2 289 20 91 – Fax : +32 2 289 21 52
E-mail : jurgen.claes@fanc.fgov.be

Michelle BOUCHONVILLE, scientific assistant.

Tel.: +32 2 289 21 64 – Fax: +32 2 289 21 52
Email: michelle.bouchonville@fanc.fgov.be

Departmental Secretariat: **Tel.: +32 2 289 21 51 – Fax: +32 2 289 21 52**

The following persons have contributed to this report:

- **François MENNESON, ing., responsible for the TELERAD network**
- **Geert BIERMANS, PhD, Environmental Radioactivity Expert – Natural Radiation**
- **Boris DEHANDSCHUTTER, PhD, Environnemental Radioactivity Expert – Natural Radiation**
- **Stéphane PEPIN, PhD, Environnemental Radioactivity Expert – Natural Radiation**

Co-operation with outside institutions

The following institutions and their respective collaborators provided the basic data for this report:

Avenue de l'Espérance, 1 - 6220 Fleurus - Tel : + 32 71 82 95 56 - Fax : + 32 71 81 38 12

Director: Erich Kollegger (Tél. : 32 71 82 95 78)

Head of the project of radiological surveillance of the territory: D. Braekers

Head of the radioactivity measurements laboratory: D. Braekers

Radioactivity measurements supervision:

- Gamma spectrometry: T. Dieudonné
- Alpha spectrometry: S. Di Pasquale
- Liquid scintillation: C. Doumont
- Proportional counting: D. Braekers

Laboratory technicians: S. Carta, J.F. Darimont, A. Demoulin, , B. Lison, D. Tomasevszky

Boeretang, 200 - 2400 Mol - Tel. : + 32 14 33 25 90 – Fax : +32 14 31 89 36

General Director: Éric van Walle (Tel. : +32 14 33 25 90)

Project Manager of the expert group Low-level radioactivity measurements: L. Sneyers

Mesures de Faible Radioactivité :

Supervision and reporting: L. Sneyers / K.Smits
Sampling & preparation of samples: H. Avci, B. Bouwens, W. Gijsbrechts, S. Goelen, K. Smits
Supervision of measurements: F. Verrezen et M. Bruggeman
Measurements: S. Cools, E. Dupuis, S. Goris, A. Hooyberghs, K. Jacobs, L. Jansen, H. Loots, E. Tessens, W. Van Baelen, M. Vanuytven, M. Verbist, L. Verheyen et D. Verstrepen

Food Safety Center, Boulevard du Jardin Botanique, 55 - 1000 Bruxelles

Chief Executive Officer : Herman Diricks, ir (Tel. : +32 2 211 85 75)

Directorate General Control Policy, secretariat: Tel. : +32 2 211 85 81 – Fax : +32 2 211 86 30

General Director Control Policy : Dr. Jean-François Heymans (Tel. : +32 2 211 86 42)

TABLE OF CONTENTS

PREFACE

Radioactivity. A word that often causes concern because of the threat to health it suggests. Nevertheless, we are surrounded by radioactivity without even being aware of it:

- *Natural* radioactivity which reaches us from the cosmos or which is present in the earth's crust, in the waters of the oceans and even in our bodies, and;
- *Artificial* radioactivity, i.e. radioactivity resulting from human activities. Here, a distinction can be made between these activities accompanied by – very weak – discharges of radioactive material into the environment, as in the operations of nuclear reactors to produce electricity, for instance, nuclear medicine through its waste and discharges of radioactive substances by patients, and those which normally entail no discharge such as medical imaging and the sterilisation of surgical equipment or certain foodstuffs. Of course, the sterilisation process does not contaminate the equipment or food and does not make them radioactive.

However surprising it may be, it is in fact natural radiation that constitutes the principal source of exposure of the population to ionizing radiation - under normal conditions and not taking account of medical applications. We are exposed to radiation on a daily basis.

Yet radioactivity, whether it is the result of human activities or of natural origin, is not without risk for humans and the environment. That is why practices involving radioactive substances are strictly regulated. Discharges of radioactivity into the environment, in particular, are strictly limited because they have to comply with strict standards.

However, while regulations reduce the risk, they do not eliminate it entirely. For this reason, the level of radioactivity in the environment has to be regularly monitored to enable appropriate action to be taken where needed. Moreover, enforcing strict regulations does not guarantee that the population will not be exposed, at one time or another, to levels of radiation significantly higher than the level of natural radiation.

Indeed, the possibility of radioactive discharges beyond the authorised limits, or of incidents and even accidents resulting in the dispersal of radioactive substances into the environment cannot be ruled out. Furthermore, radioactivity evidently does not recognise national frontiers: a nuclear accident in another country, even far away, might result in not insignificant contamination on Belgian territory, as was the case in several countries following the Chernobyl accident of 26 April 1986 or the Fukushima accident of 11 March 2011.

In Belgium, the permanent monitoring of the radiological situation of the territory was introduced as a mandatory requirement by EURATOM in 1957 by means of regulations that oblige the Member States to ensure continuous radiological monitoring of their populations and communicate the results of these controls. This monitoring requirement was incorporated into Belgian law in 1963 and was implemented at the end of the 1960s shortly before the first industrial nuclear reactors went into service.

This radiological monitoring of the territory, which originally fell within the competence of the Service for Protection against Ionizing Radiations (SPIR) at the Ministry of Social Affairs, Public Health and the Environment, has since 2001 been performed under the responsibility of the Federal Agency for Nuclear Control, which is charged, in particular, with *controlling the* *radioactivity of the territory as a whole* and *controlling the doses of ionizing radiation received by the population,* and which it endeavours to carry out with total objectivity and transparency[1].

[1]Articles 70 and 71 of the Royal Decree of 20 July 2001 on the general regulations for the protection of the population, workers and the environment against the dangers of ionizing radiation.

BASIC KNOWLEDGE RELATING TO RADIOACTIVITY AND EXPOSURE TO RADIATION

Most atoms are stable: they endure indefinitely without external action. Others have a structure or an excess of energy which makes them unstable: these are *radionuclides,* which can be of natural or artificial origin. Their nuclei are spontaneously transformed until they attain a structure in equilibrium by emitting radiation (energy or particles) on each transformation: they are *radioactive*. This invisible phenomenon is irreversible: after one or more transformations, the radionuclide stabilises into a stable nuclide once and for all.

Types of radiation There are three main types of radiation emitted by radionuclides: *alpha*, *beta* and *gamma*. Their characteristics are very different, with the two first comprising charged particles while the third is electromagnetic in nature (photons), like light, but transporting more energy.

Ionizing radiation By virtue of the electric charge or energy it carries, the radiation emitted by the nucleus is capable of modifying the atoms of the matter it passes through by making them absorb energy or lose a unit of electrical charge, thus transforming them into ions: these are said to be *ionizing.* Deprived of an electron, the atom charges positively and becomes chemically reactive, which can entail lesions and harmful biological effects in living cells.

Unit of radioactivity The unit of measurement of *radioactivity* is the *Becquerel* (Bq), which is equal to one nuclear disintegration per second. A source of radioactivity with an activity of 1 Bq corresponds to a quantity of radioactive substance in which one of the nuclei disintegrates every second. The waters of the oceans, for example, have a natural radioactivity of 12 Bq per litre and the human body, which is also radioactive, has a natural radioactivity of about 120 Bq per kilo, essentially due to the potassium 40 contained in food (about 70 Bq per kilo). In contrast, the radioactivity of radium, a metal discovered in 1898 by Pierre and Marie Curie, is 37 billion becquerels per gram. Radioactivity is measured by extremely sensitive physical methods which enable values of less than one becquerel to be detected.

Unit of measurement of the biological effect Knowing the radioactivity of a radioactive source does not, however, make it possible to foresee the significance of the effects it will entail for someone exposed to such radiation: the biological effect of ionising radiation varies depending on the nature and energy of the radiation, the duration of exposure and the part of the body exposed.

For tissues, this effect is estimated in terms of the *equivalent dose,* which corresponds to the *absorbed dose* expressed in *Grays* (Gy) – i.e. the quantity of energy deposited by the radiation per unit of mass of matter (1 joule deposited in one kilogram of matter) – multiplied by a coefficient taking account of the nature of the radiation and expressing its biological impact on the tissue (equivalent to 1 for photons – gamma and X rays - and electrons – beta rays, 5 to 20 for neutrons, 5 for protons and 20 for alpha particles and heavy ions). Thus, with an equal absorbed dose, the biological effects can be very different according to the type of radiation because, constituted of much heavier particles, alpha radiation will have a much more marked effect than beta radiation. On the other hand, it will be less penetrating.

For the whole body, the effect of ionising radiation is estimated in terms of the *effective dose*, which is calculated from the product of the equivalent dose received at the level of each organ by a risk coefficient specific to each of them and by adding the partial results obtained. This quantity is often erroneously referred to as the "dose". The equivalent and effective dose unit is the *Sievert* (Sv), generally expressed by sub-multiple, thousandths or millionths of a sievert (mSv or µSv respectively).

Dose limits In Belgium, the *statutory dose limits* for ionising radiation are based on European directives, which are themselves based on the recommendations of international organisations. Thus, for the population, the effective dose limit is 1 mSv per year. This does not take account of natural radiation or radiation used for medical purposes. The European directive of 1998 on drinking water stipulates moreover that the total annual dose resulting from the ingestion of drinking water must not exceed 0.1 mSv.

INTRODUCTION

The radiological monitoring of the territory constitutes "environmental screening", so to speak. It is hoped that nothing will be measured or, to put it more precisely, nothing significant. And this is what is actually observed most of the time: artificial radioactivity is much lower than natural radioactivity, with measurements and analyses only revealing extremely weak levels – traces – of radioactivity.

Year after year, this monitoring shows that the radiological situation for Belgium is in general terms excellent. It also reflects the efforts, undertaken by the operators of facilities carrying out activities likely to have a radiological impact on the environment, to reduce these impacts. The operators are not only required to do everything to ensure that their discharges remain below the authorised limits but must also limit their releases to a minimum level (ALARA-principle). By doing this, the operators do not entail a radiological burden for the public.

The radiological monitoring of the territory comprises two complementary parts:

- *Global monitoring of the territory* outside the zones where significant nuclear activity is carried out. It indicates, in particular, the level of radioactivity to which the population is naturally subjected. It particularly covers zones far away from nuclear sites such as the coastal region as well as the so-called "reference" zones such as the Brussels conurbation, which is the largest urban area in Belgium with 10% of the population. Special attention is given to the surveillance of non-nuclear industrial sites and particular landfills;
- *Close monitoring around nuclear sites* where an activity liable to have a radiological impact on the environment is carried out. This essentially concerns the following sites:

  1. the sites of the Doel and Tihange nuclear power stations,
  2. the surroundings, on Belgian territory, of the French nuclear power station at Chooz,
  3. the site of the Nuclear Research Centre (SCK•CEN), at Mol,
  4. the sites of Belgoprocess, Belgonucléaire and Franco-Belge de Fabrication de Combustibles International (FBFC International) at Mol and Dessel,
  5. the sites of the National Institute of Radioelements (IRE – Institut National des Radioéléments), MDS-Nordion, Sterigenics and ion Bean Applications s.a. (IBA) at Fleurus (industrial zone).

  The monitoring around these installations and nuclear sites has a large number of objectives:

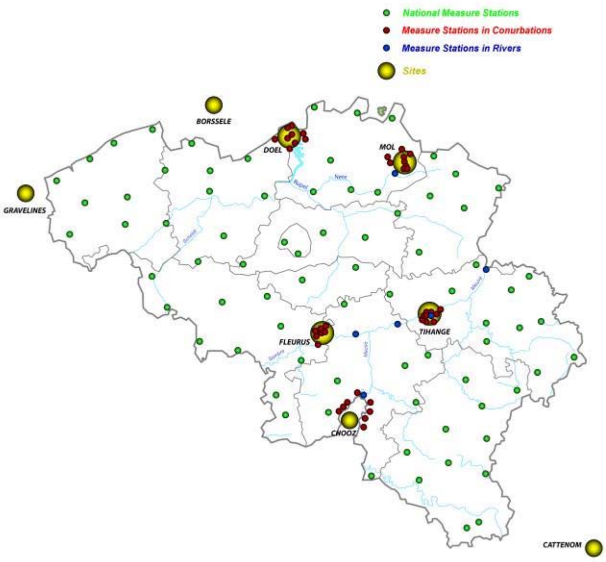
  1. ensuring that the legal and regulatory provisions concerning environmental contamination remain respected,
  2. checking through the control of discharges into the environment that these comply with the standards and authorised limits,
  3. if necessary, assessing the potential doses received by particular sections of the population,
  4. informing the public in an objective manner.

  Close monitoring also applies to installations where radionuclides are used, such as hospitals, universities or particular non-nuclear industries (NORM-industry). Also landfills, mostly from phosphogypsum, are monitored.

In practice, the radiological monitoring of the territory, which deals with the level of both artificial and natural radioactivity, is conducted in two ways:

- In a *continuous* way, by the automatic TELERAD network for measuring local ambient radioactivity;
- In an *intermittent* way, via periodic measurement of the soil and taking samples for analysis.

The TELERAD network is primarily *a measurement and early warning network.* Its 245 radioactivity measuring stations constantly measure the overall radioactivity of the air, atmospheric dusts and river waters (Meuse, Sambre, Scheldt and Molse Nete). These stations are linked to a centralised system which they alert automatically if they detect any abnormal rise in radioactivity levels. The TELERAD network is supplemented by 13 meteorological masts (9 of 10 meters and 4 of 30 meters) that measure wind speed and direction and by 24 mobile measuring stations that can be deployed at any location on the territory.



In the event of a nuclear accident, the discharge of radioactive substances into the atmosphere could lead to the launch of the nuclear emergency plan foreseen by the authorities. The TELERAD network would then play a crucial role in assessing the gravity of the accident, taking decisions, optimising interventions and measures to be implemented to avert the effects of the accident and, subsequently, to remedy them, as well as informing the population on an ongoing basis.

In normal circumstances, the TELERAD network measures the ambient dose rate due to gamma radiation. This dose rate is linked to the level of natural radioactivity, also called background radiation.

The sampling and measurement campaigns on the ground are the *real cornerstone* of the radiological monitoring of the territory. They make it possible to refine the radiological profile of the Belgian territory and must enable the levels of natural and artificial radioactivity in the environment to be precisely evaluated and radiation doses to which the population is subjected to be assessed. They therefore systematically target the main areas of the environment and the principal components of the food chain liable to be contaminated and to which the population may be exposed: the air, atmospheric dusts, rain, river, sea and drinking water, the soil, river and marine sediments, river and marine flora and fauna, milk, meat, fish, vegetables, etc.

The samples are taken for the Agency by specialised teams from SCK•CEN and IRE-Elit. The frequency of sampling has been defined in such a way as to be in possession of information that is as useful as possible, while taking account of technical and material constraints. The samples are then analysed in the laboratories of these institutions in order to determine the nature and level of radioactivity contained in them in very precise terms.

These analyses measure the alpha, beta or gamma emitting radionuclides, either in a general or specific manner. In the latter case, they attempt, in particular, to measure natural radionuclides (such as beryllium 7 and potassium 40) which serve as reference points and radioactive nuclides characteristic of specific human activities (such as radioactive nuclides linked to the manufacture of fuels powering nuclear reactors, radioactive tracers used in nuclear medicine, and radium 226, a natural radionuclide often found concentrated in the liquid effluents of the production process for feed phosphates). The results obtained are then centralised, analysed and interpreted by the Agency.

The Agency reviews when necessary its sampling and measurement programme in order to completely harmonise it with international requirements. The 1998 98/83/CE European directive replaced by the EURATOM directive 2013/51/EURATOM on drinking water had imposes stronger controls, with new requirements in terms of control and the reporting of radiological surveillance data to the European Commission resulting from the application of Article 36 of the EURATOM treaty. Finally, the OSPAR Convention (OSlo-PARis Convention, 1998 – ratified by Belgium) on the protection of the marine environment of the North Sea and North-East Atlantic makes the development of monitoring and research programmes concerning the impact of radioactive discharges on the marine environment mandatory.

The programme for the radiological monitoring of the territory currently relies on approximately 4,330 samples annually, which are subjected to more than 19,200 alpha, beta and gamma radioactivity analyses. In relation to the Belgian population and nuclear installations, the scope of this programme is within the average of the programmes of other countries with nuclear power stations, such as the United Kingdom and France.

The radiological monitoring of the territory, which makes it possible to obtain an accurate picture of environmental radioactivity in Belgium and the risks to the population, does not reveal any major problems. Most of the time, the radioactivity of artificial origin is considerably lower than radioactivity of natural origin, if it can be measured in the samples taken at all. Nuclear power stations, in particular, have a negligible or even undetectable radiological impact on the environment. Any anomaly detected by the agency or brought to its attention is, of course, examined and dealt with in the appropriate manner.

This report summarises the results of the monitoring programme obtained for 2017. After a short introduction to the TELERAD network and the key concepts of the radiological monitoring programme, it gives a summary of the radioactivity measurements carried out in:

- the Meuse and Sambre basins;
- the Scheldt and Nete basins;
- the maritime zone;
- the reference zone (Brussels Capital region);
- the foodchain;
- The monitoring of NORM-sites (impact as a result of historical activities and of installations still in operation) who are generating a supply of natural radioactivity in the environment);

for the major parts of the biosphere (air, soil, water and biocenosis) as well as in the main constituents of the food chain, supplemented with independent controls of the liquid discharges of the main nuclear sites. The raw data are available on request.

SUMMARY

The radiological surveillance programme of the territory is based on an radionuclides of harmonised libraries measured for the entire territory and taking account of the requirements of the relevant international bodies (European Commission, OSPAR in respect of the Sintra agreements under the policy to protect the North Sea and the Atlantic).

This programme – with approximately 4,330 samples giving rise to more than 19,200 radioactivity measurements – enables better monitoring of the different regions of the country while taking account of their specific nature. Comparisons between sections of each region and between regions themselves have been made easier.

The radiological situation is generally excellent:

The radiological monitoring of the territory, which makes it possible to obtain an accurate picture of environmental radioactivity in Belgium and the risks to the population, does not reveal any major problems. Most of the time, the radioactivity of artificial origin is considerably lower than radioactivity of natural origin, if it can be measured at all in the samples taken.

The radiological monitoring of the territory also clearly shows that the dose rate (ambient radioactivity), in normal conditions and medical exposures not included, particularly depends on the nature of the soil: the rocky soil in the south of the country emits more radon (natural radioactive gas) than that in the north of the country (sandy soil). It is for this reason, for example, that the dose rate measured in Wallonia is greater than that measured in the vicinity of the Doel nuclear power station, which itself has a negligible impact on the environment.

Nuclear power stations, in particular, have a negligible or even undetectable radiological impact on the environment. Of course, any anomaly detected by the agency or brought to its attention is examined and dealt with in the appropriate manner.

Particular attention is required:

The radiological situation of the Belgian territory is perfectly satisfactory; however, one basin, i.e. the entire Laak-Winterbeek-Nete-Scheldt hydrographic network, still arouses attention on account of its abnormally high charge of both artificial and historical natural radioactivity (^{226}Ra). This concerns the entire Laak-Winterbeek-Nete-Scheldt hydrographic network.

Certain nuclear facilities in the Mol-Dessel region have a measurable, though small, radiological impact on the environment. The same applies to the non-nuclear industry producing feed phosphates in the region of Tessenderlo, that discharged ^{226}Ra. The phosphate unit of this industry is now being dismantled which severely limits the effluent of radium. On the other hand, the – measurable – radiological impact of these installations in the north-east of the country has declined sharply in recent years.

1. THE CONTINUOUS RADIOLOGICAL MONITORING OF THE TERRITORY: THE TELERAD NETWORK

The TELERAD network is the automatic remote radioactivity measuring network in Belgium. It comprises 245 radioactivity measuring stations, which constantly measure the radioactivity of the air and river waters. The measuring stations are distributed throughout the entire country, around the Tihange, Doel-Dessel, Mol and Fleurus, as well as in the urban areas close to these installations and in those around the Chooz nuclear installations in France. These measuring stations are linked to a centralised system which they alert automatically if they detect any abnormal rise in radioactivity levels.

1.1 OBJECTIVES OF THE NETWORK

The TELERAD network is a *measuring and early warning network* and, as such, pursues the following two major objectives:

- The continuous recording of measurements to provide all necessary statistical information on the level of radiation found in the country;
- The setting off, without delay, of an alarm to signal the exceeding of a warning threshold.

TELERAD is thus an alarm network that enables the real-time detection of any abnormal situation, which may lead at its highest level of severity to the launching of the Emergency Plan for Nuclear Risks.

In the event of a nuclear accident, TELERAD will play an important role in the taking of decisions, optimising interventions and countermeasures implemented by the relevant authorities as well as keeping the country's citizens informed on an ongoing basis.

1.2 TELERAD: RADIOLOGICAL INSTRUMENT

The measuring stations used in the TELERAD network for measuring radioactivity in the air are of four types:

The **dosimetry stations** (Geiger Müller detector type) for measuring the ambient gamma radioactivity, of which there are 159 on the territory (including those around the boot of Givet for monitoring the Chooz nuclear site). This year, additional stations were placed on the territory to strengthen the radiological surveillance.

Each measuring station is equipped with a rain detector which provides information about the presence and duration of rainy periods. Following photographs show a station in the environment with a view on its electronics.

The 67 **gamma spectrometry stations** (NaI detector) for measuring the <u>ambient gamma radioactivity and the gamma radioactivity of some radionuclides</u> (10 predefined nuclides), are localized on the fences around nuclear sites of SCK•CEN and BELGOPROCESS, nuclear power stations of Tihange and Doel as IRE. Photographs show a station in its environment.

Three spectrometric stations have been added around the BELGOPROCESS site in 2018. These stations have the particularity of being powered by solar panels and can be moved by means of a trailer.

The **aerosol stations** (ZnS detector), of which there are 7 for measuring the radioactivity of dusts suspended in the air (aerosols and fine particles), which determine the total alpha and total beta radioactivity.

The photograph on the left shows the alpha/beta measuring unit with a view of the unreeling filter tape which collects the dusts and particles impacted when the air is pumped.

These stations are supplemented by a unit measuring radioactive iodine on the aerosols and the air particles when a pre-determined threshold of beta radioactivity is exceeded (7 units in total coupled with alpha/beta measurement). The photograph on the right shows the detector in its casing (cylinder) and the parallelepipedal tube containing the active charcoal cartridges (on the right).

If the warning thresholds are exceeded, active carbon cartridges, intended to trap the radioactive iodine, are automatically measured after pumping the outside air in order to determine the level of radioactivity.

TELERAD also has 8 **river stations** which continuously measure the gamma radioactivity of river waters. These stations are of two types:

Retrofit : this type of station (6) is installed close to the three rivers receiving discharges from nuclear sites and waste water from major urban centres (combining research centres, universities and hospitals): the Meuse, the Sambre and the Nete.

These stations are large containers from which two inlet and outlet pipes allow river water to be pumped to the detector and returned after radioactivity has been measured – photograph on the right.

On the far left of the photograph, a programmable automatic sampler (Buhler type PP MOS) enables water to be pumped into flasks for gamma, alpha and beta spectrometry (for the programme for the radiological monitoring of the territory).

The photograph here below shows the inside of the PP MOS with the pumping instruments in its upper section and all the 2.9-litre flasks (12 in all) at the bottom base.

This fully programmable unit enables pre-determined volumes of water to be collected over a fixed time period and frequency.

Above the PP MOS are the counting unit and the high voltage supply of the river station detector.

Inside is the gamma spectrometry unit ($LaBr_3$ crystal coupled to multi-channel analyser) housed in its own tank, surrounded by a strong lead screen protected by a stainless steel casing in which the water pumped from the river enters and leaves – photograph on the left. Ten radionuclides are defined in the recognition software.

To the left of the gamma spectrometry unit is a large volume water sampler (SwedMeter type) which enables a sample of the water in the pipe to be taken automatically as soon as an alarm level is exceeded. This water is stored in a 25-litre flask for the purpose of subsequent gamma (and beta) spectrometry analyses in the laboratory.

BCI : these stations have their probe directly immersed in river water. They are two in number; located in the Scheldt downstream and upstream of the Doel nuclear power plant.

TELERAD also has 4 **stations (*BCI*) in the release channels of the nuclear power plants** which continuously measure the <u>gamma radioactivity of the releases:</u> one in the release channel of the nuclear power plant of Doel and three in the release channels of the nuclear power plant of Tihange. These stations allow to monitor the liquid discharges from the electricity producers with close attention.

these stations also have a $LaBr_3$ detector which is coupled to a multichannel detector. Ten radionuclides are defined in the recognition software.

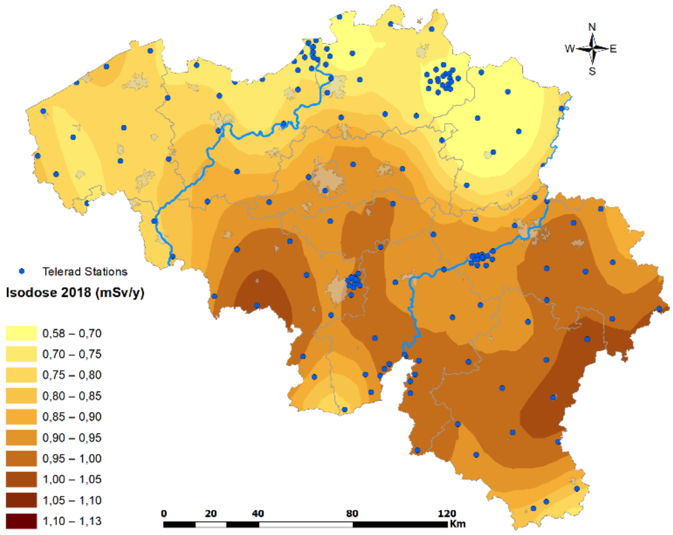
1.3 TELERAD: METEOROLOGICAL INSTRUMENT

Along the borders and around nuclear sites, TELERAD also has 9 meteorological measuring instruments (wind speed and direction) installed on 10 m masts. There are also 4 additional 30 m meteorological masts located near the nuclear sites (wind speed and direction, pluviometry, sunshine) – photograph on the left.

These data are essential to detect quickly the origin of any foreign source of radioactivity and, depending on the wind speed and direction, to forecast what regions may be over-flown by a radioactive cloud and at what time this will happen.

Finally, the TELERAD network is supplemented by a set of 24 mobile stations for the measurement of ambient gamma radioactivity. These stations can be deployed throughout the entire Belgian territory depending on the measurement needs.

1.4 TELERAD: INSTRUMENT FOR CALCULATING THE EXTERNAL EXPOSURE DOSE RATE



Since the TELERAD network measures a dose rate (µSv/h) continuously, it is possible to calculate the annual gamma exposure dose on a station-by-station basis. A group of values – only slightly different in value - can be brought together under the same colour by aid of a mathematical interpolation, enabling zones or surfaces where measurements are in a same value range to be represented on a map.

The map on the left shows the outcome of such processing which results in the construction of an illustrative map (because build up on basis of relatively limited detectors) of the natural background radiation due to gamma radioactivity. This background noise represents the annual exposure expressed in mSv (external gamma exposure dose) to which the territory is subjected.

An analysis of the exposure map shows that the average gamma exposure dose in Belgium is 1 mSv/year; it increases from 0.6 to 0.7 mSv/year in the north to about 0.8 - 0.9 mSv/year overall in Flanders until 1.0 to 1.1 mSv/year in Wallonia and, more particularly, in the Ardennes.

The exposure varies according to the nature of the soil. The doses are, indeed, generally higher in old terrains made up of rock such as chalkstone, schist, psammite and mixed sands with chalk etc. which is the case for Belgium in the Ardennes and Condroz area – see the geological map opposite. In Flanders, where the soil is predominantly made up of sedimentary terrains (sand, alluvium and clay), the doses are lower. It is noted that, in the south of the country, i.e. a marly, clayey region with sandy-silty layers over a chalk sub-stratum, the dose declines to reach values comparable to those in the north of the country.

The limit for the dose of ionizing radiation in the population, set at 1 mSv/year, does not take account of the natural radiation linked to cosmic radiation or the radiation of the soil and subsoil or the radiations used for medical purposes. Consequently, it does not apply in this case (natural ambient background noise).

2. UNDERSTANDING THE TERRITORIAL RADIOLOGICAL MONITORING PROGRAMME

2.1 ORIGIN OF THE RADIOACTIVITY MEASURED IN BELGIUM

The radioactivity that can be measured in Belgium and everywhere in the world has two origins: a *natural* origin and an *artificial* origin.

Natural radioactivity is due to *cosmic radiation* itself, which comprises two components: a relatively constant component, the primary galactic radiation consisting of very energetic particles – 85% protons, 12.5% helium and 1% heavier atoms such as iron and nickel, 1.5% electrons and a variable, the solar radiation or the solar wind which follows an eleven year cycle and which also fluctuates randomly when there are big solar flares that release an important flow of lower energy particles which can also reach the Earth.

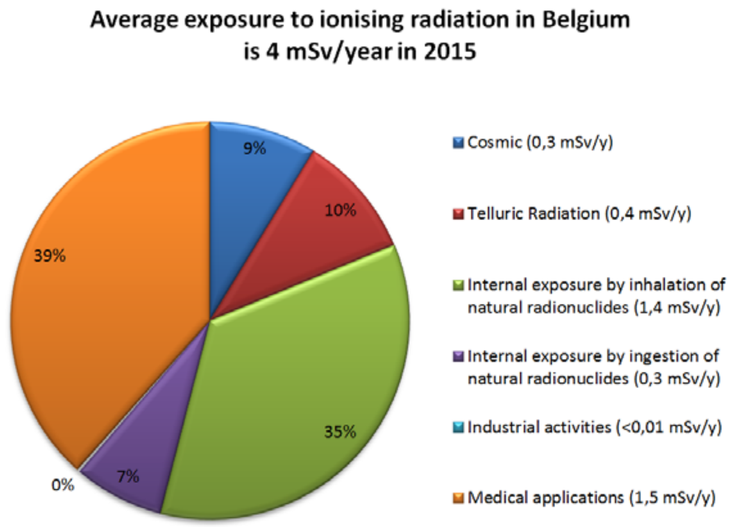
All these particles pass through the high layers of the atmosphere which partially "filter" them in order to reach the ground and living organisms and create a family of so-called "cosmogenics" such as $^{7,10}Be$, $^{32,33}P$, ^{22}Na, ^{35}S, ^{39}Cl, ^{26}Al, ^{14}C and ^{3}H.

This natural radioactivity also has a terrestrial component: *telluric radiation* which is generated by natural radionuclides present in the ground and underground water such as:

- The primary constitutive nuclides of the solar system, i.e. namely radionuclides with very long physical periods or half-lives (time required for half of the radioactivity to disappear) such as $^{235,238}U$, ^{40}K, ^{232}Th, ^{187}Re, ^{138}La, ^{147}Sm, ^{190}Pt;
- The nuclides brought about directly or indirectly by nuclear reactions due to the incidental cosmic radiation, such as ^{239}Pu, ^{237}Np, ^{30}Cl, ^{90}Sr and other fission products generated by the neutrons (and the 'cosmogenic' nuclides referred to previously, generated by the cosmic radiation itself).

In addition to this natural radioactivity, there is anthropogenic radioactivity generated by human military, industrial, research and medical activities. A number of these activities are carried out in Belgium:

- The nuclear industry (including that located abroad but situated close to our borders, such as Gravelines, Chooz and Cattenom the nuclear power stations in France and Borssele in the Netherlands) represented by the nuclear power stations of Doel on the Scheldt (four power reactors) and Tihange on the Meuse (three power reactors), as well as the facilities of Belgoprocess 1 and 2, Belgonucléaire, FBFC international and IRE;
- The NORM industry;
- Nuclear research in laboratories such as those of SCK•CEN and universities;
  - In recent years, the radiological services (and in a lesser extent the nuclear medicine) in hospitals are mainly responsible for the increasing part of the average exposure of the population, particularly among the older age groups in Belgium, rising from a typical 25 %-30 % around the year 1995 to more than 45 % at the year 2006 and following (2.1 mSv/year in 2006, 2.3 mSv/year in 2010). Efforts to optimize the dose to patients and the gradual modernization of the radiological park have halted this increase and even reduced it to 38.4% in 2015 (1.53 mSv/year) as shown below in Figure 1 (average exposure in 2015).



The entirety of this radioactivity is responsible for the overall exposure of people living on the territory of Belgium (~ 4.0 mSv/y). This exposure or dose – expressed in mSv – is essentially due to natural radioactivity and exposures of medical origin. Each state has a duty to monitor the levels of natural and artificial radioactivity to which its population is potentially subjected. This obligation is clearly specified in the legal texts defining the legal and regulatory framework applicable in Belgium.

2.2 LEGAL AND REGULATORY FRAMEWORK

The legal and regulatory framework applicable in Belgium with regard to radiological monitoring of the territory comprises two parts: the national legal framework and the European regulatory framework. The obligations associated with these frameworks have a direct impact on the direction assigned to the programme for radiological monitoring of the territory as well as on its scope. In both cases, the federal authority FANC is responsible for implementing all the means necessary to meet the regulatory requirements.

2.2.1 National legal framework:

The Federal Agency for Nuclear Control (FANC) is a public body endowed with a legal personality (category C public interest institution), established by the law of 15 April 1994 *on the protection of the population and the environment against the dangers resulting from ionising radiation and relating to the Federal Agency for Nuclear Control* (Articles 21 and 22). This statute grants it broad independence, which is essential for exercising impartially its responsibilities towards society.

The FANC has been fully operational since 1st September 2001, with the royal decree of 20 July 2001 concerning the *General regulations for the protection of the population, workers and the environment against the dangers of ionising radiation (GRPIR)* coming into force on that date. This decree renders the implementation of the law of 15 April 1994 effective and specifies the conditions and modalities for the execution of the Agency's duties. It comprises the greater part of the Belgian regulations with regard to protecting the population and environment against the dangers of ionising radiation.

Under the decree, the Agency is charged in particular with *monitoring the radioactivity of the territory and the doses received by the population* (Article 70) as well as organising the *monitoring of the population as a whole* (Article 71).

It should also be noted that the Franco-Belgian cooperation agreement of 8 September 1998, relating to the Chooz nuclear power station situated on the Meuse in France close to the border with Belgium, provides for ensuring the full monitoring on Belgian territory of all the ways of radioactivity transfer around the nuclear site as well as the periodic exchange of results between states.

The articles 4 and 9 of the GRPIR define the regulative framework concerning the "professional activities involving natural radiation sources" (NORM industries). On the basis of these articles, FANC can require a follow up of the environmental impacts of certain NORM industries.

The article 72bis of the GRPIR on *interventions and lasting exposures* defines the regulative framework for sites historically contaminated by radioactive substances. This article gives the FANC the task to assure the possible implementation of a surveillance of the related exposures.

2.2.2 International legal framework:

European Commission:

Belgium, like every other Member State of the European Union, has to meet the requirements of the European Commission (EC) under Article 36 of the EURATOM treaty to communicate data on the monitoring of radioactivity in the environment (radioactivity of the air and air dusts, surface and drinking water, milk and foodstuffs).

This covers the new provisions on monitoring the food chain resulting from the post-Chernobyl protection measures, post-Fukushima as well as the 2000/473/EURATOM[2] recommendation concerning Article 36 of the EURATOM treaty, which stipulates under point 4 that the Member States must communicate to the Commission the data necessary for monitoring radioactivity in the "mixed regime" in order to obtain overall information on the ingestion of radioactivity by humans through the food chain and, thus, on the doses released.

Since 2017, Belgium faces the obligation to control a large number of catchments, springs, etc.. for the production of drinking water, particularly in Wallonia. Indeed, the EC decided to treat the aspects "radioactivity" in the context of the new 2013/51/EURATOM Council Directive - specific - published 22nd October 2013. The technical annexes dealing with radioactivity, completed for many years, are directly incorporated into this new Directive as well as radon and its decay products with a long half-life (^{210}Po and ^{210}Pb). Natural spring waters, bottled and those distributed in large packages (fountains, cubitainers, ...) are included in the Directive. Water intended for the food industry are also concerned. The former Directive 98/83/EC of 3 November 1998 will be renewed but will deal only with aspects of biology and chemistry of drinking water.

Belgium transposed this Directive into national regulation on 31 May 2016 (Royal Decree on the protection of the health of the population with regard to radioactive substances in waters intended for human consumption). This Royal Decree is supplemented by the Agency Order (FANC) of 24 November 2016 (Decree on the implementation rules for the control of radioactive substances in water intended for human consumption)..

OSPAR (OSlo-PARis) Convention:

The Convention on the protection of the marine environment of the North-East Atlantic – the "OSPAR Convention" – was opened for signature at the ministerial meeting of the Oslo Commission (set up in 1972) concerning the dumping of waste at sea and the Paris Commission (set up in 1974) relating to marine pollution of telluric origin on 22 September 1992 in Paris.

The Convention was signed and ratified by all the original contracting parties to the Oslo and Paris Conventions (Belgium, the Commission of the European Communities, Denmark, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden,

[2] *Commission recommendation on the application of Article 36 of the EURATOM treaty concerning the monitoring of levels of radioactivity in the environment for the purpose of assessing the exposure of the population as a whole*

the United Kingdom and Northern Ireland, as well as by Luxembourg and Switzerland). The OSPAR Convention of 1992 is the current instrument directing international co-operation on the protection of the marine environment of the North-East Atlantic.

The OSPAR Convention came into force on 25 March 1998. Although it replaces the Oslo and Paris conventions, the decisions, recommendations and all other agreements adopted pursuant to these previous Conventions will remain applicable and retain the same legal character unless abrogated by the new measures adopted pursuant to the 1992 OSPAR Convention.

The first ministerial meeting of the OSPAR Commission in Sintra, Portugal in 1998 adopted Annex V to the Convention in order to extend the co-operation of the contracting parties and to cover all human activity which could harm the marine environment of the North-East Atlantic. However, programmes and measures on fisheries management issues cannot be adopted under the Convention.

The OSPAR declaration on the protection of the North Sea and the North-East Atlantic signed in Sintra on 23 July 1998 provides for a drastic reduction in radioactive discharges into the marine environment in order to achieve concentrations "close" to zero for artificial radioactivity and "near" background levels for added natural radioactivity on account of human industrial activity.

It should also be taken into account that the European Commission is increasingly supportive of the OSPAR strategy to the extent that, among other things, it urges the Member States to invest in fundamental research programmes concerning the impact of radioactivity in the marine environment (flora, fauna and humans) and it has very recently adopted the idea of an overall marine strategy (concerning all European seas), particularly for radioactivity, which in this case embraces the OSPAR objectives in full.

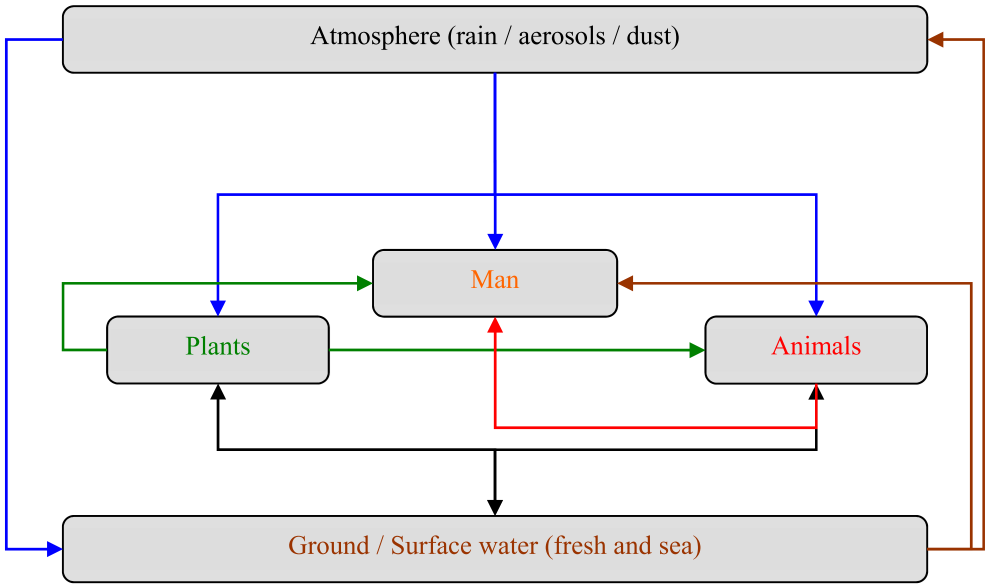
The International Atomic Energy Agency (IAEA) is in line with the trends expressed above.

2.3 PROGRAMME FOR THE RADIOLOGICAL MONITORING OF THE TERRITORY

The development of the legislative approaches described above has led to a broadening of the concept of radiological monitoring of the environment in the direction of protecting the environment itself including all its components (especially the marine environment) in addition to humans. To achieve this, the focus has switched away from the notion of the dose considered in radiation protection in favour of that concerning the concentration of radioactive nuclides, to be determined by a large number of measurements conducted on a very broad sample of components of the environment (air, water, soil, living beings).

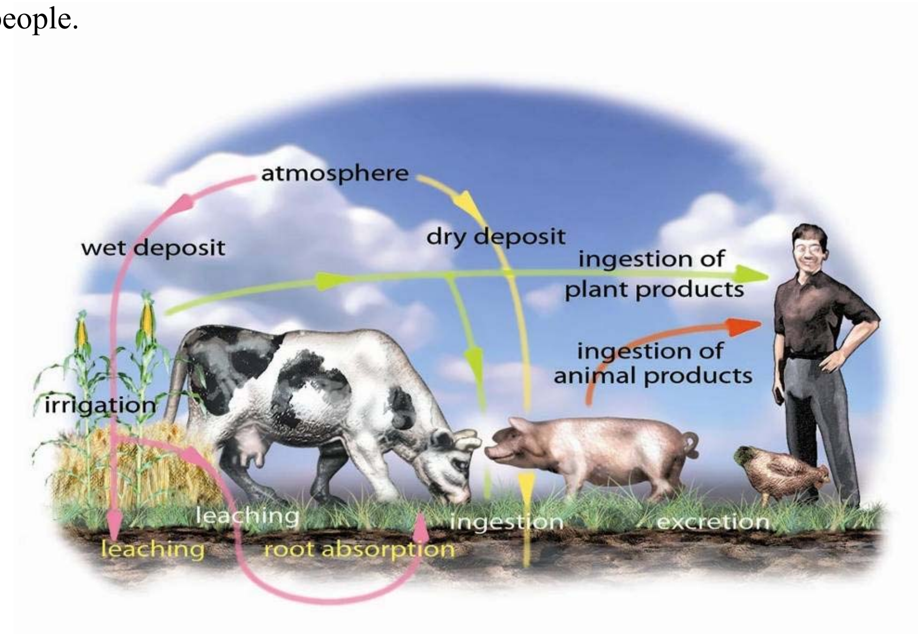
As already explained, the radiological monitoring of the territory is carried out through a programme of radiological surveillance relying on sampling and analyses (measurements of radioactivity) as well as the automatic TELERAD network, which essentially conducts measurements of dose rates at fixed points. These major means of monitoring are organised in such a way as to cover the entire territory and permit the exposure of the population to be monitored according to the various possible ways of exposure.

As illustrated by the following simplified diagram, natural and artificial radioactivity can circulate in the environment by passing from one area to another to finally reach a person through inhalation, ingestion or contamination through wet or dry deposits (rain, aerosols dust).



Depending on its chemical nature, this radioactivity is more or less concentrated in particular areas, e.g. in the clays (constituent of the soils, sediments) for the radiocaesiums which "follow" the movements of the potassium regarded as their "chemical analogue". In animals, the radiocaesiums tend to be concentrated in the muscles (meat). The radiostrontiums, for their part, follow their chemical analogue – calcium, and accumulate in the osseous structures of living beings.

The following diagram illustrates the path that radioactivity can follow to contaminate the food chain and people.



In order to monitor the environment correctly, FANC has developed its territorial monitoring programme along several lines:

- Responding to the primary duty of monitoring and protecting the environment and the population by taking account of the nuclear sites in Belgium and neighbouring countries;
- Responding to the requirements of international organisations to which Belgium adheres: EC and OSPAR convention.

In practical terms, the libraries of radioactive nuclides sought to be measured have been adapted to respond optimally to these duties and requirements. Depending on the type of facilities at the nuclear sites, the type of practices and the more specific nature of some such practices, a number of radioactive nuclides have been systematically added to the lists of radionuclides to be sought, e.g.:

- In the surroundings of IRE: iodine (^{131}I) because it may be produced by this site;
- In the waters of the Sambre, Meuse and Scheldt: iodine (^{131}I) by virtue of their receiving waste water from the hospitals in the major urban areas adjacent to them;
- In the Molse Nete: transuranic nuclides – $^{234,235,238}U$, $^{238,(239+240)}Pu$, ^{241}Am, in addition to the usual array of gamma emitters (fission and activation products including radiocaesiums) by virtue of this watercourse receiving liquid discharges from the nuclear installations of the Mol-Dessel site via the liquid waste treatment installations of Belgoprocess 2;
- In the Nete and Demer basin: ^{226}Ra by virtue of these streams draining the waters of the Grote Laak and Winterbeek where the Tessenderlo facility have produced feed phosphates (NORM-industry) and discharged its process water enriched with radium;
- In milk and drinking water: ^{90}Sr (fission product originating in nuclear reactors and nuclear fuel reprocessing plants) to meet the requirements of Article 36 of the EURATOM treaty;
- In control meals: ^{14}C produced in nuclear reactors is always verified in the context of reporting to the EC under “Article 36” of the EURATOM treaty;
- In samples of marine fauna and flora (shrimps, mussels, seaweed): transuranic nuclides – $^{234,235,238}U$, $^{238,(239+240)}Pu$, ^{241}Am, in addition to the usual array of gamma emitters (including radiocaesiums), ^{90}Sr, ^{99}Tc and organic ^{3}H as indicators of activities of the nuclear power industry – nuclear power and reprocessing plants – used nuclear fuel reprocessing plants – La Hague (France) and Sellafield (United Kingdom);
- Under Article 36 of the EURATOM treaty: natural “control” radionuclides such as (cosmogenic) ^{7}Be required by the EC, ^{40}K present everywhere in the environment and in the human body (at a level of around 60 to 70 Bq/kg).

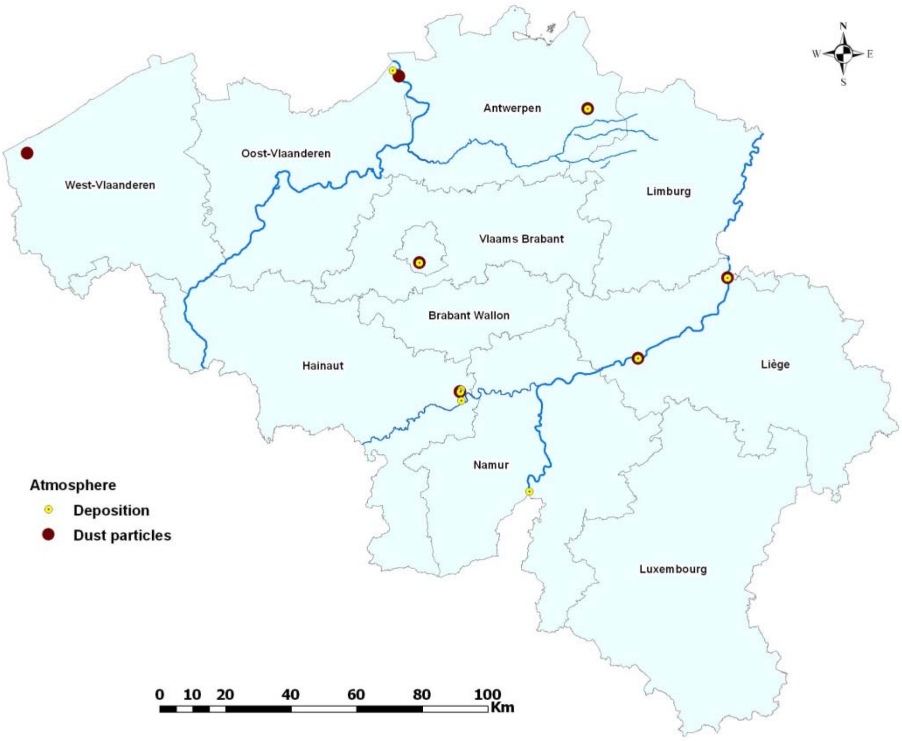
2.4 DESCRIPTION OF THE TERRITORIAL RADIOLOGICAL MONITORING NETWORK

The monitoring network comprises a series of zones, i.e. locations where samples are taken and subsequently brought to the laboratory to be prepared and then measured to determine their level of radioactivity. Around 4,330 samples are taken each year on which more than 19,200 radioactivity analyses are conducted.

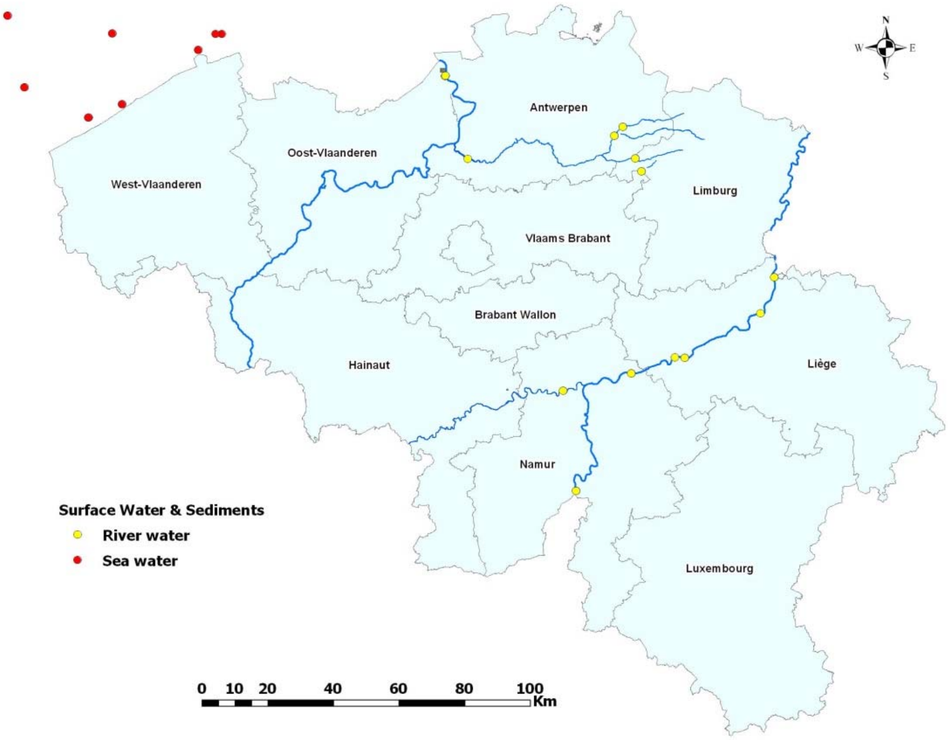
2.4.1 The main lines of the network:

The main lines of the radiological monitoring network relate to:

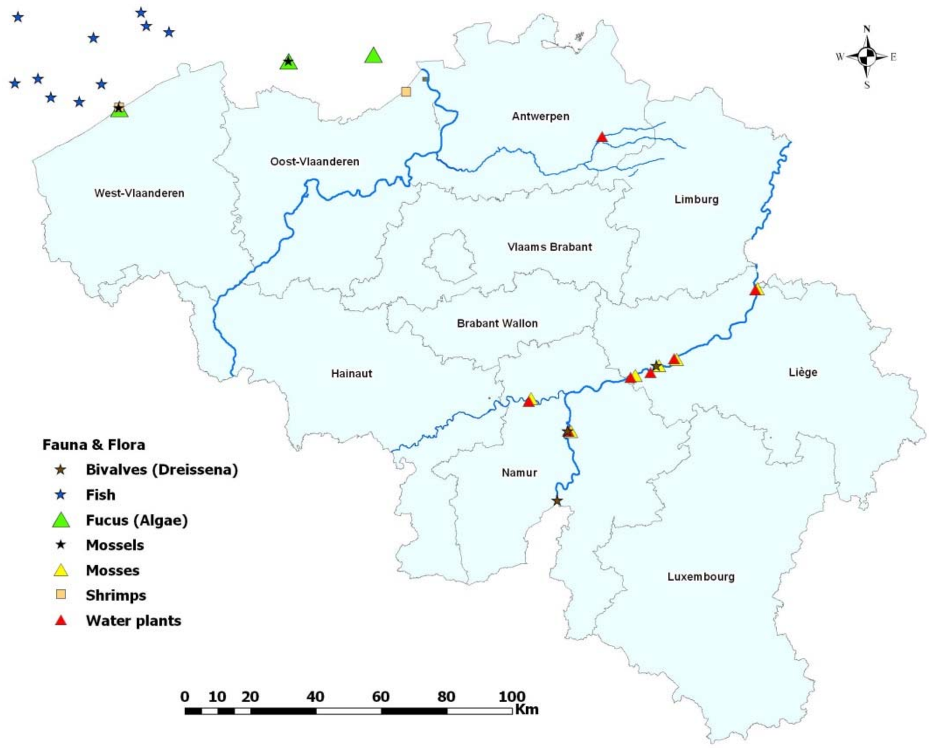
- Monitoring the atmosphere in the vicinity of the nuclear sites and in the reference zone Brussels Capital, in Coxyde (at the Nord Sea coast end of the West coast of West-Flanders) and in Lixhe at the Meuse (nearby the border of The Netherlands) by means of sampling air dusts (brown points) and surface deposits by means of dry deposits of particles and/or wet deposit by rain in tank collectors with known surface area containing a thin layer of water to trap the fine particles (yellow points);



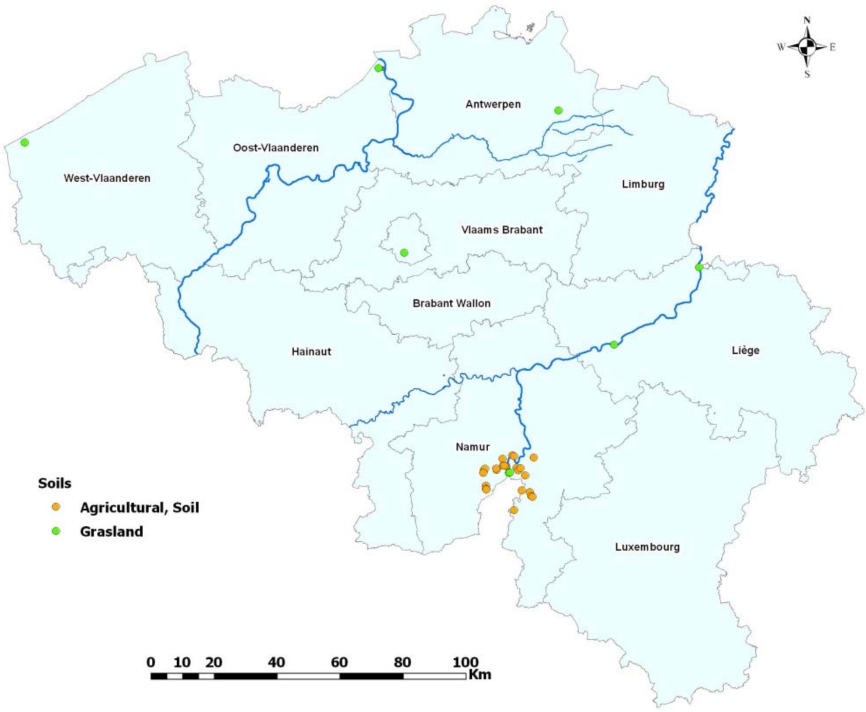
- Monitoring <u>surface water</u> and <u>sediments</u> in fresh – rivers (Sambre, Meuse, Grote Laak, Winterbeek, Grote Nete, Molse Nete and Scheldt) and marine water – North Sea;



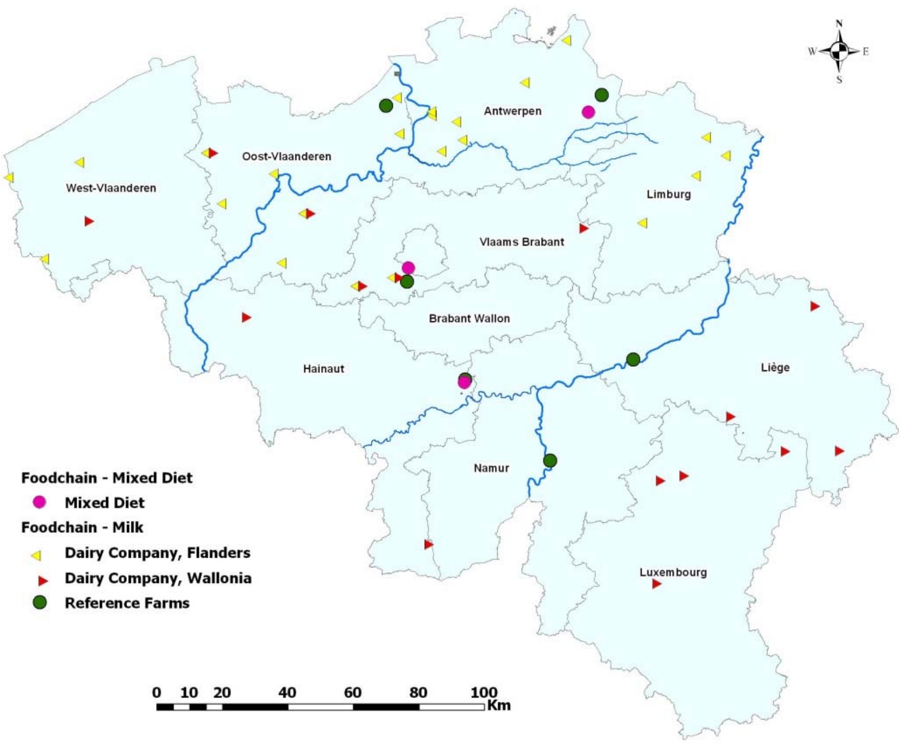
- Monitoring the <u>living environment</u> by searching for radioactivity in fauna in fresh and salt water (molluscs from fresh and salt water, shrimps and fishes) and in flora in fresh water (aquatic plants and mosses) and seawater (algae) who are <u>bio-indicators</u> of the presence of radioactivity;



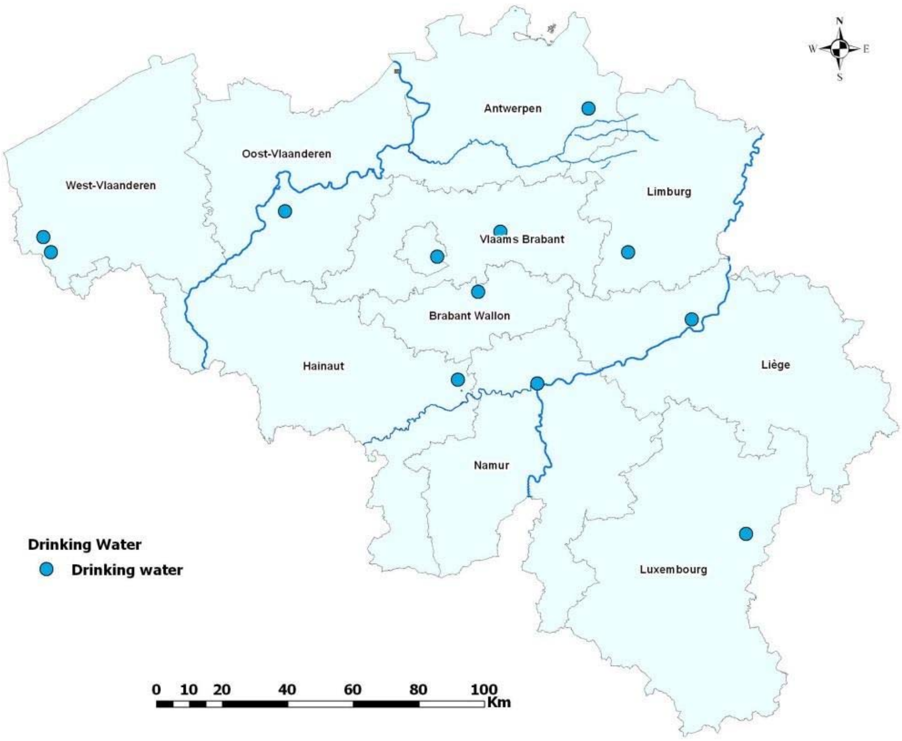
- Monitoring terrestrial zones, i.e. soils sampled in the immediate vicinity of nuclear sites and certain control regions (sea coast, Brussels Capital region) in green as well as in the agricultural zones around the booth of Givet in orange;



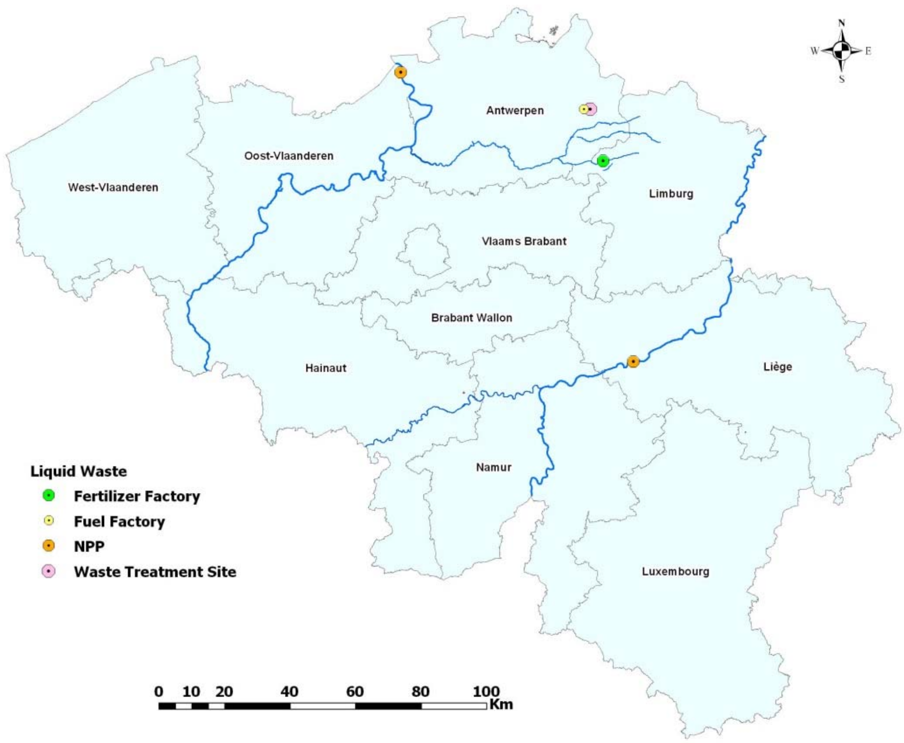
- Monitoring the food chain by checking milk (supermarkets and dairies which collect from a large number of farms, several thousands in Flanders and in Wallonia) and also on Belgian representative meals;



- of drinking water and foodstuffs taken from markets and retail outlets;



- Monitoring the liquid discharges of nuclear facilities (nuclear power stations, Mol-Dessel site) and NORM-industries (Tessenderlo historical discharges of ^{226}Ra);



The territorial monitoring programme has given priority to monitoring the possible major routes of contamination of the environment (river basins and maritime zone) as well as those of direct human contamination (food chain). All or part of the areas referred to above are monitored depending on the regions and the presence of nuclear or non-nuclear industries.

2.4.2 Vectors of transfer of monitored radioactivity

The radiological monitoring programme monitors a whole series of compartments in which samples are taken for analysing the radioactivity.

The following tables summarise the work carried out. The maps presented under 2.4.1 above localise the sampling locations set out in the tables.

The basin of the Meuse and the Sambre

This basin receives liquid discharges from several nuclear and non-nuclear sites:

- *Nuclear sites:*
  - ◊ Tihange nuclear power station (3 reactors) situated along the Meuse between Huy and Ampsin,
  - ◊ the IRE site at Fleurus close to the Sambre,
- *Non-nuclear sites:*
  - ◊ Hospitals of major urban areas such as Namur and Liege.

More than 1,100 samples are taken from the overall basin, on which near 6,280 measurements are conducted for radioactivity.

Radiological monitoring programme for the Sambre – Meuse basin

Zone		Basin and location of sampling points: Sambre	Basin and location of sampling points: Meuse	Type of measurement	Frequency of sampling
Atmosphere	dusts	close to the IRE site (Fleurus)	close to the Tihange site Lixhe	Spectrometry γ: ^{7}Be, $^{134\text{-}137}Cs$, $^{141\text{-}144}Ce$, $^{103\text{-}106}Ru$, ^{95}Zr, ^{95}Nb, (^{131}I near to the IRE)	every 4 weeks
				Spectrometry total β: on paper filters after 5 days decay	daily
	surface deposits (tanks)	close to the IRE site (Fleurus)	Heer-Agimont close to the Tihange site Lixhe	Spectrometry γ (untreated water) : ^{7}Be, $^{134\text{-}137}Cs$, $^{141\text{-}144}Ce$, $^{103\text{-}106}Ru$, ^{95}Zr, ^{95}Nb, ^{131}I	every 4 weeks
				Spectrometry total β , total α, ^{3}H, ^{90}Sr (filtered water)	every 4 weeks
				Spectrometry total β , total α (filter deposits)	every 4 weeks
				^{131}I (filtered deposits) close to IRE	every 4 weeks

Radiological monitoring programme for the Sambre – Meuse basin (cont.)

Zone		Basin and location of sampling points: Sambre	Basin and location of sampling points: Meuse	Type of measurement	Frequency of sampling
Soil	permanent meadow (superficial soil – 0.125 m² on ~ 15 cm depth + short grass cut)	close to the IRE site (Fleurus)	close to the Chooz site close to the Tihange site Lixhe	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th ^{131}I close to IRE	Annually
	agricultural soils agricultural plant production		around the boot of Chooz (24 points)	Spectrometry γ, α, ^{90}Sr, ^{226}Ra Spectrometry γ, ^{90}Sr, ^{3}H, ^{14}C	Annually
River	water		Heer-Agimont, Andenne, Huy, Ampsin, Lixhe	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{141-144}Ce$, $^{103-106}Ru$, ^{95}Zr, ^{95}Nb, ^{226}Ra Spectrometry β total, total α ^{3}H, ^{40}K, ^{90}Sr (^{131}I near to the IRE)	every 2 weeks
	sediments		Heer-Agimont, Andenne, Ampsin, Lixhe	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th, (^{131}I close to IRE)	every 4 weeks
	aquatic plants, mosses, bivalves	Floriffoux or Mornimont	Heer-Agimont/ Rivière/Hastière/ Waulsort, Andenne/Gives, Huy, Ampsin/Amay, Lixhe	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th ^{3}H organic	quarterly

The basin of the Scheldt and the Nete

This basin receives liquid discharges from several nuclear and non-nuclear sites:

- *Nuclear sites:*
  - ◊ Doel nuclear power station (4 reactors) situated along the Scheldt near Doel,
  - ◊ SCK•CEN site at Mol,
  - ◊ sites of Belgoprocess, Belgonucleaire and FBFC International at Mol and Dessel,
- *Non-nuclear sites:*
  - ◊ Hospitals of large urban areas such as Antwerp,
  - ◊ Former feed phosphates facility near Tessenderlo.

More than 1,230 samples are taken from the overall basin, on which more than 3,730 measurements of radioactivity are conducted.

Radiological monitoring programme for the Scheldt – Nete basin

Zone		Basin and location of sampling points: Scheldt	Nete	Type of measurement	Frequency of sampling
Atmosphere	dusts	close to the Doel site	close to the Mol site	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{141-144}$Ce, $^{103-106}$Ru, ^{95}Zr, ^{95}Nb	every 4 weeks
				Spectrometry total α near Mol	daily
				Spectrometry total β: on paper filters, after 5 days decay	daily
	surface deposits (tanks)	close to the Doel site	close to the Mol site	Spectrometry γ (untreated water) : ^{7}Be, $^{134-137}$Cs, $^{141-144}$Ce, $^{103-106}$Ru, ^{95}Zr, ^{95}Nb, ^{131}I	every 4 weeks
				Spectrometry total β , total α, ^{3}H, ^{90}Sr (filtered water)	every 4 weeks
				Spectrometry total β , total α (filter deposits)	every 4 weeks
Soil	permanent meadow (superficial soil – 0.125 m² on ~ 15 cm depth + short grass cut)	close to the Doel site	close to the Mol site	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th	Annually
				Spectrometry α: $^{234-235-238}$U, $^{238-(239+240)}$Pu, ^{241}Am near Mol	
River	water	near Doel	Molse Nete	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{141-144}$Ce, $^{103-106}$Ru, ^{95}Zr, ^{95}Nb, ^{226}Ra	every 2 weeks
				Spectrometry total β , total α, ^{3}H, ^{40}K	
	sediments	near Doel	Molse Nete	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th	every 4 weeks
				^{90}Sr, $^{234-235-238}$U, $^{238-(239+240)}$Pu, ^{241}Am	
	aquatic plants		Molse Nete	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th	quarterly
				^{90}Sr, $^{234-235-238}$U, $^{238-(239+240)}$Pu, ^{241}Am, ^{3}H organic, ^{99}Tc	
	shrimps	estuary downstream from Doel (Kieldrecht)		Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th	quarterly
	bivalves, seaweeds	estuary/North Sea (Hoofdplaat & Kloosterzande)		^{90}Sr, $^{238-(239+240)}$Pu, ^{241}Am, ^{3}H organic, (^{99}Tc for seaweed)	

The maritime zone: Belgian coastal region

The coastal region receives liquid discharges from several nuclear and non-nuclear sites:

- *Nuclear sites:*
  - ◊ Gravelines power station located in France near the sea between Calais and Dunkirk
  - ◊ La Hague reprocessing plant;
- *Non-nuclear sites:*
  - ◊ Hospitals in urban areas such as Ostend.

More than 250 samples are taken from the overall maritime zone, on which nearly 1,500 measurements are conducted for radioactivity.

Radiological monitoring programme for the maritime zone

Zone		Location of sampling points	Type of measurement	Frequency of sampling
Atmosphere	dusts	Coxyde	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{141-144}$Ce, $^{103-106}$Ru, ^{95}Zr, ^{95}Nb Spectrometry total β: on paper filters after 5 days decay	every 4 weeks daily
Soil	permanent meadow (superficial soil – 0.125 m² on ~ 15 cm depth + short grass cut)	Coxyde	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th	Annually
North Sea	water	off the coast (Belgica campaign), 16 locations	Spectrometry γ: $^{134-137}$Cs, $^{57-58-60}$Co, ^{54}Mn ^{40}K Spectrometry β total & α total Spectrometry α: $^{238-(239+240)}$Pu	quarterly
	sediments	off the coast (Belgica campaign), 16 locations	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th Spectrometry α: $^{238-(239+240)}$Pu	quarterly
	seaweeds	Ostende – Belgian coast	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th ^{90}Sr, $^{238-(239+240)}$Pu, ^{241}Am, ^{3}H organic, ^{99}Tc	quarterly
	mussels & shrimps	Ostende – Belgian coast	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th ^{90}Sr, $^{238-(239+240)}$Pu, ^{241}Am, ^{3}H organic	quarterly
	fish	off the coast (Belgica campaign), 16 locations	Spectrometry γ: ^{7}Be, $^{134-137}$Cs, $^{(57)-58-60}$Co, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}$Ra,^{228}Th ^{90}Sr, $^{238-(239+240)}$Pu, ^{241}Am, ^{3}H organic, ^{99}Tc	quarterly

The reference zone: the region of Brussels Capital

The choice of reference zones is dictated by the wish to situate these sampling stations on Belgian territory in a geographic situation that shields them from potential discharges of artificial and/or natural radioactivity resulting from human activities. On the other hand, a criterion like population density is also important.

Within this framework, the Brussels urban area has been selected as a representative zone. This area contains a large part of the population with more than one million inhabitants (1/10th of the total Belgian population).

About 380 samples are taken, on which near 710 measurements are conducted for radioactivity.

Radiological monitoring programme for the reference zone of Brussels Capital

Zone		Location of sampling points	Type of measurement	Frequency of sampling
Atmosphere	dusts	Brussels	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{141-144}Ce$, $^{103-106}Ru$, ^{95}Zr, ^{95}Nb	every 4 weeks
			Spectrometry total β: on paper filters after 5 days decay	daily
	surface deposits (tanks)	Brussels	Spectrometry γ (untreated water) : ^{7}Be, $^{134-137}Cs$, $^{141-144}Ce$, $^{103-106}Ru$, ^{95}Zr, ^{95}Nb, ^{131}I	every 4 weeks
			Spectrometry total β , total α, ^{3}H, ^{90}Sr (filtered water)	every 4 weeks
			Spectrometry total β , total α (filter deposits)	every 4 weeks
Soil	permanent meadow (superficial soil – 0.125 m² on ~ 15 cm depth + short grass cut)	Brussels	Spectrometry γ: ^{7}Be, $^{134-137}Cs$, $^{(57)-58-60}Co$, ^{54}Mn, ^{65}Zn, ^{110m}Ag, ^{40}K, $^{226-228}Ra$, ^{228}Th	Annually

The food chain: drinking water, milk and foodstuffs

The monitoring of the food chain attempts to assess all the routes enabling the entry of radioactivity into humans as extensively as possible. This monitoring addresses:

- The radiological state of drinking water (national and European obligations – EC Council Directive) is of primary importance;
- The radiological state of milk, which also constitutes a potentially sensitive vector in the case of radioactive contamination, especially in relation to the presence of ^{131}I, which passes rapidly from the grass to the cow to the milk – an important food in the diet of young children. Since the milk distribution chain is a rapid one, the iodine is quickly ingested by the population with the associated risks of irradiation of the thyroid;
- The radiological state of foodstuffs by means of ad hoc but varied sampling of products intended for consumption (plant and animal foodstuffs, etc).

The national territory can potentially be contaminated by all the nuclear and non-nuclear sites mentioned previously as well by illicit import of foodstuff originating from countries touched by incidents or accidents such as the Chernobyl and Fukushima accident.

Nearly 480 samples are taken, on which about 3,050 measurements are conducted for radioactivity. Added to these samples are those taken by the FASFC (Federal Agency for Safety of the Food Chain) within the framework of the co-operation between the two Agencies. 194 samples and 605 additional measurements are conducted in this frame.

Radiological monitoring programme for the food chain

	Zone	Location of sampling points	Type of measurement	Frequency of sampling
Drinking water	mains (tap)	Brussels (Brussels Capital) Wavre (Walloon Brabant) Liege (Liege) Namur (Namur) Fleurus (Hainaut) Florenville (Luxembourg) Ghent (East Flanders) Leuven (Flemish Brabant) Poperinge and Reningelst (West Flanders) Mol (Antwerp) Hasselt (Limburg)	Spectrometry total α & total β , ^{3}H, ^{40}K Where screening values are exceeded by 0.1 Bq/L in total alpha and 1 Bq/L in total beta, complete spectrometry analyses (γ, α, β)	quarterly
Milk	dairies/farms	Brussels region (Brabant) 1 farm Fleurus region 75 dairies Tihange region 118 dairies Doel region 1 dairy Dessel region1 1 dairy Chooz region 42 dairies	Spectrometry γ: of which $^{134-137}Cs$, ^{131}I, ^{40}K ^{90}Sr	weekly every 4 weeks
Foodstuffs	vegetables meat fish various (mushrooms, flour, etc.)	national territory among small and large scale retailers	Spectrometry γ: of which $^{134-137}Cs$, ^{40}K ^{90}Sr	4 samples monthly of meat, fish, vegetables 4 samples annually of meat, fish, vegetables
	control meal	company canteens: Mol (SCK•CEN), Fleurus & Brussels (CARREFOUR)	Spectrometry γ: of which $^{134-137}Cs$, ^{40}K ^{90}Sr and ^{14}C	monthly quarterly

Monitoring discharges from nuclear sites

The monitoring programme also implements a network for measuring effluents from treatment plants for liquid waste discharged into the environment. These samples are taken by the operator as well as by the body commissioned by the Agency to measure radioactivity.

The nuclear power sites (Doel and Tihange), the Mol-Dessel sites (Belgoprocess 2 – the liquid waste treatment plants of SCK•CEN, Belgoprocess 1, Belgonucléaire – and FBFC) are under this monitoring programme. As the IRE site does not release radioactive liquid waste to the environment, it has not been included in this monitoring in the past.

110 samples are taken, on which about 2,500 measurements are performed.

Radiological monitoring programme for following up discharges from nuclear sites

Nuclear site concerned	Type of measurement	Frequency of sampling
Tihange power station Doel power station	Spectrometry γ: ^{7}Be, ^{51}Cr, ^{54}Mn, $^{(57)-58-60}$Co, ^{59}Fe, ^{65}Zn, ^{95}Nb, ^{95}Zr, $^{134-137}$Cs, $^{103-106}$Ru, $^{141-144}$Ce, ^{131}I, ^{110m}Ag, ^{113}Sn, ^{123m}Te, $^{124-125}$Sb, Spectrometry β : ^{3}H	every 2 weeks (26 samples)
FBFC site	Spectrometry total β, total α ^{226}Ra, $^{234-235-238}$U, $^{238-(239+240)}$Pu, ^{241}Am	every 4 weeks (13 samples)
Mol-Dessel site (Belgoprocess 2)	Spectrometry γ: $^{134-137}$Cs, ^{54}Mn, $^{(57)-58-60}$Co, ^{131}I Spectrometry total β, total α ^{3}H, ^{90}Sr, $^{234-235-238}$U, $^{238-(239+240)}$Pu, ^{241}Am, ^{99}Tc	weekly

Monitoring discharges from NORM-industries

Many sites are monitored, as well as their releases as the groundwater around these sites: surface water and sediments of various streams affected by the historical discharges of the former phosphate unit of Tessenderlo Chemie, Kronos nv (Ghent), Prayon (Puurs and Engis), phosphogypsum stack of Zelzate (Ghent), the storage facilities related to the former radium production of Umicore (Olen), various landfills and brownfields in Wallonia and landfills registered for the acceptance of NORM waste. A survey of the sediments of various rivers in Flanders and Wallonia has been carried on in order to have a global view on the natural radioactivity in Belgian river sediments.

More than 520 samples are taken, on which 824 measurements are conducted for radioactivity.

According to the site and its specificity, the following analyzes are performed: β and α spectrometry (^{226,228}Ra, ^{210}Po, ^{210}Pb), total α, determination of ^{40}K and of the U weight.

In general, the analyses are performed on samples collected on annual or on ad hoc basis.

3. THE BASIN OF THE MEUSE AND THE SAMBRE

The Meuse and the Sambre receive radioactive discharges from several nuclear (3 power reactors at Tihange, IRE at Fleurus and the nuclear site Chooz in France) and non-nuclear sites (hospitals in big urban areas such as Namur and Liege).

As already pointed out in chapter 2 point 2.4, a whole range of samplings is carried out in this region:

- Atmospheric category: taking samples of dusts in the air (aerosols and particles deposited on filters), rain and dry or wet deposits close to the IRE, Tihange and Lixhe, harvesting of precipitation (wet and dry deposition) in the same places as the dust from the air but also near the site of French nuclear Chooz (Heer-Agimont just at the Franco-Belgian border);
- Soil category: sampling near the Tihange and IRE nuclear sites as well as in the Belgian agricultural zones (samples of agricultural crop products included) around the boot of Givet (Chooz nuclear site);
- River category: water, sediments and samples of fauna and flora from the Sambre and Meuse.

Generally:

The results obtained show that, apart from tritium, which is regularly in evidence in the waters of the Meuse, the radiological situation of the basin does not call for any particular comments.

More precisely:

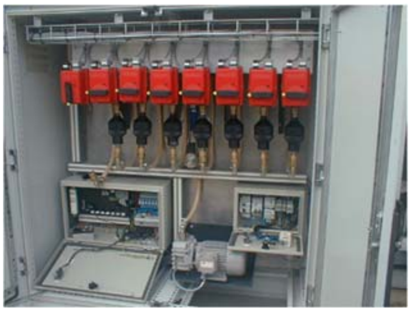
- The air around nuclear installations does not present any radiological problem. The levels measured are all lower or close to the – very low – detection thresholds of the measuring equipment;
- The measurements of the radioactivity of rain show that very small quantities of radioactivity (mainly due to natural radioactivity) can be detected by virtue of the very low detection thresholds reached by the measuring equipment;
- The radiological impact of nuclear facilities on river water is negligible and without consequence for human health;
- Only tritium is regularly detected in the Meuse water (a few dozen Bq/L) and as far as the other radionuclides are concerned, usually the levels reported are barely higher than the detection thresholds of the measuring equipment.

3.1 ATMOSPHERIC RADIOACTIVITY

Analysing air dusts is an effective method of detecting any discharge of radioactive substances into the atmosphere. Aerosols (particles > 0.5 µm), which are one of the forms of atmospheric discharge from nuclear facilities, essentially contain fission products (β-γ emitters) re-condensed on a particle nucleus.

This method of detecting radioactivity of the air was especially used for monitoring atmospheric nuclear tests when they were practised ("fallout") as well as for following-up the passage of radioactive clouds after the Chernobyl accident.

Dusts can be deposited directly on the ground (dry deposit) or washed out by the rain (wet deposit).



The collect of air dusts is realized by using pumps, air is passing through a filter which impacts dusts on a filter (photo on the left – automatic system).

Dusts are also sampled in deposit tanks where they are trapped via a thin layer of water spread over a known surface area (photo on the right).

All these apparatus represents important and complementary elements of a radiological monitoring network.

Indeed, rains which wash the atmosphere are a good means of checking the quality of the ambient air as well as its possible radioactive contamination.

The following table summarises all the results obtained for the sections of the atmosphere studied close to:

- the nuclear sites of IRE, Tihange site and of a "control site" - Lixhe - located away from any nuclear facility near the border with the Netherlands: dust from the air and rain collected in deposit tanks ;
- the nuclear site of Chooz (Heer-Agimont Belgium) with measurements of precipitation collected in deposit tanks.

These controls, conducted close to the IRE, Tihange and Chooz (Heer-Agimont at the French-Belgian border on the Meuse) nuclear facilities show that the radiological situation of the air is excellent in the vicinity of these sites.

Radioactivity measurements of the atmosphere (air and rain) in the Sambre – Meuse basin

	Air dusts (Bq/m^3)		Deposit tanks (Bq/m^2)	
	measurement	DL	measurement	DL
γ	NM	~ 10^{-5} ~ 2.5 10^{-5} ➔ $^{134,137}Cs$ ~ 2.2 10^{-4} ➔ ^{106}Ru	NM	< 4 (filtrate) < 3 (filter deposits) 1.4 to 1.6 (filtrate) ➔ $^{134,137}Cs$ 0.5 to 0.6 (filter deposits) ➔ $^{134,137}Cs$ ~ 14 (filtrate) ➔ ^{106}Ru 5.1 to 5.8 (filter deposits) ➔ ^{106}Ru
^{7}Be	(1.4 to 5.5) 10^{-3}		traces to 77 (filtrate) traces to 57 (filter deposits)	16 to 18 (filtrate) 5.3 to 7.2 (filter deposits)
β total	(1.3 to 9.4) 10^{-4}	(0.6 to 1.8) 10^{-4}	0.6 to 3.0 (filtrate) Fleurus 0.7 to 7.7 (filter deposits) Fleurus 0.5 to 4.7 (filtrate) Tihange, Heer-Agimont, Lixhe 1.0 to 7.0 (filter deposits) Tihange, Heer-Agimont, Lixhe	~ 0.3 ~ 0.1 ~ 0.3 ~ 0.1
^{131}I	NM	(8.0 to 11.4) 10^{-4}	NM	10.0 to 11.0 (filtrate) 4.3 to 6.2 (filter deposits)
^{3}H	-	-	traces	distillate: 150 to 220
α total	-	-	traces (filtrate) 0.06 to 0.60 traces (filter deposits) 0.13 to 7.3 Fleurus, Tihange, Heer-Agimont, Lixhe	~ 0.07 ~ 0.03

NM: non-measurable, measurement less than or equal to the detection limits (DL)

In greater detail:

- Natural radioactivity is mainly responsible for the – very low – level of radioactive contamination of the atmosphere. The ^{7}Be (cosmogenic natural radionuclide) sought at the request of the EC – Art. 36 of the EURATOM Treaty – is measured. The values measured are of the same order of magnitude as those observed in other European countries (Sweden, Luxembourg, France, Germany, Austria, Italy, etc.), where they vary in general from 1 to 30 10^{-3} Bq/m^3;

- Apart from any accident scenario, the radiological impact of the nuclear installations on the atmosphere and indirectly on the environment are always negligible or cannot be measured: only traces of beta emitters (total β measurements) – mainly of natural origin – are detectable;
- In the vicinity of IRE at Fleurus, watersamples taken from the deposit tank installed at a farm situated a few kilometres outside the site, do not reveal any presence of radioactive iodine (the detection limit of filter deposit is approximately 4.3 to 6.2 Bq/m^2);
- This aspect of the monitoring of atmospheric radioactivity is supported by the data of the continuous measurements carried out by all the "air" stations distributed across the territory as part of the TELERAD automatic monitoring network.

Summary:

- Natural radioactivity is mainly responsible for the level of air radioactivity;
- The Tihange nuclear power station and the nuclear facilities of the IRE site do not create – during routine operations - any measurable impact on their environment;
- The impact of the Chooz nuclear site cannot even be measured and can therefore be regarded as zero.

3.2 RADIOACTIVITY OF THE SOIL

Radioactive contamination of soil is mainly due to the fallout of radioactive substances present in the atmosphere (most often associated with very fine particles or aerosols) through dry or wet deposits (washing out of the atmosphere by rain).

Soil samples are taken once a year close to the IRE in Fleurus, Tihange and around the "botte de Givet" in Belgium (French nuclear site of Chooz) as well as near the Dutch border in Lixhe. In places, the possible depositing of radioactivity is checked by taking samples of grass (surface deposits).

Around the boot of Givet, on Belgian territory, a more exhaustive control is aimed at checking the radiological state of the agricultural zones and their plant production. This monitoring falls within the framework of the Franco-Belgian agreement on the Chooz nuclear power station and the exchange of information in the event of any incident or accident. This agreement makes provisions concerning crisis situations requiring the Nuclear Emergency Plan to be launched as well as regular exchanges of information dealing particularly with radiological measures practised in Belgium and France.

The analyses relate to the detection of gamma, beta and alpha emitters. Detection limits can vary depending on the quantity and density of the soil sampled, the geometry used for carrying out the measurements and the global level of activity of the sample.

The table below summarises all the results obtained for the soils.

Measurements of soil radioactivity in the Sambre – Meuse basin (meadows/ topsoils) and of agricultural production around the boot of Givet

	Close to nuclear sites and to Lixhe		Around the boot of Givet (Chooz)			
	Permanent meadows (Bq/m^2)		Agricultural zones (Bq/kg dry) *		Agricultural production (Bq/kg dry)	
	measurement	DL	measurement	DL	measurement	DL
γ	NM	23 to 83	NM	1.0 to 3.7	NM	2.3 to 9.5
^{137}Cs	NM to 370	30	3.6 to 8.1	1.1 to 1.7	NM	2.1 to 5.3
^{90}Sr			NM	0.5 to 3.6	NM to 1.7	0.03 to 0.6
^{14}C					0.21 to 0.27 (Bq/g C)	~ 0.12
^{3}H org.					NM to 32	13 to 14
^{40}K	(0.8 to 1.1) 10^4		480 to 930		240 to 830	
^{226}Ra	(1.0 to 1.3) 10^3		33 to 47		NM	4 to 10
^{228}Ra	(0.7 to 0.9) 10^3		41 to 55		NM	9 to 23
^{228}Th	(0.8 to 1.0) 10^3		44 to 61		NM	3 to 10
^{235}U			0.6 to 1.2	~ 0.3		
^{238}U			18 to 21	~ 4		
^{234}U			18 to 19			
^{238}Pu			NM	0.3 to 0.6		
$^{239+240}Pu$			traces (NM to 0.2)	~ 0.3		
^{241}Am			NM	0.6 to 1.6		

NM: non-measurable, measurement lower than or equal to the detection limits (DL)
** the density of the soils varies from 1.6 to 1.8 kg/L, depth of sampling: 20 cm*

In greater detail:

- The results firstly show the very considerable prevalence of natural radioactivity emitted by the potassium 40 of the soils which follows stable potassium (^{40}K represents 0.0119% of the total potassium), with the concentration varying from one soil to another, as well as depending on the seasons. The natural alpha emitters ($^{226,228}Ra$, $^{234,235,238}U$, ^{228}Th) are also detected on a regular basis;
- As far as artificial radioactivity is concerned, traces of ^{137}Cs are measured around the boot of Givet which are due to the fallout from the Chernobyl accident and the much older fallout from atmospheric nuclear tests (which reached their peak in the 1960s). That is explained by the persistence of radio-caesium in the environment due to its physical half-life of ~ 30 years (half-life = time required for 50% of the radioactivity to disappear);

  Another artificial radionuclide that is present as traces is ^{90}Sr. This beta emitter (half-life of ~ 29 years) is still present in the biosphere as a result of nuclear weapon tests in the atmosphere. Artificial transuranic alpha emitters (Pu and Am) are not measurable;

The summary table below shows the trend since 2001, of the results for ^3H in plants:

In 2016, the measures of the 24 samples taken, are under the detection limit which has increased by a factor of two compared to 2015. These detections of ^3H since 2005 may be linked to the decrease of the detection limits DL (Bq/kg dry matter) which went down from 50-90 in the period 2002 to 2004 to around 20 to 40 Bq/kg these last years, to a very low value of about 5 Bq/kg in 2015 and to 11-14 Bq/kg since 2016.

Campaign	Case of detection of ^3H in plants	Detection limits in case of absence of detection (Bq/kg DM)	Mean of concentrations observed in case of detection (Bq/kg DM)
2001	0 / 30	25	/
2002	0 / 30	54 to 75	/
2003	0 / 30	58 to 68	/
2004	0 / 24	60 to 95	/
2005	5 / 24	40 to 58	63
2006	18 / 24	23 to 26	54
2007	18 / 25	23 to 25	34
2008	5 / 24	23 to 29	56
2009	2 / 25	23 to 38	49
2010	2 / 24	4 to 19	10
2011	2 / 25	21 to 23	23
2012	0 / 24	23 to 25	/
2013	15 / 24	22 to 39	31
2014	5 / 24	24 to 34	26
2015	9 / 24	4.9 à 5.7	7.5
2016	0 / 24	11.3 to 12.2	/
2017	3 / 12	11.1 to 13.5	19.6
2018	0 / 12	13.4 to 13.9	/

In 2001, ^3H - if it was present in the plants - was only present in concentrations of less than 25 Bq/kg of dry matter. From 2002 to 2004, it was impossible to determine whether there had been any change, due to the higher detection limits.

Since 2005, it has been proved that ^3H is indeed present in the plants, which could already have been the case from 2001 to 2004, except that it could not be verified. Since 2006, the return of the detection limit to around 25 - 30 Bq/kg and around 4 – 19 Bq/kg of dry matter in 2010 has permitted to measure the tritium content with sufficient accuracy.

Until 2012, it seems that less ^3H has been detected regarding to 2006-2007, whereas the detection limits remained at the same level. One can assume that this illustrates that less tritium is present in the environment. In 2013, the detection of ^3H is significantly higher although the detected values itself are barely significant. This may be due to a quality improvements of all conditioning and/or measurement processes of radioactivity. Since 2014, ^3H is again less frequently detected. It should be noted that the amounts detected in recent years and, especially in 2015 where the detection limits have been greatly improved, are barely above the detection limits.

Summary:

- Natural radioactivity is mainly responsible for the level of radioactive soil contamination;
- Neither the Tihange nuclear power station nor the nuclear facilities of the IRE site or the Chooz site have any significant measurable impact on the soil.

3.3 RIVER RADIOACTIVITY

Two rivers are concerned: the Meuse and the Sambre. The Meuse receives radioactive discharges from the French nuclear site at Chooz, as well as from the Tihange and IRE sites via its tributary, the Sambre. These two rivers also collect radioactive discharges from the hospitals and laboratories of large urban areas such as Namur, Huy, Liege and Charleroi.

The Meuse constitutes, after treatement, a source of drinking water for a substantial section of the Belgian and Dutch populations. In this respect, total alpha and beta radioactivity are performed. Gamma spectrometry measurements are also carried out.

These controls are all the more important on account of the application of European Council 2013/51/EURATOM Directive concerning the quality of water intended for human consumption transposed into Belgian legislation (Royal Decree of 31 May 2016).

The water is automatically sampled by independent collectors (PPMOS) installed in the containers of the TELERAD river station (photographs opposite).

In order to assess the fixing potential of the radioactivity of matter in suspension and fine particles of sediments which constitute an important compartment for fixing radioactive nuclides, analyses are conducted on sediments collected monthly in sedimentation tanks (photo on the right).

These tanks are installed in the containers of the TELERAD river station which measure in continuous the gamma radioactivity of the rivers.

These tanks constantly collect suspended particles in the water via a bypass on the water pumping circuit of the TELERAD stations.

The samples also cover the aquatic biocenosis: mosses (*Cinclidotus danubicus*), aquatic plants (if available of *Salix sp*. type) and bivalve molluscs (*Dreissena polymorpha*), which are good biological indicators or "bio-indicators" of the presence of radioactivity. Mosses and aquatic plants are particularly sensitive to liquid discharges in the short and medium term because these organisms have a high potential for concentrating stable or radioactive chemical nuclides. *Dreissena*, like all filtering bivalves, are very good integrators of radioactivity over medium time spans (of the order of one month).

The water, sediment and biocenosis sampling and radioactivity control points were chosen in such a way as to enable verification of the impact of the nuclear facilities along the course of the Meuse and the Sambre:

- The Floriffoux (*Flo*), Mornimont (*Mor*) or Sambreville (*Sam*) sites incorporate the discharges of Fleurus (IRE) and of Charleroi on the Sambre river;
- The sites of Heer-Agimont (*H-Ag*), Hastière (*Has*), Waulsort (*Wau*), Rivière (*Riv*) or Godinne (*God*) for the Meuse fauna and flora incorporate the discharges of the French nuclear power station at Chooz as well as those from the hospitals situated in France in the Meuse basin;
- The Andenne (*And*), Lives-sur-Meuse (*Lsm*) or Gives (*Giv*) sites incorporate the intake from the Sambre as well as the discharges from the hospitals of the Namur and Charleroi urban areas;
- The Huy (*Huy*) site provides a radiological picture of the river upstream from the Tihange power station;
- The Ampsin (*Amp*) or Amay (*Ama*) sites and Flémalle (*Flé*) for the Meuse flora, located just downstream from the Tihange nuclear power station, enables the impact of the Tihange liquid discharges on the Meuse to be checked against the Huy data;
- The Lixhe (*Lix*) site incorporates all the Belgian intakes at the Dutch border.

The following table summarises the results obtained.

Radioactivity measurements in the rivers of the Sambre – Meuse basin

	Waters (Bq/L)		Sediments (Bq/kg dry)		Fauna (*D. polymorpha*) (Bq/kg dry)		Flora (Bq/kg dry)	
	measurement	DL	measurement	DL	measurement	DL	measurement	DL
γ	NM	≤ 1	NM	< 10	-	< 40	Mosses NM 4 to 16 (^{60}Co – Amp)	 < 15 < 5
^{137}Cs	NM	0.15 to 0.19	3.7 to 21.7 (H-Ag) 3.9 to 10.4 (And) 5.6 to 23.8 (Amp) NM to 13.5 (Lix)	4 to 14	NM (And, Giv, Amp, Lix)	5 to 37	Mosses traces (Mor, Sam, Amp, Lix) NM (Riv, God, Giv, Lsm, Huy)	 3.7 to 7.9 3.5 to 14.0
^{131}I	NM	0.5 to 0.6	NM (H-Ag, And, Amp) traces (Lix)	53 to 63 ~ 170	NM (And, Giv, Amp, Lix)	67 to 310	Mosses NM (Mor, Sam, Riv, God, Lsm, And, Giv, Huy, Amp, Lix)	 12 to 52

Radioactivity measurements in the rivers of the Sambre – Meuse basin (cont.)

	Waters (Bq/L)		Sediments (Bq/kg dry)		Fauna (*D. polymorpha)* (Bq/kg dry)		Flora (Bq/kg dry)	
	measurement	DL	measurement	DL	measurement	DL	measurement	DL
^{3}H	7.0 to 41.6 (H-Ag) 2.8 to 30.6 (And, Huy) 7.8 to 70.0 (Amp) 4.6 to 46.3 (Lix)	~ 2.7			NM (And, Giv, Amp) NM to 26 (Lix)	13 to 14	Mosses NM to traces (Mor, Sam, Riv, Lsm, And, Giv,) NM to 21 (Lix)	13 to 14 ~ 13
total α	NM to 0.029 (H-Ag, And, Huy, Amp, Lix)	0.019 to 0.022						
^{226}Ra			8 to 87 (Meuse)	~ 50	NM (And, Giv, Amp) NM to 21 (Lix)	6 to 74	Mosses 35 to 43 (Mor, Sam) 17 to 42 (Riv, God, Lsm,And, Giv, Huy, Amp, Lix)	15 to 20
^{228}Ra			NM to 72	50 to 70	NM (And, Giv, Amp, Lix)	22 to 160	Mosses 19 to 34 (Mor, Sam) NM to 32 (Riv, God, Lsm, And, Giv, Huy, Amp, Lix)	24 to 64
^{228}Th			12 to 79	30 to 60	NM (And, Giv, Amp, Lix)	8 to 50	Mousses 11 to 28 (Mor, sam) NM to 36 (Riv, God, Lsm, And, Giv, Huy, Amp, Lix)	7 to 23
total β (residual)	0.07 to 0.31 (H-Ag, And, Huy, Amp, Mon, Lix)	~ 0.06						
40K	0.049 to 0.188		120 to 670		NM (And, Giv, Amp, Lix)	100 to 720	Mosses 125 to 610 (Mor, Sam, Riv, God, Lsm, And, Giv, Huy, Amp, Lix)	~ 175

NM: non-measurable, measurement less than or equal to the detection limits (DL)
total β residual: total β apart from ^{40}K

In greater detail:

- The results obtained show that the presence of natural radioactivity and, as far as artificial radioactivity is concerned, mainly ^{3}H is detected in the waters on a regular basis: levels of ^{3}H, which can reach 70 Bq/L, are measured downstream from the nuclear power stations;
- In sediments: ^{40}K fluctuates between 120 and 670 Bq/kg dry, while ^{226}Ra ranges between 8 and 87 Bq/kg dry in the Meuse and ^{228}Ra between "unmeasurable" and 72 Bq/kg dry, ^{228}Th from 12 to 79 Bq/kg dry;
- ^{131}I is not highlighted in sediments collected downstream of large urban areas;
- In flora: ^{40}K is measured in concentrations from 125 to 610 Bq/kg dry in the mosses;

Summary:

- Natural radioactivity (^{40}K, and to a lesser extent $^{226,228}Ra$ and ^{228}Th) is mainly responsible for the level of radioactive contamination in the different river sections;
- The Tihange nuclear power station, the one at Chooz in France and the nuclear facilities of the IRE site do not have a significant impact on the rivers;
- Only ^{3}H is routinely measured in the Meuse water, though it remains at concentrations below the parametric value of 100 Bq/L defined in European Council 2013/51/ EURATOM Directive of 22 October 2013 laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption.

4. THE BASIN OF THE NETE AND THE SCHELDT

The Scheldt receives radioactive discharges from several nuclear sites (4 power reactors at Doel, SCK•CEN at Mol, the sites of Belgoprocess, Belgonucléaire and FBFC International at Mol and Dessel) and non-nuclear sites (hospitals in big urban areas such as Antwerp, former feed phosphate facility near Tessenderlo).

A whole range of samples are taken in this region near the nuclear sites of Doel on the Scheldt and Mol-Dessel near the Molse Nete, as well as the former non-nuclear site of Tessenderlo near the Grote Laak (both tributaries of the Grote Nete, itself a tributary of the Ruppel, which then flows into the Scheldt) and the Winterbeek (tributary of the Demer):

- Atmospheric category: sampling of air dusts (filters), rain and dry or wet deposits near the Mol-Dessel and Doel sites;
- Soil category: sampling near the Mol-Dessel and Doel nuclear sites;
- River category: waters, sediments and samples of the flora and fauna of the Molse Nete and the Scheldt near Doel.

Generally:

- The air in the vicinity of the nuclear installations does not present any radiological problem. The levels measured are all lower or close to the – very low – detection thresholds of the measuring equipment;
- The measurements of the radioactivity of rain show that very small quantities of radioactivity (mainly due to natural radioactivity) can be detected by virtue of the detection thresholds reached by the measuring equipment;
- The radiological situation of the Scheldt is good;
- The impact of the nuclear facilities on the waters of the rivers is negligible and without consequence for human health. Nevertheless, the water of the Nete (Molse Nete) basin needs be subjected to stricter controls on account of the liquid discharges of artificial radioactivity from the Mol-Dessel site and radium due to the historical discharges from the installations at Tessenderlo (Grote Laak, Winterbeek).

More precisely:

- The radioactivity of certain radionuclides (including ^{3}H) in the Molse Nete is abnormally high even though the nuclear industrial activities in the region of Mol-Dessel comply with the stipulated discharge limits;
- Natural radioactivity due to ^{226}Ra (highly radiotoxic with a very long physical period – 1620 years, with gaseous ^{222}Rn, ^{210}Pb as descendants – 22 years physical period) in the Grote Laak and Winterbeek is not negligible. On the other hand, the situation of the hydrographic network of the Nete needs to be monitored very carefully. Since 2016, several actions have been initiated by FANC with the aim to better characterize the situation on the banks of the Grote Nete downstream from the Grote Laak (see 4.4).

4.1 ATMOSPHERIC RADIOACTIVITY

The following table summarises all the results obtained for the atmospheric categories studied: air dusts, dry deposition and rain collected in deposit tanks.

These controls are carried out close to the Doel and Mol-Dessel nuclear facilities and do not reveal any radiological problems.

In greater detail:

- Natural radioactivity is mainly responsible for the – very low – level of radioactive contamination of the atmosphere. ^{7}Be (a natural cosmogenic radioactive nuclide) is very closely monitored;
- The impact of nuclear installations on the atmosphere and indirectly on the environment is negligible or cannot even be measured: only traces of alpha and beta emitters (measurements in total α and β) – mainly of natural origin – are detectable near the Doel and Mol-Dessel nuclear sites;
- This aspect of the monitoring of atmospheric radioactivity is supported by the data of the continuous measurements carried out by all the "air" stations distributed across the territory as part of the TELERAD automatic monitoring network.

Summary:

- Natural radioactivity is mainly responsible for the level of air radioactivity;
- The Doel nuclear power station and the nuclear facilities of the Mol-Dessel site do not have a measurable impact in the atmosphere.

The following table summarises the results obtained.

Measurements of atmospheric radioactivity (air and rain) in the Nete – Scheldt basin

	Air dusts (Bq/m^3)		Deposit tanks (Bq/m^2)	
	measurement	DL	measurement	DL
γ	NM	~ 10^{-5}	NM	1.4 to 15 (filtrate) 0.4 to 4.3 (filter deposits) → γ 1.4 to 1.7 (filtrate) 0.4 to 0.5 (filter deposits) → $^{134,137}Cs$
^{7}Be	(0.9 to 3.6) 10^{-3}		traces to 42 (filtrate) traces to 58 (filter deposits)	~ 20 5 to 10
total β	(0.1 to 2.2) 10^{-3}	~ 0.02 10^{-3}	Filtrate 0.9 to 34.7 Mol 1.1 to 32.2 Doel Filter deposits 0.8 to 4.2 Mol 1.1 to 4.5 Doel	~ 0.02
^{3}H			NM	770 to 930 (filtrate)
total α	(8 to 24) 10^{-6} Mol-Dessel	~ 5 10^{-6}	Filtrate NM to 0.8 Filter deposits 0.23 to 2.48	~ 0.50

NM: non-measurable, measurement less than or equal to the detection limits (DL)

4.2 RADIOACTIVITY OF THE SOIL

The soil samples are taken once per year close to the Doel and Mol-Dessel nuclear sites. The possible deposit of radioactivity is checked by means of grass samples (surface deposits).

The analyses relate to the detection of gamma, beta and alpha emitters. Detection limits can vary depending on the quantity and density of the soil sampled, the geometry used for carrying out the measurements and the global level of activity of the sample.

In greater detail:

- The results firstly show the very considerable prevalence of natural radioactivity emitted by the potassium 40 of the soils which follows stable potassium (^{40}K represents 0.0119% of total potassium), with the level varying from one soil to another, as well as depending on the seasons. The natural alpha emitters ($^{226,228}Ra$, $^{234,235,238}U$, ^{228}Th) are also detected on a regular basis;
- As far as artificial radioactivity is concerned, traces of ^{137}Cs are measured in the soils which are due to the fallout from the Chernobyl accident and the much older fallout from atmospheric nuclear tests (which reached their peak in the 1960s).

  The artificial transuranic alpha emitters (Pu and Am) are not measurable.

The table below summarises all the results obtained for the soils.

Soil radioactivity measurements (meadows/topsoils) of the Nete – Scheldt basin

	Doel site (Bq/m^2)	Mol-Dessel site (Bq/m^2)	
	measurement	measurement	DL
γ	NM	NM	4 to 13
^{137}Cs	41 to 53	60 to 83	~ 5
^{40}K	(4.5 to 5.5) 10^3	(0.54 to 0.70) 10^3	
^{226}Ra ^{228}Ra	420 to 600	59 to 71	
^{228}Th	450 to 890	39 to 55	
^{235}U ^{238}U		(0.016 to 0.096) 10^3 (0.79 to 1.14) 10^3	
$^{238,(239+240)}$Pu		NM	32 to 48
^{241}Am		NM	~ 40

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Summary:

- Natural radioactivity (K, Ra, U, Th) is mainly responsible for the level of radioactivity of the soils;
- In the Mol-Dessel region, only natural radioactivity (uranium and thorium) is detectable. There is no evidence of detectable quantities of heavy nuclides belonging to the americium and plutonium family which might have been discharged by the site facilities, including those of Belgoprocess 1 (Cilva - solid waste incinerator, Pamela – highly radioactive waste vitrification plant), those of Belgoprocess 2 (former SCK•CEN liquid waste treatment plant) and those of the former activities of Belgonucleaire involved in the discharges of alpha and Pu emitters. It should be noted that FBFC International – a plant manufacturing nuclear fuel enriched with ^{235}U and at present MOX – is not concerned here by virtue of its discharges being negligible in terms of activity;
- The Doel nuclear power station and the nuclear facilities of the Mol-Dessel site do not have any measurable impact on their surroundings (by the way of the atmospheric releases).

4.3 RADIOACTIVITY OF THE RIVERS

Several rivers are concerned: the Molse Nete is a watercourse which receives the discharges of Belgoprocess 2 and the liquid radioactive effluent treatment plant of the Mol-Dessel site; the Grote Laak and the Winterbeek, which received the discharges of the site manufacturing feed phosphates at Kwaad-Mechelen and Tessenderlo (discharges of ^{226}Ra); the Grote Nete in which the Molse Nete and Grote Laak debouche; the Ruppel in which the Grote Nete falls into and also receives the water of the Winterbeek (via the Demer which flows into the Dijle which ends into the Ruppel. Finally, the Scheldt, which drains the entire Nete basin. It receives the discharges from the Doel nuclear power station as well as the radioactive discharges of the Antwerp hospitals and laboratories. The Scheldt ends in an estuary area before flowing into the North Sea.

Belgoprocess 2 (former SCK•CEN liquid discharge treatment plant) receives all the liquid radioactive waste of the other installations of the Mol-Dessel site (SCK•CEN, Belgoprocess, Belgonucleaire, FBFC) for treatment prior to discharge. The discharges into the Molse Nete must not exceed 25 GBq/month of alpha, beta and gamma radioactivity according to the following formula:

$2{,}5\,[\alpha \text{ total}] + 0.4\,[^{90}\text{Sr-}^{90}\text{Y}] + 2.5\;10^{-5}\,[^{3}\text{H}] + [^{60}\text{Co}] + 1.5\,[^{134}\text{Cs}] + 1.5\,[^{137}\text{Cs}] + 0.1\,[\beta\,] \leq 25$ GBq/month (150 GBq/year maximum with a concentration limit of 15 MBq/m^3) in the river Molse Nete.

with $[\beta] = [\beta \text{ total}] - ([^{90}\text{Sr-}^{90}\text{Y}] + [^{60}\text{Co}] + [^{134}\text{Cs}] + [^{137}\text{Cs}])$

Total alpha and beta radioactivity is checked in these waters. Gamma spectrometry analyses and specific measurements of radium are carried out. The freshly deposited sediments on the river beds and close to the banks (sedimentation trays) are also analysed.

The samplings also cover the aquatic biocenosis: mosses (*Cinclidotus danubicus)*, fresh water plants and algae (if available), as well as marine mussels (*Mytilus edulis*) or wild oysters, shrimps (*Crangon sp.*) if available - as regards the Scheldt estuary part - which are good biological indicators or "bio-indicators" of the presence of radioactivity.

The water, sediment and biocenosis sampling and radioactivity control points were chosen in such a way as to enable verification of the impact of the nuclear and non-nuclear facilities along the water courses referred to above.

- On the Molse Nete (*MNe*) near the discharge point of the outlet channel of Belgoprocess 2 at the Mol-Dessel site;
- On the Scheldt (*Sch*) near Doel;
- Further in the estuary for fauna (shrimps and marine oysters) and flora (algae – *Fucus vesiculosus*): Kieldrecht region near Doel (shrimps), Kloosterzande or Hoofdplaat (oysters and algae) situated on the estuary section of the Scheldt to the north of the Belgian-Dutch border (*Estu*).

The results obtained show that the presence of natural radioactivity (^{226}Ra in the Grote Laak and the Winterbeek) is detected regularly and, as far as artificial radioactivity is concerned, mainly ^{3}H in the Molse Nete.

In greater detail:

- In the waters of the Molse Nete, the artificial radioactivity is due to ^{3}H, which fluctuates from 7 to 113 Bq/L. Only traces of transuranic nuclides are detected (^{241}Am, ^{238,239}Pu) with a maximum level of respectively 1.8 10^{-3} Bq/L and 2.1 10^{-4} Bq/L, detection limits are in the vicinity of ~ 1 to 2 10^{-4} Bq/L. The natural radioactivity is due to ^{40}K (a few Bq/L) and to the ^{234,238}U with concentrations of 0.0016 to 0.0057 Bq/L (^{235}U is generally not detected or detected as traces with a detection limit of ~ 0.00015 Bq/L);
- In the sediments, the radioactivity is mainly of natural origin (K and Ra). Radium is easily detectable in the Molse Nete with concentrations of 19 to 114 Bq/kg dry matter. The levels decrease further into the basin towards the Scheldt. Recent sediments of the Molse Nete displays traces of artificial radioactivity (mainly ^{137}Cs with concentrations of 38 to 434 Bq/kg, transuranic nuclides – Pu and Am respectively, with levels ranging from 2 to 31 Bq/kg and 10.5 to 61 Bq/kg, sometimes ^{99}Tc is detected as traces and up to 150 Bq/kg) coming from the liquid discharges of Belgoprocess 2 (discharges which comply with the authorised limits) and from possible resuspension of older deposits. This radioactivity quickly becomes very difficult to detect further away from the discharge point;

- The main source of radioactivity in flora and fauna is ^{40}K. In the Molse Nete (mosses and aquatic plants) ^{137}Cs is sometimes measured with levels up to 8 Bq/kg (detection limit is ~ 6 Bq/kg). This is indicative of discharges of artificial radioactivity from the Mol-Dessel site (discharges carried out by the Belgoprocess 2 installation). In the estuary environment (Scheldt), traces of ^{226}Ra are occasionally detected in the marine flora and fauna.

The following table summarises the results obtained.

Radioactivity measurements in the Nete - Scheldt basin rivers

	Waters (Bq/L)		Sediments (Bq/kg dry)		Fauna (Bq/kg dry)		Flora (Bq/kg dry)	
	measurement	DL	measurement	DL	measurement	DL	measurement	DL
γ	NM	≤ 2	NM	1 to 27	NM (Estu)	< 3	NM (MNe) NM (Estu)	< 10 < 5
^{60}Co			NM to 11.3 (MNe) NM (Sch)	~ 3.1 ~ 1.8	NM (Estu)	~ 1.1	NM to 9 (MNe) NM (Estu)	~ 3.4 ~ 1.5
^{137}Cs	NM	0.18 to 0.23	38 to 434 (MNe) 3.3 to 7.1 (Sch)	1.5 to 2.5	NM (Estu)	~ 1.0	NM to 8.1 (MNe) NM (Estu)	~ 6 ~ 1.3
^{131}I	NM	~ 0.68	NM (MNe) NM (Sch)	~ 250 ~ 30	NM (Estu)	~ 20	NM (MNe) NM (Estu)	~ 40 ~ 21
total α	NM to 0.076 (MNe) NM to 0.28 (Sch)	~ 0.014 ~ 0.11						
^{241}Am	(0.3 to 1.8) 10^{-3} (MNe) (NM to 8.1) 10^{-4} (Sch)	~ 2.0 10^{-4} ~ 1.0 10^{-4}	10.5 to 61 (MNe)		NM (Estu)	~ 0.05	0.12 to 0.17 (MNe) NM to traces (Estu)	~ 0.007 ~ 0.03
$^{238,(239+240)}Pu$	(NM to 2.1) 10^{-4} (MNe) NM (Sch)	~ 1.1 10^{-4} ~ 1.2 10^{-4}	2 to 31 (MNe)		NM to 0.10 (Estu)	0.04 to 0.05	0.04 to 0.10 (MNe) NM (Estu)	~ 0.003 ~ 0.04
^{226}Ra	0.015 to 0.156 (Sch)		19 to 114 (MNe) 25 to 42 (Sch)	~ 20	NM to traces (Estu)	~ 2.8	NM (MNe) 5.3 to 8.1 (Estu)	~ 6 ~ 5

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Radioactivity measurements in the Nete - Scheldt basin rivers (cont.)

	Waters (Bq/L)		Sediments (Bq/kg dry)		Fauna (Bq/kg dry)		Flora (Bq/kg dry)	
	measurement	DL	measurement	DL	measurement	DL	measurement	DL
total β	0.29 to 0.46 (MNe) 1.8 to 5.7 (Sch)	~ 0.06						
^{3}H	7 to 113 (MNe) NM to 15 (Sch)	~ 10 ~ 10			NM (Estu)	~ 14	NM (MNe) NM (Estu)	~ 15.5 ~ 15.6
^{90}Sr			NM (MNe)	~ 5.3	NM (Estu)	~ 4.1	NM (MNe, Estu)	3 to 7
^{99}Tc			NM to 150 (MNe)	~ 82			NM to 58 (MNe) NM (Estu)	~ 47 ~ 45
^{40}K	NM to 14 (MNe) NM to 8 (Sch)	~ 3.1 ~ 6.1	90 to 206 (MNe) 306 to 540 (Sch)	~ 70	190 to 250 (oysters)		360 to 700 (MNe) 870 to 1,200 (Estu)	

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Summary:

- Natural radioactivity (^{40}K and to a lesser extent ^{226}Ra and ^{228}Th) is mainly responsible for the level of radioactivity in the different sections of the rivers;
- The Doel nuclear power station does not have any measurable impact on the Scheldt;
- The ecological situation of the Molse Nete is more problematic from the point of view of chemical contamination in general. From the radiological point of view, this watercourse contains abnormally high levels of artificial radioactive nuclides (principally tritium and caesium), the result of industrial nuclear activity at the Mol-Dessel site, which nevertheless adheres to the discharge limits set for it. However, the situation seems to have improved over the past few years;

  This observation must be balanced by remarking that these waters cannot be used for human consumption as such. On the other hand, they inundate agricultural zones which may therefore be contaminated locally – especially in chemical terms (banks, dredging spoil deposit zones, etc.). The input of chemical and radioactive contaminants needs to be reduced in the future.

4.4 RADIOACTIVITY IN THE GROTE NETE VALLEY

In previous reports, we had already highlighted the radiological situation in the Grote Nete basin.

Despite the end of phosphate products production late 2013 and its associated discharges, the radiological contamination in the Grote Laak valley is still being transported by the river – albeit in concentrations which are significantly lower than those during the discharge period. The "legacy" on the banks of the Grote Laak is yet to be remediated, though remediation of the Winterbeek valley is ongoing. The observed radiological anomalies for ^{226}Ra complement a problem which is in reality more important: that of a chemical contamination by heavy metals, co-localized with radium.

Historically, the more detailed radiological characterization of riverbanks and -beds has focused on the rivers which directly receive(d) discharges : Molse Nete, Winterbeek and Grote Laak. Nevertheless, studies from the early years 2000 by the Flemish Region show that the riverbanks of the Grote Nete – which receives the water of both Molse nete and Grote Laak – also show a ^{226}Ra contamination in flooding zones near Lier[3], comparable to that present on the banks of the Grote Laak. This shows that part of the radium present in discharges was deposited by the river several dozens of kilometers downstream from the mouth of the Grote Laak. These identified zones being largely inaccessible and the radiological risk negligible, a more detailed characterization was neither feasible nor justified at that time.

Recently, the presence of radium in the Grote Nete valley has come to the forefront again, due to discoveries made during the preparation of works planned by the Flemish Region to reorganize the riverbanks and bed. During a preparatory study, significantly increased concentrations of heavy metals have also been measured in the same zones. Therefore, FANC has contacted OVAM, the competent regional authority for non-radiological soil pollution.

FANC and OVAM have identified several zones in the lower Grote Nete valley where more detailed soil investigation seemed advisable. This complementary study has confirmed the presence of a ^{226}Ra contamination in zones which were frequently flooded in the past (either by acute events or by tidal effects). The radium concentrations are situated in the order of magnitude of a few Bq/g.

Late 2016, a soil investigation (still ongoing) has been initiated by OVAM to identify and characterize chemical and radiological pollution on the riverbanks and in the riverbed of the Grote Nete between Geel and Lier. Within this study, FANC evaluates the radiological risk whereas OVAM evaluates the chemical risk. FANC monitors closely the progress of the investigation and will take appropriate measures if necessary.

[3] VMM (2002) Supplement to the inventory and characterization of increased concentrations of natural radionuclides of industrial origin in Flanders.
http://www.milieurapport.be/upload/main/miradata/MIRA-T/02_themas/02_06/ioni_O&O_03.pdf

5. THE MARITIME ZONE: THE BELGIAN COASTAL REGION

In addition to directly receiving the liquid effluents from the French nuclear facilities (Gravelines nuclear power station via the English Channel; those of Paluel and Flamanville and the Hague reprocessing plant) and English nuclear installations (Dungeness, Bradwell and Sizewell power stations), the North Sea is also the final destination of several rivers themselves receiving radioactive effluents, including the Meuse and the Scheldt for Belgium.

That is why it is closely monitored by all the riparian countries that are signatories to the Oslo and Paris conventions (OSPAR).

Several sampling points have been chosen off the Belgian coast where sampling of sea water, sediments and fish living on the bottom is organised 4 times a year by the oceanographic vessel, the “Belgica” (photo on the right taken from the site of the Management Unit of the North Sea Mathematical Models - MUMM). Twelve samplings are carried out in a belt of 5 to 25 km offshore from the towns of Coxyde, Newport, Ostend and Blankenberge (one point is located 37 km directly below Wenduine near Blankenberge). The measurements taken relate to monitoring the levels of alpha, beta and gamma emitting radioactive nuclides, as well as ^{40}K as far as natural radioactivity is concerned.

On the coast, because of their accumulation and concentration capacity, samples are essentially taken of seaweed, fish, molluscs and crustaceans to measure the main fission and activation products as well as Th, Pu and U.

The compartments monitored are:

- Atmosphere compartment: dust samples from the air (filters) near Coxyde;
- Land compartment: taking of soil samples (meadows) near Coxyde;
- Marine compartment: water sediments and samples of fauna (crustaceans, bivalves, fish) and flora (seaweed).

Generally: The results obtained clearly show that the radiological situation of the maritime area does not give rise to any particular comments and does not require any action. Indeed, only natural radioactivity is measured (^{40}K). Although traces of artifical radioactivity (^{137}Cs and transuraniums in fish) are sometimed detected (at the level of the detection limits of the measuring equipment), they remain entirely negligible.

5.1 RADIOACTIVITY OF THE ATMOSPHERE

The table below summarises all the results obtained for the dust particles in the air.

Atmosphere radioactivity measurements (air) of the Belgian coast

	Air dust particles (Bq/m^3)	
	measurement	DL
γ	NM	~ 10^{-5} ~ 0.5 10^{-5} ($^{134,137}Cs$) ~ 4.0 10^{-5} (^{106}Ru)
^{7}Be	(1.5 to 2.6) 10^{-3}	
total β	(0.11 to 0.52) 10^{-3}	~ 2.0 10^{-4}
^{40}K	NM	~ 0.9 10^{-4}

NM: non-measurable, measurement less than or equal to the detection limits (DL)

The results obtained show clearly that the air in the region of Coxyde (Belgian littoral) poses not a single radiological problem. The measured values are all below or in the neighbourhood of the – very low – detection limits of the equipment. Only natural radioactivity can be sufficiently measured.

Summary:

- The natural radioactivity is mainly responsible for the – very low - level of radioactive contamination of the atmosphere. ^{7}Be is monitored very closely (natural cosmogenic radioactive nuclide).
- This aspect of controle of the atmospheric radioactivity is confirmed by the data of continuous measurements performed by all "air measuring stations", spread on the territory within the framework of the automatic monitoring network TELERAD.

5.2 RADIOACTIVITY OF THE SOIL

Soil samples on meadows are taken at Coxyde once a year. The possible deposit of radioactivity is checked by means of grass or soil samples (surface deposits).

The analyses relate to the detection of gamma, beta and alpha emitters. Detection limits can vary depending on the quantity and density of the soil sampled, the geometry used for carrying out the measurements and the global level of activity of the sample.

In greater detail:

- The results firstly showed the very considerable prevalence of natural radioactivity emitted by the potassium 40 of the soils which follows stable potassium (^{40}K represents 0.0119% of total potassium), with the level varying from one soil to another as well as depending on the seasons. The natural alpha emitters ($^{226,228}Ra$, ^{228}Th) are also detected on a regular basis;
- As far as artificial radioactivity is concerned, traces of ^{137}Cs are measured in the soils which are due to the fallout of the Chernobyl accident and much older fallout from atmospheric nuclear tests (which reached their peak during the 1960's).

The table below summarises all the results obtained for the soils.

Soil radioactivity measurements (meadows/topsoils) of the Belgian coast

	Coxyde site (Bq/m^2)	
	measurement	DL
γ	NM	4 to 13
^{137}Cs	13 to 20	~ 5
^{40}K	(1.16 to 1.44) 10^3	
^{226}Ra ^{228}Ra	54 to 66	
^{228}Th	58 to 76	

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Summary:

- Natural radioactivity (K, Ra, Th) is mainly responsible for the level of radioactive contamination of the soils;
- ^{137}Cs is detected, which is normal since, as already mentioned, this comes from the fallouts of atmospheric testing of nuclear weapons during the sixties, as well as the passing of the Chernobyl radioactive cloud. On the other hand, the levels measured are logically lower than those found in the Sambre-Meuse basin, where the deposits due to Chernobyl were somewhat greater than in Flanders.

5.3 RADIOACTIVITY OF THE MARINE ENVIRONMENT

Different sampling points are visited quarterly by the oceanographic vessel, the “Belgica”. They are situated in a band of 5 to 25 km off the towns of Coxyde, Newport, Ostend and Blankenberge (one point is situated 37 km offshore from Wenduine near Blankenberge).

Samples of algae (Fucus vesiculosus) are taken on a pier in Ostend, shrimps (*Crangon sp.*) and mussels (*Mytilus edulis*) are also sampled.

The measurements taken relate to monitoring the levels of alpha, beta and gamma emitting radioactive nuclides, as well as ^{40}K as far as natural radioactivity is concerned.

Samples of sea water are taken with the help of “Niskin” bottles (photo on the right).

The sediments are brought to the surface using a “Van Veen” scoop (photo on the left), a sort of grapnel with an open jaw lowered to the sea bottom at the end of a steel cable.

As soon as the jaws touch the bottom, the spring which keeps the jaws open is released. Before returning to the surface, the jaws close and trap a quantity of sand or sediment from the sea bed.

Samples of the fauna (fish) are collected for subsequent radioactivity analyses using a trawl net (photos to the right).

The results obtained confirm the absence of any problem concerning the radiological state of the marine environment.

In greater detail:

- The results obtained show that the presence of natural radioactivity (^{40}K) is detected on a regular basis;
- Traces of artificial radioactivity (^{137}Cs) are revealed in the marine sediments and the fish (barely significant);
- No artificial radioactivity is demonstrated in fish.

The following table summarises the results obtained.

Radioactivity measurements for the marine environment : waters and sediments

	Waters (Bq/L)		Sediments (Bq/kg dry)	
	measurement	DL	measurement	DL
γ	NM	~ 0.1 to 0.2	NM	0.6 to 2.1
^{137}Cs	traces (1.1 to 3.0) 10^{-3}	~ 2.1 10^{-3}	NM to 2	~ 0.7
^{60}Co	NM	0.1	NM	~ 0.7
total β	~ 11			
^{40}K	~ 10.5		200 to 320	
α total	NM	~ 0.3		
$^{226,228}Ra$	NM	0.2 to 0.4	6 to 13.5	~ 5
$^{238,(239+240)}Pu$	NM	~ 10^{-4}	NM to 0.9	~ 0.3

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Radioactivity measurements for the marine environment : flora and fauna

	Flora (seaweeds) (Bq/kg dry)		Fauna (mussels and shrimps) (Bq/kg dry)		Fauna (flat fish) (Bq/kg dry)	
	measurement	DL	measurement	DL	measurement	DL
γ	NM	< 1.5	NM	< 2.6	NM	< 5.0
^{137}Cs	NM	~ 1.0	NM	~ 1.0	NM	~ 1.8
^{60}Co	NM	~ 1.2	NM	~ 1.0	NM	~ 1.9
^{131}I	NM to 25	~ 20	NM	14 to 18	NM	~ 52
^{90}Sr	NM	~ 6.0	NM	~ 3.5	NM	~ 5.9
^{40}K	880 to 970		180 to 240 (mussels) 180 to 210 (shrimps)		390 to 470	
^{3}H	NM	~ 14	NM	~ 13	NM	~ 15
^{99}Tc	NM	~ 45.0			traces	~ 6.5
$^{226,228}Ra$	NM to 9	4 to 9	NM	2 to 5	NM to 11	3.7 to 7.4
$^{238,(239+240)}Pu$	NM	~ 0.035	NM	0.036 to 0.070	NM	~ 0.05
^{241}Am	NM to 0.06	~ 0.04	NM	0.046 to 0.060	NM	~ 0.05

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Summary:

- Natural radioactivity (^{40}K) is mainly responsible for the radioactivity of the different sections of the marine environment;
- ^{137}Cs, $^{238,(239+240)}Pu$ and ^{241}Am, transuranic nuclides of artificial origin (produced and discharged by the nuclear power plants and discharged by the reprocessing industry of used fuel – reprocessing plants of the Hague in France and Sellafield in the United Kingdom) are not detectable: all the levels are of the order of the detection limits.

6. THE REFERENCE ZONE : THE REGION OF BRUSSELS CAPITAL

The sampling stations were chosen on Belgian territory with regard to their geographic situation which shields them from potential discharges of artificial and/or natural radioactivity due to human activity and which accounts for a large part of the population.

In this respect, the Brussels urban area with more than one million inhabitants (1/10th of the total Belgian population) was chosen as a reference zone.

The categories monitored are:

- Atmospheric category: samples of air dusts and rain;
- Soil category.

Generally: the results obtained clearly show that the radiological situation of the Brussels urban area is excellent.

6.1 ATMOSPHERIC RADIOACTIVITY

The following table summarises all the results obtained for the atmospheric categories studied: air dusts and rain collected in deposit tanks.

Radioactivity measurements for the atmosphere (air and rain) of the reference zone

	Air dusts (Bq/m^3)		Deposit tanks (Bq/m^2)	
	measurement	DL	measurement	DL
γ	NM	~ 10^{-5} ~ 2.8 10^{-5} (^{134,137}Cs) 2.5 10^{-4} (^{106}Ru)	NM	1.5 to 14.7 (filtrate) 0.5 to 5.1 (filter deposits) Filtrate ~ 1.5 (^{134,137}Cs) ~ 14.7 (^{106}Ru) Filter deposits ~ 0.55 (^{134,137}Cs) ~ 5.1 (^{106}Ru)
^{7}Be	(1.1 to 4.2) 10^{-3}		NM to 40 (filtrate) 3.4 to 32.0 (filter deposits)	~ 17 ~ 6
total β	(0.29 to 0.75) 10^{-3}	~ 0.17 10^{-3}	0.6 to 2.6 (filtrate) 1.4 to 5.6 (filter deposits)	~ 0.7 ~ 0.1
^{40}K	(0.7 to 1.0) 10^{-3}		NM to 1.35 (filtrate) NM (filter deposits)	~ 1.3 (filtrate) ~ 8.0 (filter deposits)
^{3}H			NM (distillate)	~ 215
total α			0.05 to 0.20 (filtrate) 0.38 to 1.28 (filter deposits)	~ 0.05 ~ 0.05

NM: non-measurable, measurement less than or equal to the detection limits (DL)

The results obtained clearly show that the air in the Brussels urban area (Royal Meteorological Institute of Belgium - MRI - Uccle-Brussels) does not present any radiological problem. The levels measured are all lower than or close to the – very low – detection limits of the measuring equipment. Only natural radiation is detected.

Summary:

- Natural radioactivity is mainly responsible for the – very low – level of radioactive contamination of the atmosphere. ^{7}Be (a natural cosmogenic radioactive nuclide) is very closely monitored;
- This aspect of the monitoring of atmospheric radioactivity is supported by the data of the continuous measurements carried out by all the “air” stations distributed across the territory as part of the TELERAD automatic monitoring network (located in Brussels, Uccle, Dilbeek and Zaventem).

6.2 RADIOACTIVITY OF THE SOIL

The soil samples are taken once a year on the Royal Meteorological Institute of Belgium site in Brussels. The possible deposit of radioactivity is checked by means of grass samples (surface deposits).

The analyses relate to the detection of gamma, beta and alpha emitters. Detection limits can vary depending on the quantity and density of the soil sampled, the geometry used for carrying out the measurements and the global level of activity of the sample.

In greater detail:

- Firstly, the results show the considerable prevalence of natural radioactivity emitted by the potassium 40 of the soils which follows stable potassium (^{40}K represents 0.0119% of the total potassium), with the concentration varying from one soil to another as well as depending on the seasons. The natural alpha emitters ($^{226,228}Ra$, ^{228}Th) are also detected on a regular basis;
- As far as artificial radioactivity is concerned, traces of ^{137}Cs are measured in the soil which are due to the fallout from the Chernobyl accident and much older fallout from atmospheric nuclear testing (which reached its peak in the 1960s). The artificial transuranic alpha emitters (^{241}Am) are not measurable.

The table below summarises all the results obtained for the soils (meadows/soil surface).

Summary:

- Natural radioactivity (^{40}K, $^{226,228}Ra$, ^{228}Th) is mainly responsible for the level of radioactive contamination of the soil;
- ^{137}Cs is detected because, as already mentioned, it comes from the fallout of atmospheric nuclear weapons testing in the sixties as well as the passage of the Chernobyl radioactive cloud. On the other hand, the levels measured are logically lower than those found in the Sambre – Meuse basin, where the deposits due to Chernobyl were somewhat higher.

Soil radioactivity measurements (meadows/topsoils) of the reference zone

	RMI (Uccle-Brussels) site (Bq/m^2)	
	measurement	DL
γ	NM	26 to 270
^{137}Cs	40 to 110	~ 32
^{40}K	(7.8 to 11.8) 10^3	
^{226}Ra ^{228}Ra	(7.7 to 11.8) 10^2	
^{228}Th	(6.4 to 9.6) 10^2	

NM: non-measurable, measurement less than or equal to the detection limits (DL)

7. THE FOOD CHAIN: DRINKING WATER, MILK AND FOODSTUFFS

At the beginning of the 60's, the ISP (the former IHE – Institut d'Hygiène et Epidémiologie - Institute of Hygiene and Epidemiology) conducted a study of the radiological contamination of the food chain. This programme was taken over by the SPIR (Service of Protection against the Dangers of Ionising Radiations at the Ministry of Social Affairs, Public Health and the Environment) and has been run by the FANC since 2001.

Samples of mains water, foodstuffs such as milk, meat, salt and fresh water fish, plus vegetables and company canteen meals (control meals) are collected regularly. These samples are then analysed and their radionuclide levels determined.

The artificial radioactivity of foodstuffs mainly comes from the presence of long life fission products such as ^{90}Sr and ^{137}Cs, which result essentially from nuclear testing which took place in the atmosphere in the 1960s.

In the event of an accident (such as that in Chernobyl), an increase in radiological contamination will be caused, in particular, by any presence of ^{131} I in the short term and of ^{137}Cs, ^{134}Cs, ^{90}Sr, or possibly ^{103,106}Ru, etc. in the long term.

Checks are carried out in Belgium on the following categories:

- Drinking water: samples taken from the distribution networks (tap water) at points spread evenly throughout Belgium so as to meet the EC obligation to establish a tightly knit (numerous points, classical radioactivity measurements) and widespread control network (small number of points, measurements of very low level radioactivity – Article 35/36 of the EURATOM treaty);

- Milk: samples also taken throughout Belgium from dairies and farms, once again to meet the EC obligation to establish a tightly knit and widespread control network;

- Foodstuffs: samples are taken from supermarkets and markets, while sea fish is controlled from fisheries on the Belgian coast;

- "Control" meals: samples are taken from company canteens on a monthly basis for each region of Belgium, i.e. Brussels Capital region, Flanders and Wallonia (EC obligation Art. 35/36 of the EURATOM treaty – establishing a tightly knit and widespread network).

Generally, this monitoring programme shows and confirms after several decades of observations that there is no evidence of any influence of nuclear facilities on foodstuffs and that the radiological state of the "housewife's shopping basket" is excellent in Belgium.

7.1 RADIOACTIVITY OF DRINKING WATER

Up to 1998, there were no European standards for the radioactivity of drinking water where the "ALARA" principle – "As Low As Reasonably Achievable" – applied. A WHO recommendation nevertheless set the following levels:

7,800 Bq/litre in ^{3}H, 5 Bq/litre in ^{90}Sr, 20 Bq/litre in ^{60}Co, 6 Bq/litre in ^{131}I, 10 Bq/litre in ^{137}Cs, 1 Bq/litre in ^{226,228}Ra, 0.1 Bq/litre in ^{232}Th, 4 Bq/litre in ^{234,238}U, 0.3 Bq/litre in ^{239}Pu, etc.

In November 1998, the European Commission issued ***Council directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption***. This directive dealt with the microbiological, chemical and radioactive aspects. As far as the last point is concerned, the technical annexes specifying the analyses to be carried out as well as the directive's modalities of application were never finalised and published.

On the other hand, the directive specified two parametric values to be complied with: ***100 Bq/litre in tritium*** (^{3}H) and an ***annual total indicative dose – TID of 0.1 mSv*** (in its calculation, this dose does not take account of the contribution of tritium ^{3}H, potassium ^{40}K, radon ^{222}Rn or daughter nuclides lead ^{210}Pb and polonium ^{210}Po, most important from a radiological point of view). The dose is calculated on the basis of an annual ingestion of 730 litres of water for adults or children over the age of 10.

October 22nd, 2013, the European Commission has published under the EURATOM Treaty the Council 2013/51/EURATOM Directive: ***laying down requirements for the protection of the health of the public with regard to radioactive substances in water intended for human consumption***. This directive reflects accurately the principles of the technical annexes which have to be integrated into the Directive 98/83/EC.

It considers the previous two parametric values and a third was added: ***100 Bq/litre Radon (^{222}Rn)***.

With regard to the necessity of calculating the total indicative dose or not, two approaches have been included in the technical annexes based on "screening" values. The Member States can opt for either depending on their customs and preferences in the matter of radiological monitoring of the environment and their populations. These "screening" values facilitate control of the water and avoid the pointless duplication of costly analyses while still ensuring that the water distributed actually meets the standards. In both cases, the parametric value of 100 Bq/litre for tritium also serves as a "screening" value.

- The first approach, the so-called *"global"* approach, is based on an assessment of the overall natural and artificial radioactivity with screening values of 0.1 Bq/litre in total alpha and 1 Bq/litre in total beta. These values enable the water to be screened quickly. If these levels are exceeded, it is then necessary to check whether natural radioactivity is responsible for the levels measured and, conversely, to analyse a maximum number of radionuclides (beta and alpha spectrometries).

  This is the approach followed in Belgium under its programme for the radiological monitoring of drinking water (together with systematic gamma spectrometry analyses) and transposing the European directive into federal legislation through the Royal Decree of 31 May 2016 (Royal Decree on the protection of the health of the population with regard to radioactive substances in water intended for human consumption). This Royal Decree is supplemented by the Agency Order (FANC) of 24 November 2016 (Decree on the implementation rules for the control of radioactive substances in water intended for human consumption). The screening value for beta emitters has been fixed in Belgium on the basis of beta residual (total beta - K-40) at 0.2 Bq/L.

- The second approach, the so-called *"specific analyses of radionuclides"* approach, is based on the measurement of a certain number of radionuclides (uranium; in β: ^{14}C and ^{90}Sr; in α: $^{239+240}Pu$ and ^{241}Am; in γ: ^{60}Co, $^{134-137}Cs$ and ^{131}I), the levels of which must be lower than 20% of the reference concentration value (a concentration which would alone lead to a dose of 0.1 mSv).

If any of the screening values are exceeded, complete analyses in α, β and γ have to be carried out to calculate the total indicative dose using the conversion factors of the Basic Safety Standards set out in Directive 96/29/EURATOM (for an annual ingestion of 730 litres of water for adults and children over the age of 10).

Belgium, which has hundreds of catchment points, has put a general plan in place for monitoring its water so as to be able to apply and abide by this new directive in the framework of the Royal Decree of 31 may 2016.

7.1.1 Radiological monitoring programme of the territory

The radiological monitoring programme already monitors the quality of the water distributed by the country's biggest water distributors. The provinces where controls are undertaken are the following: Flemish Brabant (Leuven), Walloon Brabant (Wavre), Brussels Capital region (Brussels), Liege (Liege), Namur (Namur), Hainaut (Fleurus), Luxembourg (Florenville), East Flanders (Ghent), West Flanders (Reningelst and Poperinge), Antwerp (Mol) and Limburg (Hasselt).

The control of radioactivity covers the total alpha, total beta, ^{226}Ra and ^{40}K (natural) emitters as well as tritium ^{3}H (artificial). The following table summarises the results obtained in the monitoring of drinking water.

Analysis of the table shows:

- Only ^{3}H and ^{40}K can be detected, with the measurements barely higher than the detection limits of the measuring equipment when they are significant;
- In some places, the total α levels exceed the screening value of 0.1 Bq/litre, which represents a caution threshold. Nevertheless, the TID never reaches the parametric value of 0.1 mSv/year;
- The mains water is therefore completely drinkable and fully meets European standards.

Radioactivity measurements for drinking water

	Radioactivity of the water (Bq/L)	DL (Bq/L)	"Screening" value (Bq/L)
^{3}H	NM (Florenville, Fleurus, Liege) 5 to 47 (Namur) NM to 41 (Wavre) NM (Mol, Hasselt, Leuven, Reningelst, Poperinge) 16 to 33 (Brussels) NM to 34.0 (Ghent)	~ 2.9 ~ 2.9 ~ 3.0 7.2 to 8.3 3.0 to 8.0 ~ 8.5	100
total β (residual) *	NM to 0.075 (Fleurus, Liege) NM to 0.070 (Florenville, Namur, Wavre) NM to 0.060 (Mol) NM (Hasselt, Reningelst, Poperinge, Ghent) NM to **0.12** (Leuven) NM (Brussels)	0.047 to 0.177	1 (total β) 0.2 (residual total β)
total α	NM to 0.017 (Florenville) NM to 0.043 (Namur, Wavre) 0.064 to **0.156** (**Fleurus**) NM to 0.036 (Liege) NM (Mol) NM to 0.029 (Hasselt) **0.127** to **0.213 (Reningelst)** NM to **0.129** (Poperinge) NM (Ghent) 0.033 to 0.046 (Leuven) NM (Brussels)	0.012 to 0.029	0.1
^{226}Ra	0.101 to **0.136 (Reningelst)** NM to **0.147** (**Poperinge**) 0.040 to 0.073 (Fleurus) NM to 0.011 (Florenvlle, Liege, Namur, Wavre)	~ 0.01	0.1
^{222}Rn	4.5 to 51.9 (Florenville) 1.0 to 16.0 (Fleurus) NM to 0.5 (Namur) ~ 13.0 (Wavre) 0.4 to 0.9 (Liege) 0.6 to 1.4 (Mol) NM to 1.6 (Poperinge) 2.3 to 4.9 (Hasselt) 1.0 to 2.2 (Reningelst) 2.0 to 4.7 (Leuven) NM (Ghent) NM (Brussels)	0.40 to 0.47	100

NM: non-measurable, measurement less than or equal to the detection limits (DL)
* total β residual: total β apart from ^{40}K

Summary:

- The radiological impact of the nuclear industry on distributed drinking water is not measurable: it meets the new standards put in place by the European Directive on drinking water;

- It should be noted that the greater part of beta radioactivity is explained by the presence of ^{40}K, a natural radioactive nuclide whose contribution must not be taken into account when calculating the dose to which humans are subjected;
- A closer analysis of the monitoring programme results shows that although the water intended for human consumption generally complies with the standards, special attention must be paid at particular points (especially at Reningelst in the vicinity of Poperinge, and at Fleurus) to the total alpha emitter content, with the greatest input coming from ^{226}Ra (natural), which sometimes exceeds the screening value of 0.1 Bq/litre. Even though this does not lead to the TID being exceeded, this water must be subjected to more particular monitoring. The origin of these exceeding's at Reningelst are due to mixtures of water coming from Wallonia (region of Fleurus / Mons), which are naturally more rich in radium. Checks are also applied to the main grid of Poperinge themselves which show quite no exceedings. So the routine checks also take into account the city of Poperinge in addition to these applied to Reningelst.

7.1.2 Radiological state of groundwater in Belgium

As part of its diverse activities outside of the radiological surveillance programme, FANC regularly obtains data on natural radioactivity in groundwater from the different aquifers present in Belgium. In particular in NORM declarations (see 8.2), groundwater analysis is required as part of the declaration procedure or during imposed routine site monitoring. In addition, a large amount of data is available from literature and previous studies.

These analyses, though not individually aimed at evaluating the global radiological state of an aquifer, allow at long term the establishment of average radioactivity levels for groundwater from the different aquifers. FANC has therefore initiated in 2014 an action to collect these data in order to create a global image of the radiological state of groundwater in Belgium.

While the exercise is still ongoing, it is however useful to present a summary of the results obtained until 2018.

FANC works together with ISSeP in Wallonia (see chapter 8) and with Brussels-Environment in Brussels in order to perform radioactivity analysis on selected samples of their control network of quality of groundwater. In 2018, ISSeP put at FANC disposal 35 samples collected in the following Walloon aquifers:

- E013 – Limestone of Peruwelz-Ath-Soignies
- E032 – Chalk of Deûle valley
- E033 - Alluvium and sand of Haine valley
- E034 – Thanetian Sand of Rumes-Brunehaut
- E060 – Tournesian Limestone
- E061 – Sand of Flanders
- E160 - Basement of Brabant
- M022 – Limestone and Sandstone of Sambre basin
- M023 - Limestone and Sandstone of Calestienne and Famenne
- M041 – Sand and Chalk of Méhaigne
- M052 – Brusselian Sand of Haine and Sambre
- M073 - Alluvium and Gravels of Meuse (Engis - Herstal)
- M091 - Conglomerates of Rhetian (Upper Triassic)
- M092 – Lower Lias (Sinemurian)

- M100 – Sandstone and shale of the Ardenne massif : Lesse, Ourthe, Amblève
- M103 - Sandstone and shale of the Ardenne massif : Semois, Chiers et Viroin
- M141 – Limestone and Sandstone of Gueule basin
- M142 - Limestone and Sandstone of Vesdre basin
- M151 – Chalk of Pays de Herve
- R092 – Sandstone of Luxembourg (Sinemurian – Lower Lias)
- R101 - Sandstone and shale of the Ardenne massif : Moselle basin

The following table shows the ***mean radioactivity values of screening parameters*** (global alpha, global beta, ^{40}K and radon) measured in groundwater from aquifers for which at least 3 independent analyses are available.

Values of radiological screening parameters in Belgian groundwater[4]

Paramètre	**^{40}K**	**Beta-T**	**Alpha-T**	**Rn-222**
Valeur de screening (Bq/L)	-	*1*	*0,1*	*100*
Basement of the Brabant Formation	0,44 ± 0,28	***0,6 ± 0,5***	<u>**0,27 ± 0,17**</u>	68 ± 29
Tournaisian carboniferous limestone	0,38 ± 0,09	0,54 ± 0,12	<u>**0,27 ± 0,14**</u>	17 ± 9
Namur Basin carboniferous limestone	0,06 ± 0,03	0,14 ± 0,04	<u>**0,24 ± 0,15**</u>	29 ± 30
Chalk of the Mons Basin	0,14 ± 0,10	0,22 ± 0,14	<u>**0,13 ± 0,09**</u>	12 ± 4
Devonian limestone of Dinant	0,08 ± 0,06	0,11 ± 0,07	***0,083 ± 0,023***	11 ± 2
Landenian	0,23 ± 0,17	0,18 ± 0,10	***0,06 ± 0,04***	23 ± 9
Chalk	0,26 ± 0,06	0,25 ± 0,15	***0,06 ± 0,04***	
Carboniferous limestone of Dinant	0,057 ± 0,020	0,090 ± 0,009	0,06 ± 0,01	19 ± 15
Virtonian	0,032 ± 0,016	0,078 ± 0,017	0,053 ± 0,023	13 ± 3
Brusselian	0,044 ± 0,013	0,12 ± 0,09	0,0447 ± 0,027	
Shale Formation of the Ardennes	0,03 ± 0,04	0,06 ± 0,04	0,029 ± 0,015	<u>**128 ± 101**</u>

For four aquifers, FANC the mean value of global alpha (alpha-T) exceeds the screening value of 0.1 Bq/L as defined in the Directive 2013/51/EURATOM. For three others, the sum of mean and standard deviation also exceeds this value. We must also note that for the aquifer of the Shale Massif of the Ardennes, the radon screening level of 100 Bq/L is exceeded (also see below).

For certain aquifers, FANC has gathered analyses of the complete natural radiological vector. These aquifers, and the values measured, are summarised in the table below.

This overview, though for the moment based upon a limited number of samples from just four aquifers, contains nevertheless a few important elements:

- groundwater from the Tournaisian carboniferous limestone show the highest levels of natural radioactivity of the four studied aquifers. The indicative dose, as defined by 2013/51/EURATOM, exceeds 0.1 mSv/year. The largest contribution to this dose is due

[4] Values in Bq/L. Every value is a mean ± standard deviation of at least 3 analyses. Means exceeding the screening values are marked <u>**bold and underlined**</u>. Values where mean ± standard deviation exceed the screening value are marked ***bold italic***.

to the presence of ^{226}Ra and of ^{228}Ra. This observation is important, as the aquifer is one of the most important sources of groundwater for drinking water distribution in the Walloon region. It should be noted however, that these values were measured in untreated groundwater, and that the majority of the radioactive substances in the water are removed during treatment by filtration or ion exchange.

- The basement of the Brabant Formation shows elevated ^{228}Ra levels, as well as a ^{222}Rn-concentration close to its screening value of 100 Bq/L. It should also be noted that its daughter isotopes, such as ^{210}Pb, contribute to an elevated indicative dose.
- The Shale Massif of the Ardennes is well known for its radiferous properties, which translates in groundwater enriched in radon, as well as ^{210}Pb et ^{210}Po. We must also mention the notable absence of radium and uranium.

The aim of this exercise, beyond its evident scientific interest, is to establish reference values which can be used as a standard for each aquifer or for each geographically distinct part of an aquifer. These values will allow for a better detection and evaluation of radiological anomalies due to human activity and a better identification of risk zones in the monitoring of water intended for human consumption (see 7.1.1).

Measurement of natural radioactivity in Belgian groundwater – the complete natural radiological vector

Parameter	*Screening Value (Bq/L)*	**Tournaisian carboniferous limestone** *N=2*	**Basement of the Brabant Formation** *N=3*	**Shale Massif of the Ardennes** *N=2*
^{222}Rn	*100*	17 ± 49	68 ± 29	**128 ± 101**
^{238}U	*2,8*	< 0,003	0,011 ± 0,005	< 0,002
^{234}U	*3*	0,010 ± 0,007	0,019 ± 0,016	< 0,003
^{226}Ra	*0,5*	0,31 ± 0,04	0,059 ± 0,009	< 0,021
^{228}Ra	*0,2*	0,07 ± 0,05	0,101 ± 0,015	< 0,028
^{210}Po	*0,1*	< 0,02	0,004 ± 0,004	0,03 ± 0,03
^{210}Pb	*0,2*	0,015 ± 0,007	0,045 ± 0,003	0,0333 ± 0,0016
***Indicative Dose*[5]**	*0,1 mSv/y*	***0,104 ± 0,026***	*0,090 ± 0,009*	*0,05 ± 0,03*

In the future, this table will be completed with the available historical data of the other Belgian aquifers. This will already yield global averages for each groundwater body which do not take into account the possible geographical variations within the same aquifer. In a second phase, a geographical analysis will be performed, which will allow at long term for a detailed cartography of natural radioactivity in groundwater.

[5] the Indicative Dose is calculated by dividing each measured radionuclide concentration by its screening value (2013/51/EURATOM), and by subsequently taking the sum of the ratios thus obtained. A sum of 1 corresponds to an annual dose of 0.1 mSv/year.

7.2 RADIOACTIVITY OF MILK

Milk is a staple product for infants, in particular, as well as an important biological indicator of the transfer of radionuclides to humans via the food chain. That is why it is subjected to particular monitoring. Regular monitoring of the radioactivity of milk coming from dairies is preferable to sampling foods consumed, which is often too uncertain. This measurement reflects very well the total average ingestion of artificial radionuclides by the population since the dairies spread across the area collect the milk produced by the cows, which play an "integrator" role in relation to the radioactivity deposited or fixed in the plants consumed. The contamination of milk therefore gives a fairly true and quick picture of the state of radioactive contamination of a region.

Routinely, the detection of ^{137}Cs present in a weighted mixture of milk can be sufficient to calculate the effective dose rate due to diet. Nevertheless, milk is also collected from farms and dairies. The dairies included for taking the samples are located in a radius close to the nuclear power stations (20km) depending on the extent of their production. They cover practically the entire dairy production of the region. The farms are located in the line of the prevailing winds close to the nuclear sites.

Each month, a national mixture is carried out from the main Belgian dairies. This mixture is weighted according to the relative size of each of them.

The radionuclides mainly checked in the milk samples are: ^{40}K for natural radioactivity and ^{90}Sr, $^{134,137}Cs$ and ^{131}I for artificial radioactivity (beta and gamma emitters).

In greater detail:

- The results relating to the natural radioactivity of milk show that the average content of a litre of milk remains constant at around 44-50 Bq. The other artificial radionuclides are undetectable;
- The milk distributed in Belgium fully meets the limits set by the European Commission: maximum 370 Bq/kg in ^{134}Cs and ^{137}Cs in milk and products derived from milk (Council Regulation on Radiation Protection no. 737/90 of 22 March 1990 extended by regulations no. 686/95 of 28 March 1995 and no. 616/2000 of 20 March 2000).

The following table presents a summary of the results obtained.

Radioactivity measurements for milk according to region

	National territory	Sambre – Meuse basin		Nete – Scheldt basin		
	National mixture	Fleurus, Tihange regions	Chooz region	Mol – Dessel region	Doel region	
	measurement (Bq/L)					DL (Bq/L)
^{137}Cs	NM	NM	NM	NM	NM	0.2 to 0.7
^{131}I	NM	NM	NM	NM	NM	0.3 to 1.8
^{90}Sr	NM	NM	NM	NM	NM	0.05 to 0.09
^{40}K	46 to 50	39 to 50	42 to 49	45 to 51	44 to 48	

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Summary:

- Artifical radiation cannot be measured for $^{134,137}Cs$ and ^{131}I and is hardly detectable for ^{90}Sr (residue of "fallout" from atmospheric nuclear tests, with measurements at the level of the detection limits);
- The nuclear installations have no impact on the radiological quality of milk;
- Natural radioactivity (^{40}K) is by far predominant.

7.3 RADIOACTIVITY OF FOODSTUFFS

Samples of different foodstuffs are taken on the national territory by targeting small retail outlets and supermarkets, markets, abattoirs, fishmongers, etc.

The report includes data obtained as part the surveillance of the territory programme (480 samples resulting in nearly 3,050 measurements of radioactivity) increased by those provided by the Federal Agency for Security of the Food Chain - FASFC (194 samples), resulting in 605 additional radioactivity measurements. Also, 674 food samples were tested (non alcoholic beverages, tea, food additives and animal proteins not included) and the data analyzed and interpreted. The FASFC targets in particular border entry points for import from non-European countries, customs agencies, slaughterhouses, farms, warehouses, manufacturers and wholesalers... All these checkpoints are accessible to this agency as part of its mission.

Common staple vegetables are collected: lettuce, leeks, celery, cauliflowers, Brussels sprouts, white cabbages, red cabbages, broccoli, beans, carrots, chicory, asparagus, tomatoes, cucumbers, peppers, salsifies, turnips, eggplant, zucchini, spinach, beets, fennel, pumpkins, onions, rutabagas, potatoes, cultivated mushrooms, wild mushrooms, etc.

Common staple of fruits are also collected: pears, appels, nectarines, kiwis, plums, mangos, melons, oranges, bananas, berries, strawberries, blackberries, grapes, etc.

Meat is also analysed from markets and abattoirs: beef, veal, horse, pork, sheep, goat, rabbit, lamb, poultry (including chicken, turkey, pheasants, ducks, geese, ostriches, etc.), roe and wild boar season. Snails and frog legs are also controlled. The organs concentrate radionuclides differently in the same animal. These differences are linked to the metabolic paths taken by the radioactive nuclides to penetrate and possibly settle in the organism. As an example, caesium mainly settles in the muscles (and in the bones over the longer term), while strontium behaves like calcium and, for its part, settles in the bony structures. The physiological factors of concentration, i.e. the differences in fat and water levels of the organs, can also influence the mechanism of radionuclide concentration. In general, however, the edible part is constituted of muscles. It is therefore sufficient, for example, to look into the radio-caesium content of the muscles (meat) in order to obtain a general idea of the quantity of radioactivity that may be transferred to humans.

Fish from fisheries are also taken into account: fresh water fish (tilapias, silurids, etc.) and deep-sea marine fish (tuna, swordfish, bream, bass, cod, herring, whiting, ray, sea trout, mullet, ocean perch, pollack, salmon, etc) and fish living on the bottom (plaice, sole, etc.).

In greater detail:

- The data analysed reveal a good radiological state of the foodstuffs consumed. Indeed, the samples display practically no detectable artificial radioactivity (the greater part of the samples measured have non-measurable levels of radioactivity, since they are lower than or equal to the detection limits of the measuring equipment);
- The results obtained adequately confirm the positive record revealed for the previous years: the foodstuffs circulated in Belgium as well as national production are of an excellent radiological level, with no problems noted. Furthermore, these foodstuffs fully meet the limits set by the European Commission: maximum concentration of 600 Bq/kg in ^{134}Cs and ^{137}Cs (Commission regulation on Radiation Protection no. 737/90 of 22 March 1990 extended by regulations no. 686/95 of 28 March and no. 616/2000 of 20 March 2000).

The following table presents a summary of the results obtained.

Radioactivity measurements for foodstuffs in Belgium (Bq/kg dry)

	Vegetables, fruits & cereals		Sea fish	
	measurement	DL	measurement	DL
^{137}Cs	NM	0.2 to 1.1	NM to traces	0.2 to 5.0
^{226}Ra	NM vegetables NM fruits	0.6 to 2.0 ~ 0.4	NM	0.6 to 1.8
^{40}K	23 to 800 vegetables 31 to 79 fruits		42 to 410	

Radioactivity measurements for foodstuffs in Belgium (Bq/kg dry)

	molluscs crustaceans (marine)		Meat (beef, veal, horse, pig, sheep, rabbit, poultry, game: roe, deer, boar)	
	measurement	DL	measurement	DL
^{137}Cs	NM	~ 1.0	NM traces	0.3 to 0.8 ~ 5
^{226}Ra	NM	2.0 to 2.5	NM	0.6 to 1.6
^{40}K	180 to 240	~ 45	92 to 420	~ 45

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Measurements of ^{90}Sr made on mixtures of meat never show a detection (the detection limits fluctuate between 0.2 and 0.5 Bq/kg). The same applies to molluscs and crustaceans (detection limits fluctuatearound 3.5 Bq/kg depending on the analysed samples).

Summary:

- The measurements carried out on everyday foodstuffs in Belgium do not call for any particular comments with regard to their radiological state. This control is nevertheless necessary because it constitutes a good tool for detecting a nuclear incident or accident, with the products measured often playing the role of indicators of radioactive pollution;

7.4 RADIOACTIVITY OF CONTROL MEALS

Samples of "control" meals are taken from canteens, supermarkets restaurant or company restaurants (mess) in the Brussels Capital region, Flanders and Wallonia on a monthly basis (EC obligation under Art. 35/36 of the EURATOM treaty – establishing a closely knit and widespread network) for radiological analyses.

The following table presents the results of these controls.

Radioactivity measurements for control meals (Bq/meal)

	Brussels (Drogenbos - CARREFOUR)		Wallonia (Fleurus - canteen)		Flanders (Mol- mess SCK•CEN/VITO)	
	measurement	DL	measurement	DL	measurement	DL
$^{134,137}Cs$	NM	~ 0.20	NM	~ 0.52	NM	~ 0.20
^{90}Sr	NM	~ 0.28	NM	~ 0.20	NM	~ 0.40
^{40}K	27 to 53		25 to 82		20 to 54	
^{14}C	0.19 to 0.24*	< 0.04*	NM*	< 0.12*	0.19 to 0.20*	< 0.04*

NM: non-measurable, measurement less than or equal to the detection limits (DL)
* *expressed in Bq ^{14}C / g of stable C*

Summary:

The results obtained confirm the observation drawn from the analysis of the radioactivity of foodstuffs: no radiological problem for Belgian consumers.

8. MONITORING DISCHARGES FROM NUCLEAR SITES AND NORM INDUSTRIES

The effluents from liquid waste treatment installations are controlled under the territorial radiological monitoring programme. These controls are conducted on samples taken by the operator and/or the institute charged by the Agency to measure radioactivity.

The operators of nuclear power stations also provide declarations on atmospheric discharges via the chimneys. These discharges are not controlled directly via the territorial radiological monitoring programme but, rather, by FANC under its site controls (controls on the serviceability of the installations and compliance with operating permits). An information dossier that specifically treats the radioactive discharges from Class I nuclear installations, is also published by the FANC. The information relates to the discharge declarations of operators of nuclear installations (http://fanc.fgov.be/nl/informatiedossiers/radioactiviteit-het-leefmilieu/radiologisch-toezicht-op-belgisch-grondgebied for the Dutch version or http://afcn.fgov.be/fr/dossiers-dinformation/la-radioactivite-dans-lenvironnement/surveillance-radiologique-du-territoire-2 for the French version).

The sites monitored are:

- Nuclear power sites (Doel and Tihange);
- Sites of Mol-Dessel (Belgoprocess 2 – former SCK•CEN liquid waste treatment installation, Belgoprocess, Belgonucléaire and FBFC International);
- IRE site: does not produce radioactive liquid waste in the environment but may reject noble gases and gaseous iodines in a controlled manner in accordance with its operating permit;
- Tessenderlo NORM-industry (production unit for feed phosphates), which discharged ^{226}Ra into the Grote Laak and the Winterbeek. The follow-up of these discharges is integrated into the radiological surveillance programme. Furthermore, other NORM-sites or historically contaminated sites have been integrated in the radiological surveillance programme or are monitored under responsibility of the operator.

Generally, the analysis of liquid discharges from the nuclear sites indicates that they remain well below the limits imposed on them.

The liquid discharges into the Molse Nete are less negligible and make it necessary to monitor this eco-system. The presence of a chemical industry at Tessenderlo and its past discharges of ^{226}Ra strengthen the obligation to monitor the radio-ecological status of this region. This monitoring is also needed for other sites with historical NORM contamination.

8.1 LIQUID DISCHARGES OF NUCLEAR INSTALLATIONS

The following sites discharge into rivers:

- Nuclear power sites (Doel nuclear power station into the Scheldt and Tihange into the Meuse):
- Sites of Mol-Dessel (Belgoprocess 2 - former SCK•CEN liquid waste treatment installation, Belgoprocess, Belgonucléaire and FBFC International - into the Molse Nete).

8.1.1 Nuclear power stations:

The liquid discharge limits set for the *Tihange site*, three reactors with a total capacity of 3,016 MWe, are 1.48 10^5 GBq in ^3H and 8.88 10^5 MBq in beta-gamma emitters; for the *Doel site*, four reactors of a total capacity of 2,9011 MWe, they are set at 1.04 10^5 GBq in ^3H and 1.50 10^6 MBq in beta-gamma emitters; see the information dossier[6] on the discharges of radioactive waste from Class I nuclear installations).

In greater detail:

- For the Tihange nuclear power station: the primary wastewaters are the most radioactive.

The following table summarises the available data.

Measurements of the radioactivity of liquid discharges from the Tihange NPP of different discharge circuits expressed in Bq/liter (DL: detection limit)

	Treatment of primary effluent (drain)		Purging of the steam generators	
	Measurement	DL	Measurement	DL
^{137}Cs	NM to 25.0	2.4 to 2.9	NM to 18.1	~ 1.5
^{134}Cs	NM	~ 2.3	NM	~ 1.6
^{60}Co	NM to 182	~ 1	NM (548 in August)	~ 1.5
^{58}Co	NM to 74	~ 2	NM (41 in August)	~ 2.1
^{54}Mn	NM to 9	1.2 to 1.5	NM (11 in August)	~ 1.5
^{110m}Ag	NM to 91	~ 2	NM (70 in August)	~ 1.8
^{51}Cr	NM	28 to 60	NM	~ 47
$^{124, 125}Sb$	NM to 42	3 to 5	NM (30 in August)	2.7 to 3.9
^3H	4.4 10^2 to 4.8 10^6		89 to 1,600	

NM: non-measurable, measurement less than or equal to the detection limits (DL)

These wastewaters are not discharged as such, they are diluted with "cold" wastewater from technical areas and rooms, as well with the recovered condensate from the cooling towers.

[6] French : https://afcn.fgov.be/fr/system/files/2019-06-21-rejets-2018-afcn.pdf
Dutch : https://fanc.fgov.be/nl/system/files/2019-06-21-lozingen-2018-fanc.pdf

Summary: no radiological problem indicated on the basis of these results.

- For the Doel nuclear power station: the primary wastewaters are the most radioactive.

The following table summarises the available data.

Measurements of the radioactivity of liquid discharges from the Doel NPP of different discharge circuits expressed in Bq/liter (DL: detection limit)

	Treatment of wastewater from the controlled areas		Treatment of secondary wastewater from the controlled areas	
	Measurement	DL	Measurement	DL
^{137}Cs	NM to 5.8	~ 1.5	NM	~ 1.1
^{134}Cs	NM	~ 1.4	NM	~ 1.1
^{60}Co	NM to 16	~ 1.5	NM	~ 1.1
^{58}Co	NM to 20	~ 2.1	NM	~ 1.4
^{54}Mn	NM	~ 1.3	NM	~ 1.1
^{110m}Ag	NM to 7.2	~ 1.6	NM	~ 1.1
^{51}Cr	NM	~ 20	NM	~ 16
$^{124,\,125}Sb$	NM to 25	1.7 to 3.7	NM to 11.2	1.3 to 3.0
^{3}H	0.7 10^5 to 7.2 10^5		16 to 61	

NM: non-measurable, measurement less than or equal to the detection limits (DL)

These wastewaters are not discharged as such, they are diluted with "cold" wastewater from technical areas and rooms, as well with the recovered condensate from the cooling towers.

Summary: no radiological problem indicated on the basis of these results.

8.1.2 Other nuclear sites:

Mol-Dessel site:

The liquid discharges from the Mol-Dessel nuclear site enter the Molse Nete via the installations of Belgoprocess 2.

The discharges from the site into the Molse Nete adequately comply with the limit set, even though they are detectable, as also attested by the radioactivity measurements taken in the river (water, sediments, fauna and flora). These controls at the source and in the environment need to be maintained.

In greater detail:

The following table summarises the data obtained.

Radioactivity measurements for liquid discharges from the Mol-Dessel nuclear sites, sampled in the drain pipe just before the discharge, expressed in Bq/liter

Radioactive nuclide	Measurement	DL
^{137}Cs	NM to 10	1.3 to 1.5
^{134}Cs	NM	~ 1.3
^{60}Co	NM	1.2 to 1.3
^{58}Co	NM	1.4 to 1.8
^{54}Mn	NM	1.2 to 1.3
^{99}Tc	0.1 to 1.5	~ 0.1
total β	0.2 to 15.4	~ 2.0
^{90}Sr	0.5 to 4.3	~ 1.0
total α	NM to 19.8	~ 0.04
^{241}Am	0.1 to 18.5	~ 0.08
$^{239,240}Pu$	0.025 to 2.37	0.003 to 0.009
$^{234,238}U$	NM to 1.2	0.0011 to 0.0018
^{3}H	$2.2\ 10^3$ to $1.1\ 10^5$	

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Summary: no radiological problem indicated on the basis of these results.

FBFC International site:

The liquid discharges of ***FBFC International***, a manufacturer of nuclear fuel and assembler of MOX fuel elements, enter a sink located on the site. These discharges do not reach the Molse Nete. They are nevertheless monitored regularly (every month). The production of UO_2 pellets has stopped since early 2012. The assembly of MOX fuel (mixed oxides of U and Pu) continued with a shutdown in 2015. In addition, the dismantling of part of the facilities started in 2011.

In greater detail:

The shutdown of the UO_2 pellet production results in a reduction of discharges. Measurable quantities of alpha emitters are still discharged every month: up to 0.16 Bq/L (a decrease is recorded compared to 2001-2002 and is even more pronounced since 2011-2013). It should be noted that the detection limits are less than 0.03 Bq/L, which indicates that these discharges are barely measurable. The site can’t discharge more than 20 Bq/L in total alpha (GRPIR).

On the other hand, the dismantling of part of the facilities led to a slight detection of transuranic discharges (Pu).

The following table summarises the data obtained.

Radioactivity measurements for liquid discharges from the FBFC International Mol-Dessel nuclear site expressed in Bq/L (DL: detection limit)

Radioactive nuclide	measurement	DL
γ	NM	1.0 to 2.0
^{137}Cs	NM	~ 1.43
total α	NM to 0.16	~ 0.028
total β	NM to 0.64	~ 0.002
^{234}U	0.002 to 0.104	~ 0.0016
$^{235,236}U$	NM to 0.005	~ 0.0015
^{238}U	NM to 0.052	~ 0.001
^{241}Am	NM to 0.009	~ 0.008
^{238}Pu	NM to 0.056	~ 0.002
$^{239+240}Pu$	NM to 0.0035	~ 0.002

NM: non-measurable, measurement less than or equal to the detection limits (DL)

Summary: no radiological problem to report.

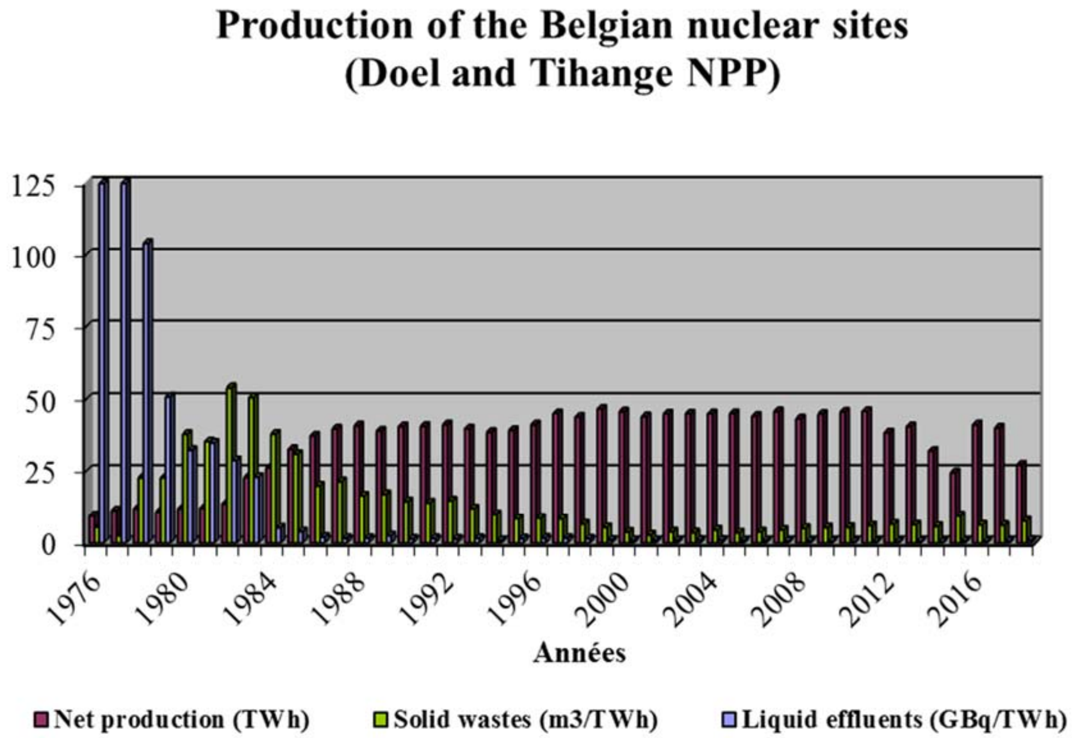
8.1.3 Electrabel data on nuclear power stations:

Another interesting point to note concerns the quantity of liquid and solid waste (removed for treatment by the ONDRAF - National Organisation for Radioactive Waste and Enriched Fissile materials) generated by nuclear power stations (following chart).

The total production of electricity has remained up to 2011 around 45 TWh with a decrease to about 40 TWh in 2012-2013, approximately 32 TWh in 2014 and then to 24.6 TWh in 2015 due to a long-term stop of some reactors, increased to 41.3 TWh in 2016 and remains at 40,2 TWh in 2017. The quantity of radioactivity discharged in the liquid effluents has sharply declined: from around 42 GBq in 2003 and 2004, it decreased progressively to about 16-17 GBq from 2010 to 2013 (~ 0.40 GBq/TWh) to ~ 9 GBq in 2014 (being 0,28 GBq/TWh), to 14 GBq in 2015 (being 0.57 GBq/TWh), to ~ 19-20 GBq in 2016 and 2017 (being 0.46 to 0.50 GBq/TWh) and to 26.3 GBq in 2018 (being 0.96 GBq/TWh).

This observation is even more amplified by the volume of solid waste generated per TWh removed for treatment by the ONDRAF: current volumes remain low and stable around 6 m^3/TWh from 2012 to 2014, they increased to about 9,5 m^3/TWh in 2015, decreased in 2016 to about 6.3 m^3/TWh, to 6,2 m^3/TWh in 2017 and to 7.8 m^3/TWh in 2018.

This shows the efforts made by Belgian electrical engineers to reconcile the objectives of optimising industrial operations, notably in reducing the volumes of waste produced and the related costs while, on the other hand, “reducing” the discharge of effluents as far as possible. These elements of assessment clearly demonstrate the application of the B.A.T. – “Best Available Technology” – concept with regard to liquid and solid waste.



8.2 NORM-INDUSTRIES AND HISTORICALLY CONTAMINATED SITES

Belgium accounts for several active NORM-industries, e.g. in the sector of phosphate or titanium dioxide production. The residues of these industries are in some cases disposed of in *mono-landfills*. As one is dealing in this case with significant amounts of material – several million m^3 - the radiological impact of these mono-landfills on the environment may not necessarily be neglected. This of course justifies the implementation of a system for surveillance of these sites.

Furthermore, in Belgium, there exist also a number of sites that were contaminated by radioactive substances as a consequence of past activities – one speaks about « historically contaminated sites » or « legacy sites ». Besides those sites related to the NORM-industry – like the former phosphogypsum stacks - there are also some sites related to the past activities of radium extraction.

Since 2013, several of these sites have been integrated in the radiological surveillance programme. In some cases, the environmental monitoring has been carried out by the operator of the site.

8.2.1 Sites related to the phosphate industry

8.2.1.1 Sites related to the activities of TESSENDERLO CHEMIE nv

TESSENDERLO CHEMIE nv produced in particular animal feed phosphates from sedimentary phosphate rocks from North African origin. The phosphate unit shut down end 2013 and has achieved in 2015 most of its decommissioning. The dissolution of phosphate ore was carried out with hydrochloric acid. It resulted in the production of large amounts of waste essentially made of calcium fluoride. This waste was deposited on landfills.

a) Streams *Grote Laak* and *Winterbeek*

Until the 90s, a significant proportion of radium present in the phosphate ore was discharged via the waste water releases. The concentration of radium in the waste water could reach at that time 20 to 25 Bq/L. To reduce this concentration, the process of co-precipitation with barium was used: this led to a remarkable decrease in the concentration of radium in water.

Since 2000, releases operated by TESSENDERLO CHEMIE have been measured directly in the discharge channel which flows into the Winterbeek river. The stopping of the phosphate production end 2013 and the decommissioning of the installations took away the source of radium discharges; control measurements have confirmed that Ra-226 concentration in liquid discharges of the facility had become negligible.

This natural radioactivity was hence being artificially added into the Nete basin, originally through the Grote Laak and later on also through the Winterbeek into the Demer basin.

This led to a contamination of the beddings of the Laak and Winterbeek. The dredging and sediment disposal on their banks has led to the contamination of these banks. Concentrations of radium in the order of a few Bq/g were found. A site remediation project for the Winterbeek's bedding, its banks and flooding areas has started in 2017 and is controlled by a working group of which FANC is a member. Control analysis have been done on remediation materials in the framework of the radiological surveillance. They indicate an average Ra-226 activity concentration of 1.3 Bq/g with a maximum of 12.6 Bq/g.

b) The landfills

The sludge pond (mono-landfill) "Veldhoven" on which TESSENDERLO CHEMIE nv dumps its solid waste is also subject to a monitoring program. Some residues from the decommissioning of the phosphate unit have also been dumped onto this landfill – the conditions of landfilling had been defined in an authorization granted by FANC. Outdoor radon concentration is followed on and around the waste site. Following table shows the radon concentrations (in Bq/m^3) as measured since 2013. The S1 and S2 areas are the oldest zones of the sludge pond. The table also shows radon concentration on a former sludge pond located inside the premises of the factory.

	On and around S1 and S2 areas	S3	Surroundings of the landfill	Landfill within the premises of the factory
2013	45	20	10	43
2014	45	35	15	58
2015	40	25	15	37
2016	35	25	15	32
2017	40	25	15	22
2018	50	25	15	17

Dust deposition around this landfill are also followed by TESSENDERLO CHEMIE. In 2018, FANC asked for analysis of the uranium concentration in these dust samples. Some results indicated a value higher than the one of the reference sample.

Next to the Veldhoven sludge pond which is still partly in operation, TESSENDERLO CHEMIE still owns other landfills and ponds which are not in operation anymore.

Tessenderlo Chemie also started on the former Kepkensberg sludge pond a storage facility for the materials coming from the remediation of Winterbeek and (in the future) Grote Laak and from various remediated sites of Tessenderlo Chemie. A radiological monitoring has been imposed to this facility.

8.2.1.2 Sites related to the activities of PRAYON sa

The company PRAYON produces phosphoric acid and fertilizers; it uses the process of dissolution by sulfuric acid, which leads to the production of phosphogypsum as residue. It owns two production sites: one in Puurs between Brussels and Antwerp, and the other in Engis near Liege.

Currently, the production of the site at Puurs is made directly from phosphoric acid, so that only marginal quantities of phosphogypsum are produced. The site at Engis uses as raw materials mainly phosphate ores from magmatic origin. They have a concentration of natural radioactive elements significantly lower than the sedimentary phosphates.

PRAYON operates near its production site of Engis a mono-landfill – in Wallonia also known as "Centres d'Enfouissement Technique" or CET of class 5.2[7] of « Engihoul » - where the surpluses of phosphogypsum from the production process are disposed off.

There is also in Engis a former phosphogypsum stack – the Hardémont site – which is not in operation anymore (see the surveillance report of 2010). The outdoor radon concentration on the landfill of Engihoul and on the Hardémont site have been followed as well as water around the "Engihoul" CET. Only one piezometer of that stack shown a "gross alpha" value higher than the screening value for drinking water. This "gross alpha" value can be explained by a moderate uranium concentration (6 µg/L) – well below the WHO recommendation for drinking water (30 µg/L).

8.2.1.3 The site of the former RHODIA CHEMIE in Ghent

The phosphogypsum stack located on the boundary of the municipalities of Zelzate and Ghent was operated from 1925 to 2009 first by RHODIA, later by NILEFOS company. This last one was declared bankrupt in 2009. The area of the landfill covers approximately 65 ha and the total volume of phosphogypsum is estimated to ~ 18 million tonnes.

The gross alpha and beta values in the groundwater and leachate of this stack are followed every six months. For groundwater, the maximal value in gross alpha (resp. beta) amounted to < 0.12 Bq/L (resp. 0.41 Bq/L). The value of radioactivity parameters in the leachate have significantly decreased in 2018: gross alpha and gross beta values amount to < 0.03 Bq/L and 0.88 Bq/L respectively. This decrease shows the positive impact of the remediation measures which have been implemented these last years.

In concertation with the various interested parties, FANC also continued to follow the issue of the soil contamination outside of the stack within the perimeter of the old production units..

[7] CET class 5.2: mono-landfill for non-hazardous waste

8.2.2 Other NORM-sites

8.2.2.1 River sediments in Flanders and Wallonia

FANC carried on in 2018 its cooperation with VMM in Flanders and ISSeP in Wallonia in order to carry out radioactivity analysis on the sediments of various Belgian streams. VMM and ISSeP manage in their respective region a sediments surveillance network and put to FANC disposal a sediment sample for the selected rivers.

In Wallonia, 25 samples from the following watercourses have been analyzed :

- Vesdre in Chaudfontaine ;
- Ourthe in Hamoir ;
- Grande Gette in Jodoigne;
- Hantes in Erquelinnes ;
- Senne in Tubize ;
- Meuse in Hastière, Andenne and Visé ;
- Scheldt in Brunehaut, Celles, Antoing and Pecq ;
- Haine in Hensies ;
- Sambre in Erquelinnes, Merbes-le-Château and Namur ;
- Canal Blaton-Ath in Maffle ;
- Old canal Charleroi – Bruxelles in Braine-le-Comte ;
- Canal Charleroi-Bruxelles in Seneffe ;
- Canal du Centre in Mons ;

Activity concentrations in the natural isotopes of the thorium decay chain (Ra-228 and Th-228) vary between 20 and 70 Bq/kg. These values are comparable to the “background” values in Walloon soil.

For the uranium decay chain (U-238 and Ra-226), the radium-226 concentration exceeds 100 Bq/kg for three samples : the sediment from the Haine in Hensies and the two sediments taken at the surface and in depth in the canal du Centre in Havré. For each of these three samples, Ra-226 concentration is sensibly higher than U-238 concentration.

These anomalies could possibly be linked to the proximity of the former phosphates mines of Saint-Symphorien for the canal du Centre and the proximity of the former coal mine of Harchies for the Haine in Hensies.

Among artificial isotopes, only cesium-137 has been systematically identified. Almost all Cs-137 values registered in the Meuse exceed 10 Bq/kg, which confirms observations already made in 2016 and 2017. However, these concentrations stay below the clearance levels of GRPIR (1,000 Bq/kg) and of the 2013/59/EURATOM directive (100 Bq/kg). Traces of cobalt-60 have also been measured in the Meuse in Visé.

Figure 8.1 shows the values measured in the Meuse river between 2016 and 2018, from stream upwards to downwards. Note that the profile of the sampling is not the same for all samples: samples SVN001, SVN002 and SVN011 are superficial sediments (5 to 10 cm deep).

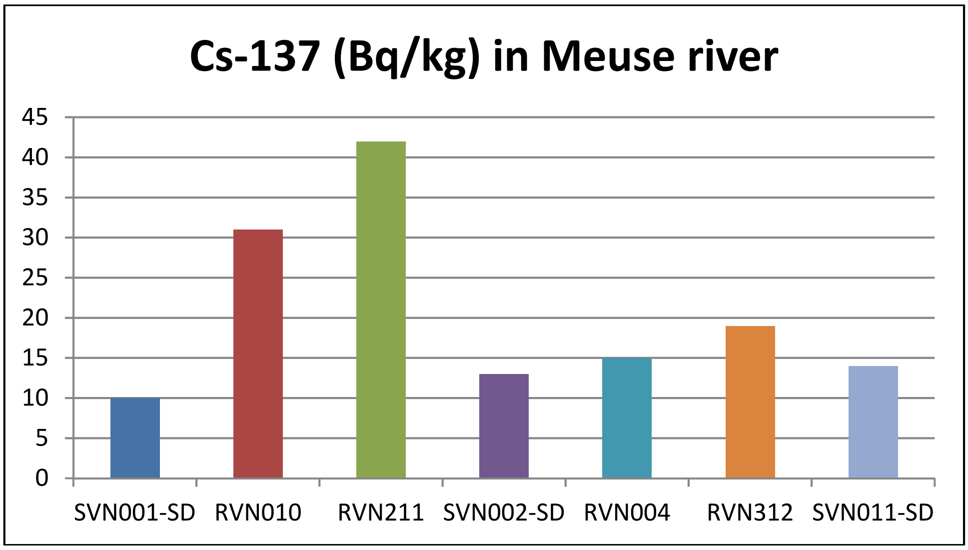
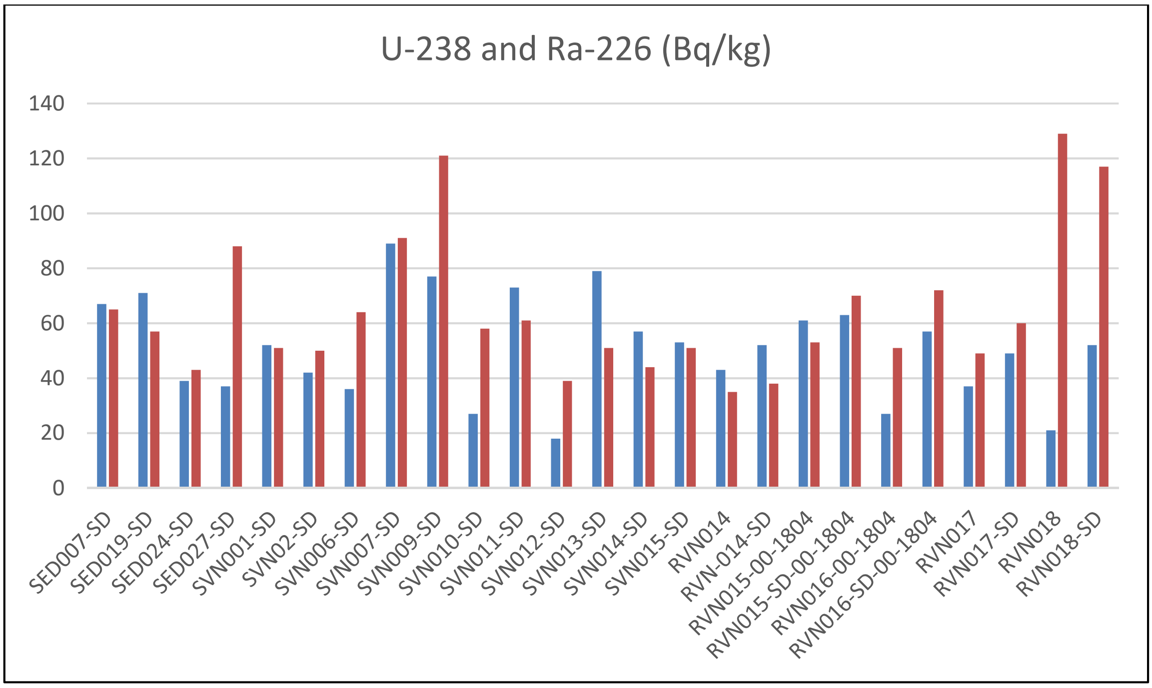


Fig. 8.1 : Cs-137 activity concentration in the Meuse river; sampling points from stream upwards to downwards (SVN001 – Hastière, RVN010 – Dinant, RVN211- Namur, SVN-002 – Andenne, RVN004 – Huy, RVN312 and SVN011 – Visé). Sampling profile is not the same for all samples.).

As an example, the following figures compare the concentrations in radium-226, uranium-238 and cesium-137 in the selected Walloon watercourses in 2018.



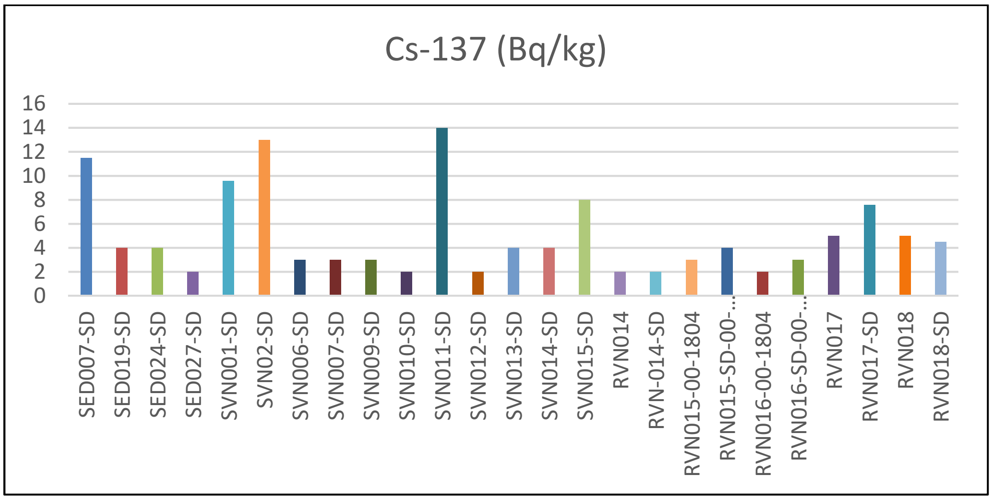


Fig. 8.2: activity concentration of uranium-238, radium-226 and cesium-137 in sediments of Walloon watercourses.

In Flanders, 25 sediment samples from the VMM network and 6 from the Port of Antwerp have been analysed:

The conclusion for these samples are identical to those in Wallonia, with nevertheless slightly lower values of natural radionuclides (15 - 48 Bq/kg), the result of slightly lower background values in Flemish soils. The Cesium-137 concentrations are situated between 0.4 and 4 Bq/kg.

8.2.2.2 Brownfields in Wallonia.

In the framework of the convention[8] between FANC and SPAQuE, radioactivity analysis have been carried out on samples of groundwater and soil from some Walloon sites belonging to the surveillance network of SPAQuE or currently investigated by the latter. The selection of these sites has been determined by the nature of their former industrial activities or of the waste which have been disposed on these sites.

Eight sites have been selected in 2018.

- The 'Horloz' and 'Chimeuse-Est' sites in Liège;
- 'AMS Sud' in Marchienne-au-Pont;
- The former 'Radar' quarry in Flobecq;
- The former landfill of 'Fond du Houtia' in Hannut;
- The former landfill 'SAFEA' in La Louvière;
- The 'La Rochette' site in Chaudfontaine;
- The 'Produits Chimiques d'Auvelais' in Sambreville;
- The 'NAM' (Nouveaux Ateliers Mécaniques) foundry in Morlanwelz;

Gross alpha, residual beta, uranium and radium-226 measurements have been systematically carried out for each water samples. Dose-rate measurements have also been carried out on several sites – for instance, at the site of 'La Rochette' in Chaudfontaine (Fig. 8.3); samples of soil or backfill material have been sampled and analysed by gamma spectrometry when the dose-rate exceeded 2 times the local background.

[8] Convention of March 26, 2009 regarding the exchange of environmental data between FANC and SPAQuE and access to the measurement network of SPAQuE.

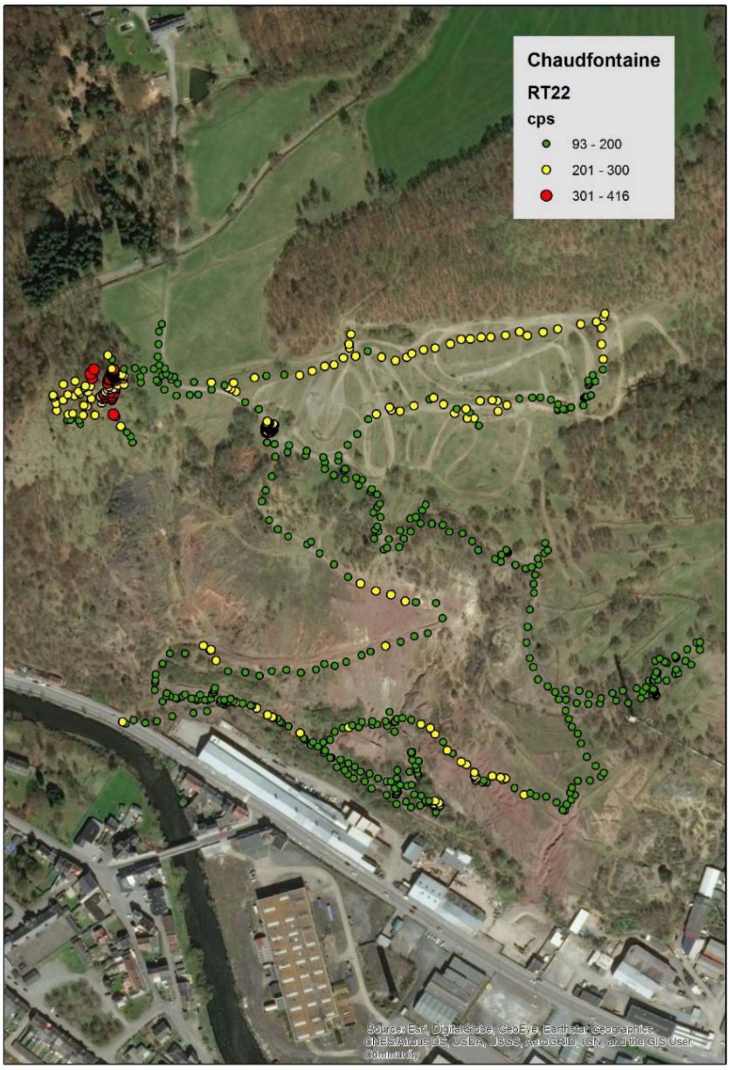


Fig. 8.2: dose-rate at the surface of the la Rochette site. In green, level comparable to the natural background. In yellow, between 1 and 2 times the background ; in red, > 2 x background

The conclusions of these measurements are the following:

For groundwater:

- No reference values were exceeded.
- Presence of uranium (max. 15 µg/L) and radium-226 in the groundwater of the 'Fond du Houtia' landfill has been confirmed and is stable compared to 2017. These concentrations stay however below the reference values for drinking water.
- Same is true for the uranium concentration in the piezometer P19 of the former landfill of the 'Radar' quarry (28 µg/L) – an increase compared to 2016.
- Presence of traces of uranium in the piezometers of the "landfill" zone of the former 'NAM' foundry has also been confirmed.
- Traces of uranium have also been found in some piezometers of the site of 'Produits Chimiques d'Auvelais'.

For soil and backfill material:

Concentrations in natural radioactive substances higher than the notification values to FANC have been measured on the sites 'AMS Sud' and 'La Rochette'. Advice of FANC should be asked in case of remediation or redevelopment of these two sites. They could be considered for being included in the list of « antropogenous » radon-prone areas published by FANC in the Belgian Official Gazette.

8.2.2.2 3 Measurements of groundwater and leachate of landfills

In Flanders, the leachate and groundwater of the landfills operated by OVMB in Ghent and Vanheede Landfill Solutions in Rumbeke have also been analysed. These two landfills have been authorized by FANC for accepting NORM residues. The results of the monitoring do not show any abnormal values.

In Wallonia, analyses have been carried out on the groundwater of the landfills of Cour-au-Bois and the former landfills of Marbais in Villers-la-Ville and of 'Bois de Hal' in Braine-le-Château.). All measured values were below the reference values for drinking water.

8.2.2.4 Production of titanium dioxide: the site of Kronos Europe

KRONOS EUROPE company in Ghent produces titanium dioxide; the production process is based on an acid attack of the raw materials with hydrochloric acid. The production residues (essentially filter-cakes) are disposed on a landfill within the premises of the company: see the surveillance report of 2012.

The company is subjected to the obligation of declaration as requested by article 9 of the Royal Decree of July 20, 2001. In this framework, FANC imposed a follow-up of radioactivity in the discharge water (Ra-226 and Ra-228) and in the groundwater of the landfill in operation.

Ra-226 and Ra-228 activity concentrations in discharge waters are followed every three months. Values varies between 0.52 and 1.9 Bq/L (resp. 0.17 and 0.46 Bq/L) for Ra-226 (resp. Ra-228). However, the maximal values stay below the discharges limits of the Royal Decree.

Gross alpha and gross beta measurement have also been performed on groundwater sampled from a piezometer located near the disposal site. Results are below detection limits and below the screening values for drinking water.

8.2.2.5 Varia

The metallurgical company UMICORE nv in Olen is also subjected to the obligation of declaration as requested by article 9 of the Royal Decree of July 20, 2001 in the framework of its cobalt and other non-ferrous metals production activities[9]. FANC imposed a follow-up of radioactivity in groundwater and leachate of its landfill in operation (stortplaats « De Rendelaer »). The leachate shows significant concentration in uranium (max. 57 µg/L in 2018), probably of historical nature. Traces of uranium (5 µg/L) have also been measured in one of the piezometers.

In summary, the **current** radiological impact of the NORM-industries still active in Belgium is limited. However, the activity levels of the residues dumped on their mono-landfill by some producers justifies a radiological monitoring of these sites. In particular, any new allocation of the landfills will require a detailed radiological impact study.

[9] This, independently from its historical activities of radium and uranium production mentioned in § 8.2.3

In addition, monitoring of **historical** « NORM » sites is also necessary: although the current environmental impact is limited, any change in allocation of these contaminated sites should be subject to a risk analysis. For instance, the exhalation rate of radon from phosphogypsum is important and a possible conversion of these former phosphogypsum stacks for construction purposes (whether residential houses or workplaces) could lead to a significant exposure if no precaution against the infiltration of radon is taken during the construction of these buildings. These sites are considered by FANC as anthropogenic radon-prone areas.

8.2.3 Other contaminated historical sites: sites linked to the former radium extraction activities in Olen

Between 1922 and 1969, the metallurgical plant of the former UNION MINIÈRE (now UMICORE) located in Olen (province of Antwerp) was active in the extraction of radium and uranium and the production of radium sources. In addition to its radium extraction activities, the company was also active in the production of other metals, including cobalt. Part of the production wastes (tailings, radium needles, ...) and decommissioning waste were disposed off in an authorized storage facility: UMTRAP (*Uranium Mill Tailings Remedial Action Project*).

Between 2006 and 2008, the banks of the river Bankloop, which had been contaminated as a result of the company's activities, have been subject to remediation. Materials resulting from the remediation project were disposed in another authorized storage facility.

Contaminated material excavated during infrastructure works within the premises of the factory are stored in a third authorized storage facility (« LRA »).

These three licensed facilities are located on the site of the company and are subject to a radiation monitoring program imposed by the regulator. The radon concentrations in open air, the radium concentrations in the surface and ground water are measured around each facility.

The table below shows the minimum and maximum values for each measured variable in 2017 around the UMTRAP, "Bankloop" and "LRA" facilities. The variations are related among others to the location of measurement points and weather conditions.

	UMTRAP			**« Bankloop »**			**LRA**		
	# meas-urement points	Min	Max	# meas-urement points	Min	Max	# meas-urement points	Min	Max
Rn-222 concentration open air (Bq/m^3)	3	52	146	6	17	123	3	32	100
Ra-226 concentration surface water (mBq/L)	2	11.8	22.6	2	6.6	54.4	2	13	46
Ra-226 concentration groundwater (mBq/L)	4	5	14,7	4	< 5	39	2	11.4	26.6
Ra-226 concentration percolate (mBq/L)	NA	-	-	1	< 5	5.9	NA	-	-

Moreover, although the radium concentration in water are normal, the radiological monitoring of groundwater around these facilities has shown an uranium contamination in groundwater.

In addition to the materials stored in these three licensed facilities, one can find on and around the site of the company a number of sites with significant radium contamination and which must still be subject to a remediation process.

In particular, some production wastes and decommissioning wastes from the radium extraction unit had also been dumped on two landfills, the dumps D1 and S1.

D1 shows the most important levels of contamination: the average activity concentration of Ra-226 for the entire volume of the landfill (217,000 m^3) is between 5 and 20 Bq/g, but the maximum concentration of some "hot spots" approaches 1 kBq/g. Both landfills are however not accessible to the public: the **current** radiological impact is hence not significant. Radioactivity analysis have been carried out in some piezometers around the D1 dumpsite and didn't indicate any anomaly.

Radium contamination can also be found outside of these two dumps, particularly inside the premises of the factory itself but also in some surrounding streets.

In summary, the **current** radiological impact of the sites contaminated by past radium extraction activities does not require urgent action. However, it could become significant in case of change in allocation of the land concerned. The level of the contaminations requires however a continuation of the monitoring.

9.NATURAL RADIOACTIVITY OF BUILDING MATERIALS

9.1 INTRODUCTION

The 2013/59/EURATOM directive (Basic Safety Standards directive – art. 75) sets a reference level of 1 mSv/a for external exposure to the natural radioactivity of building materials. It asks member states to identify building materials of concern from a radiation protection point of view taking into account an indicative list published in Annex XIII of the directive: this annex includes on one hand natural building materials such as granite and on the other hand building materials incorporating by-products of the NORM industry, e.g. fly-ashes or slag.

In order to identify possible building materials "of concern" in Belgium, FANC has included the surveillance of natural radioactivity of building materials in its radiological surveillance program. 41 construction products have been analysed in 2018. Most of them have been collected in collaboration with the Section « Specifications in construction » of the Ministry of Economy.

9.2 ANALYSES AND RESULTS

In conformity with the requirements of directive 2013/59/EURATOM, the samples have been analysed by gamma spectrometry in order to determine the activity concentrations of the natural nuclides: radium-226, thorium-232 et potassium-40.

The EURATOM directive defines a screening index I – weighted sum of the concentrations of these three isotopes, where the activity concentrations are expressed in Bq/kg :

$$I = C_{Ra-226}/ 300 + C_{Th-232}/ 200 + C_{K-40}/ 3000$$

If the index I is lower than 1, there is no risk to exceed the reference level of 1 mSv/a as defined in the EURATOM directive.

If the index I is higher than 1, the use and specific characteristics of the material (density, thickness,…) must be taken into account to assess the risk of exposure.

41 construction products have been analysed in 2018. The Table below gives the number of samples per product category as well as the minimum, maximum and average values of the index.

Category	# samples	I min	I max	I average
Insulation wool	6	0.08	0.28	0.17
Ceramic tiles	17	0.53	1.14	0.86
Natural stones: blue stone and marble	7	0.04	0.1	0.06
Natural stones: granite	3	1.23	1.45	1.31
Other natural stones: sandstone and shale	5	0.17	0.74	0.6
Other (cement, concrete, roof tile)	3	0.16	0.66	0.42

Table 9.1 : number of samples analysed in 2018 per category of products and minimum, maximum and average value of the screening index I.

Average values per product categories are reproduced in Figure 9.1. Relative contributions of Th-232, Ra-226 and K-40 are also indicated.

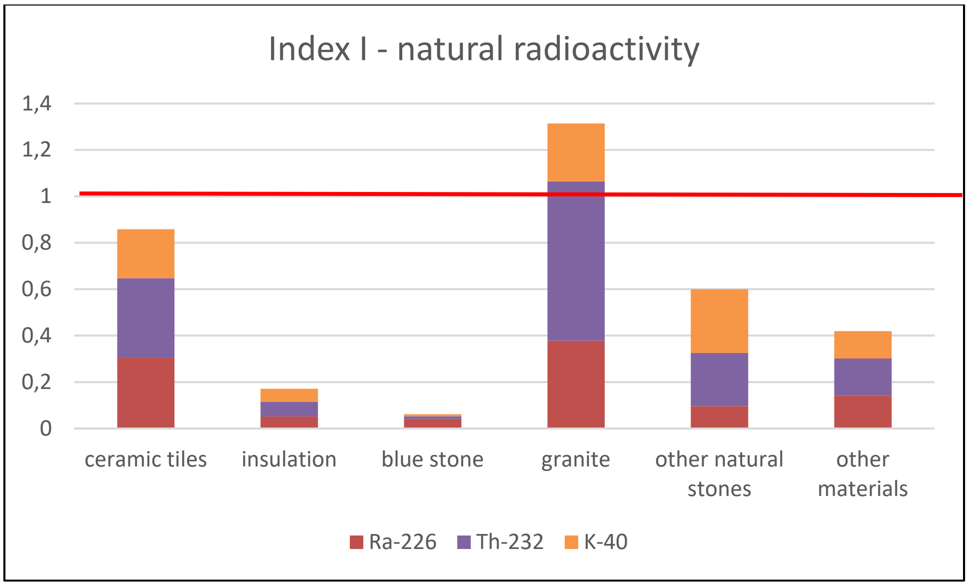


Fig. 9.1 : average value of the screening index I for the different products categories. The three colours correspond to the respective contributions of Ra-226, Th-232 and K-40.

9.3 ASSESSMENT OF EXTERNAL DOSE

Results of the survey showed that only imported granite and some ceramic tiles have an activity index higher than 1. These floor and wall tiles however are superficial materials and the activity index is obviously far too conservative to assess their effective dose-impact. The European Committee of Normalization (CEN) developed a formula[10] which takes into account the density and thickness of the material to assess the dose :

[10] Technical Report, CEN/TR 17113:2017 E, Radiation from Construction Products – Dose assessment of emitted gamma radiation, European Committee for Standardization (CEN), 2017

$$D = \begin{bmatrix} [281 + 16,3\rho d - 0,0161(\rho d)^2] \times C_{^{226}\text{Ra}} \\ + [319 + 18,5\rho d - 0,0178(\rho d)^2] \times C_{^{232}\text{Th}} \\ + [22,3 + 1,28\rho d - 0,00114(\rho d)^2] \times C_{^{40}\text{K}} \end{bmatrix} \times 10^{-6}$$

with

ρ	=	density, in kg/m^3;
d	=	thickness, in m;
C	=	activity concentration, in Bq/kg.

If the building material is a superficial material (d ≤ 30 mm), the dose to the public can be obtained by adding 0.19 mSv to the value calculated according to this formula.

For a granite tile with an index I =1.45 (ρ =2.7, d=30 mm), the application of this formula results in an external dose of 0.73 mSv. For a ceramic tile with index I = 1.14, the external dose would be 0.36 mSv. These estimations are already below 1 mSv/a but are still quite conservative, as CEN formula is based on the assumption that the room is completely covered (walls, ceiling, floor) by the material.

More realistic calculations can be performed by e.g. using the tables of the CEN technical report and calculating the contribution of each building material to the external dose. A similar calculation can be performed by using a specific calculation code such as RESRAD-BUILD.

Such a calculation allows assessing the external exposure of a person living in a room of standard dimensions and made of building materials analysed in 2018 or during previous surveys. One considers the standard CEN room with dimensions 4 x 3 x 2.5 m. The elements of the room are made of the following products:

- The walls are made of bricks and are covered with ceramic tiles;
- The floor is made of concrete and covered with granite tiles;
- One assumes that the room is located under the roof of the house and considers thus that the ceiling is made of roof tiles under which lies a layer of insulation material and gypsum.

Data used for this calculation are shown in Table 9.5. Activity concentrations values in the building materials are taken from the results of the analysis described in this chapter (granite and ceramic tiles, concrete, insulation and roof tiles) or in the radiological surveillance report of 2017 (bricks and gypsum). For each material, the maximum value of activity concentration in the corresponding product category has been used.

		Granite tiles	bricks	Gypsum	concrete	Ceramic tiles	Roof tile	Insulation
C (Th-232)	Bq/kg	163	46	56	10	91	56	22
C (Ra-226)		120	53	35	18	134	40	23
C (K-40)		702	800	51	158	608	753	288
Index I	-	1,45	0,67	0,41	0,16	1,1	0,66	0,28
d	cm	1	20	1	20	0,9	2	15
ρ	g/cm^3	2,77	2	1,1	2,35	2,28	2,05	0,04

Table 9.2 : value of the parameters used for the assessment of external exposure in a standard room.

The calculation leads to an external dose[11] for the person living in this « standard room » of 0.23 mSv/a by using the CEN method. If the same calculation is done for a room with a floor which is not covered by granite tiles and walls not covered with ceramic tiles, the external dose is 0.16 mSv/a by the CEN method. The external dose increment due to the superficial materials with an activity index slightly higher than 1 (floor granite tiles and ceramic wall tiles) is thus 70 µSv/year.

Figure 9.2 shows the respective contributions of each element of the « standard room » to the external dose.

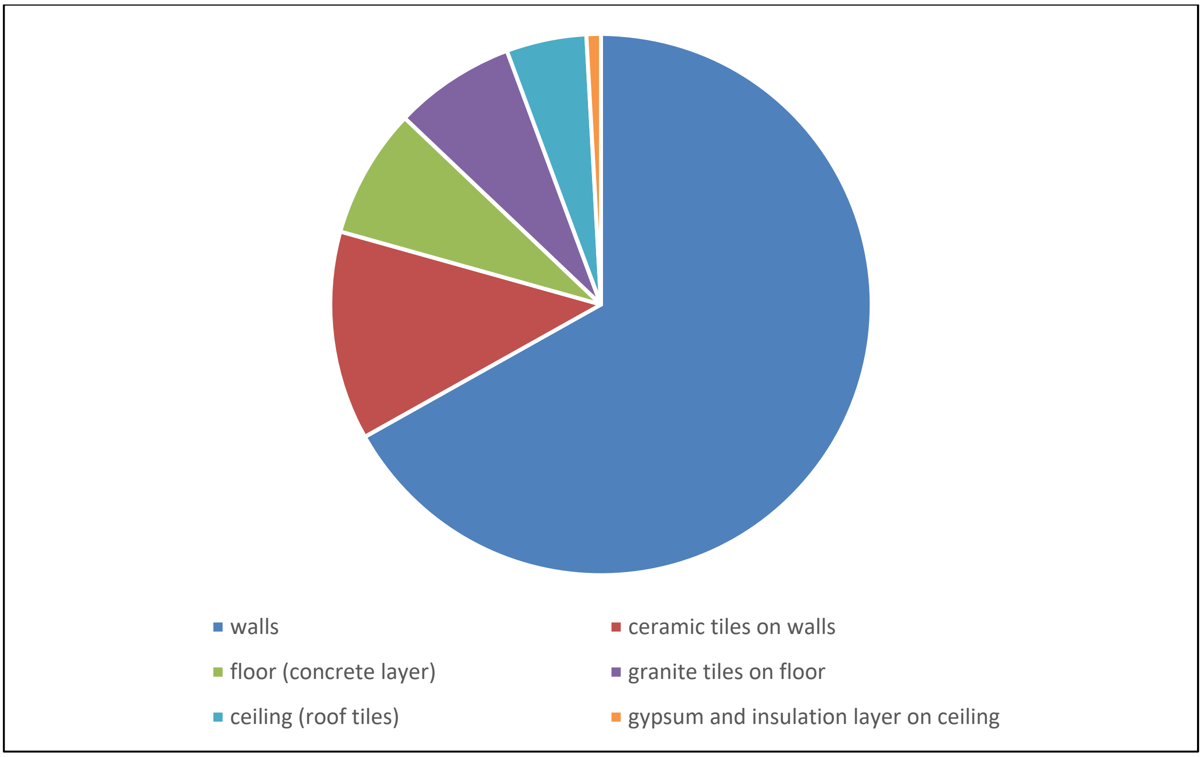


Fig. 9.2 : respective contributions of each element of the « standard room » to the external dose

[11] Additional to background.

In all cases, the external dose in a room made of building materials analysed in the framework of the surveillance of the territory is only a fraction of the reference level of 1 mSv/year.

9.4 CONCLUSIONS

Among all analysed construction products in 2018, no building material « of concern » was identified. The activity index is below the screening value I=1 for most samples – except for natural granite stones and some ceramic tiles. The latter however are only devoted to superficial applications in construction and the resulting external dose is thus lower than the reference level of 1 mSv/year.

External dose to a person living in a standard room made from building materials analysed in the surveillance program does not exceed 0.23 mSv/year.

10. OVERALL CONCLUSIONS

The programme for the radiological monitoring of the territory takes into account the requirements of international bodies (European Commission, OSPAR with respect to the Sintra agreements under the policy of protecting the North Sea and the North-East Atlantic). It allows to monitor the different regions of the country taking into account their specific features.

An analysis of the results obtained within the framework of the radiological monitoring of the Belgian territory of 2018 gives rise to the following comments:

Overall:

The discharge limits in force are very well respected by the operators of nuclear installations.

The radiological monitoring of the territory also clearly shows that, under normal conditions and excluding medical exposure, the dose rate depends above all on the nature of the soil, with the rocky soils of the south of the country emitting more radon than those of the north (sandy). It is for this reason, for example, that the dose rate measured in Wallonia (Ardennes) is greater than that measured in the vicinity of the Doel nuclear power station, whose impact on the environment is negligible.

The radiological contamination levels of the samples measured are generally extremely low and, for this reason, the greater part of the data obtained are not significant. Natural radioactivity (^{40}K and ^{7}Be) is by far the most prominent and more present than most artificial beta-gamma emitters. The monitoring programme demonstrates its value and ability to "finely" monitor the impact of radioactive nuclides on the environment and consequently on humans: "traces" of artificial radioactivity, considerably lower than natural radioactivity, are routinely detected.

This situation is reassuring at the health level, but it becomes awkward with regard to capitalising on the results: indeed, significant measurements justify a more exact and quantifiable description of the radiological situation. Radioactivity transfer parameters can then be drawn up to facilitate calculations of the doses to which the population is subjected. That then implies increasing the volumes or masses of the samples in order to be able to "drop down" to very low level measurements, which are alone capable of providing significant and, hence, reliable values. The European Commission moreover demands this type of endeavour from the Member States in relation to certain measurements (establishing a widespread network of measuring points aimed at detecting very low levels of radioactivity). A similar effort has been made to measure very low concentrations of Cs-137 in sea water (with use of resins for concentrating this radioactivity).

In greater detail:

The radiological situation of the Belgian territory is perfectly satisfactory; however, one basin, i.e. the entire Laak-Winterbeek-Nete-Scheldt hydrographic network, still arouses attention on account of its higher charge of both artificial and natural radioactivity (^{226}Ra) enhanced by human activity. This concerns the entire Laak-Winterbeek-Nete hydrographic network.

The monitoring of the northeast of Belgium reveals that some nuclear installations in the Mol-Dessel region have a measurable, although small, radiological impact on the environment and that it is also true for the historical releases of the former feed phosphate industry – NORM industry - in the Tessenderlo region (currently dismantled). This means that the sediments of the Molse Nete contain a significant level of fission products (^{137}Cs) and heavy artificial radionuclides in the form of traces of transuranic nuclides ($^{239+240}Pu$, ^{241}Am). ^{226}Ra activity is also relatively high in the sediments of the Grote Laak and the Winterbeek in the vicinity of Tessenderlo.

On the other hand, the – measurable – radiological impact of the nuclear installations in the northeast of the country has nevertheless declined sharply in recent years.

The Federal Agency for Nuclear Control have installed in 2012 new automatic and continuous measuring stations for gamma radiation present in surface water. Continuous data are used among others to demonstrate more fully that Belgium meets its obligations under the OSPAR convention and Articles 35/36 of the EURATOM (EC) Treaty.

As in the past, one can conclude that Belgium respects its national and international obligations.