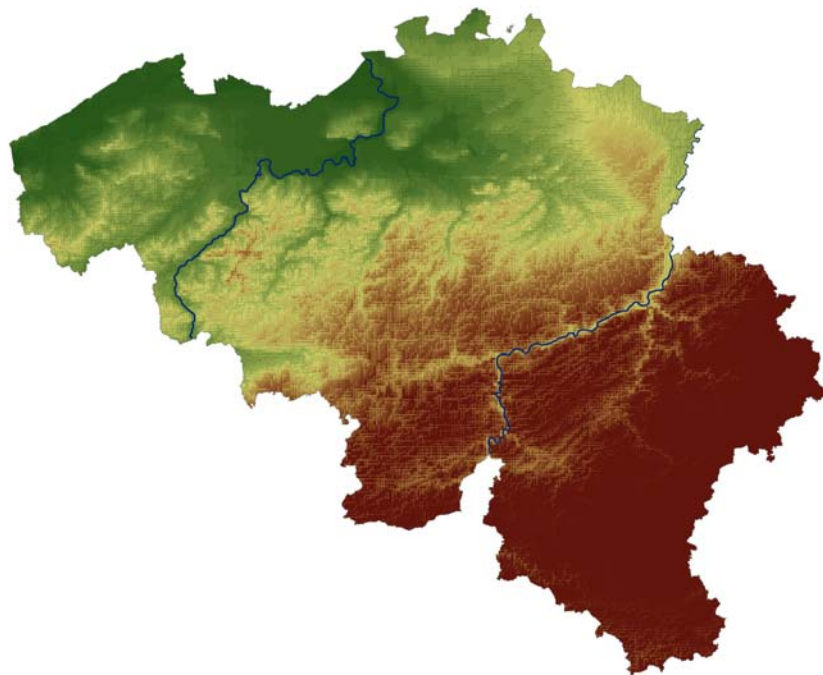




federal agency for nuclear control

**SURVEILLANCE OF THE TERRITORY &
NATURAL RADIATION SERVICE**

Radiological Monitoring in Belgium Summary report 2009



- July 2010 -



Federal Agency for Nuclear Control

Health and Environment Department

Territorial Monitoring & Natural Radiation Service

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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.

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.

¹Articles 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 *radioelements*, 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 radioelement stabilises into a stable element once and for all.

Types of radiation There are three main types of radiation emitted by radioelements: *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 μ Sv 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 (and the region of Vielsalm programmed in 2007);
- *Close monitoring around 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 Beam Applications s.a. (IBA) at Fleurus (industrial zone).

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

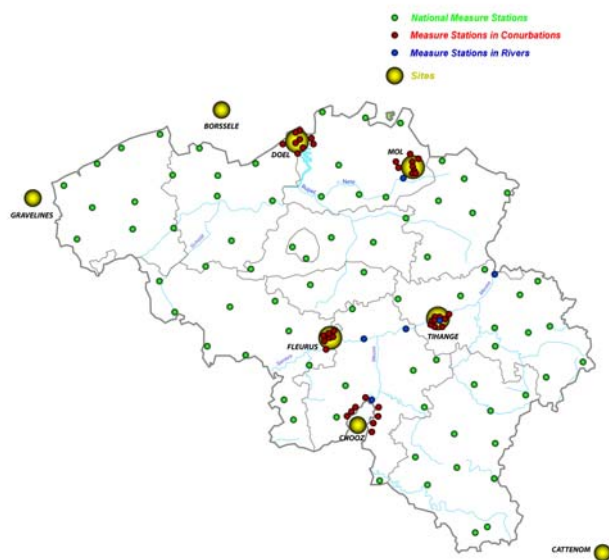
1. ensuring that the legal and regulatory provisions concerning environmental contamination remain respected,
2. checking through the control of discharges into the environment that these comply with the standards and authorised limits,
3. if necessary, assessing the potential doses received by particular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

Close monitoring also applies to installations where radioelements are used, such as hospitals, universities or particular industries, such as the industry producing feed phosphates in the Tessenderlo region. The process of this non-nuclear industrial activity has the special feature of concentrating a natural nuclide, radium 226, in the liquid effluents it discharges.

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 211 stations constantly measure the overall radioactivity of the air, atmospheric dusts and river waters (Meuse, Sambre and Mosele). 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 meteorological masts (10 meters and 30 meters) that measure wind speed and direction and by a set of mobile 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, IRE, the Scientific Institute of Public Health (ISP - Institut scientifique de Santé publique) in Brussels and the University Faculty of Agronomic Sciences (FUSAGX - Faculté universitaire des Sciences agronomiques) of Gembloux. 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 radioelements, either in a general or specific manner. In the latter case, they attempt, in particular, to measure natural radioelements (such as beryllium 7 and potassium 40) which serve as reference points and radioactive elements characteristic of specific human activities (such as radioactive elements linked to the manufacture of fuels powering nuclear reactors, radioactive tracers used in nuclear medicine, and radium 226, a natural radioelement 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.

Between 2002 and 2004, the Agency reviewed its entire sampling and measurement programme in order to completely harmonise it with international requirements. The 1998 European directive on drinking water had imposed 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 more or less 5,300 samples annually, which are subjected to almost 32,000 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 2009. 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);

for the major parts of the biosphere (air, soil, water and biocenosis) as well as in the main constituents of the food chain, supplemented by the follow-up of the atmospheric and liquid discharges of the main nuclear sites and through dose rate measurements around these facilities. The raw data are available on request, as are reports specific to the radiological monitoring of the food chain.

SUMMARY

The revision of the entire radiological surveillance programme of the territory, the redrafted version of which was implemented from 2003 to 2004, was based on an effort to harmonise the libraries of radioelements measured for the entire territory and taking account of the latest 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 new programme – with almost 5,300 samples giving rise to more or less 32,000 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) 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 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, with a discharge of ^{226}Ra . 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 211 stations, which constantly measure the radioactivity of the air and river waters. The stations are distributed throughout the entire country, around the Tihange, Doel, Mol and Fleurus, as well as in the urban areas close to these installations and in those around the Chooz nuclear installations. These 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 stations used in the TELERAD network for measuring radioactivity in the air are of three types:

The **dosimetry stations** for measuring the ambient gamma radioactivity, of which there are 128 on the territory and 60 around the nuclear sites of SCK•CEN, Tihange, Doel and IRE (and around the boot of Givet for monitoring the Chooz nuclear site). The photograph opposite shows an open station with a view of its three detectors and electronics.

Each station is equipped with a rain detector which provides information about the presence and duration of rainy periods.

The **aerosol stations**, 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. Three aerosol stations (situated on the sites of SCK•CEN, IRE and FANC) are linked to a gamma spectrometry unit which measures dusts in the air.





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). 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

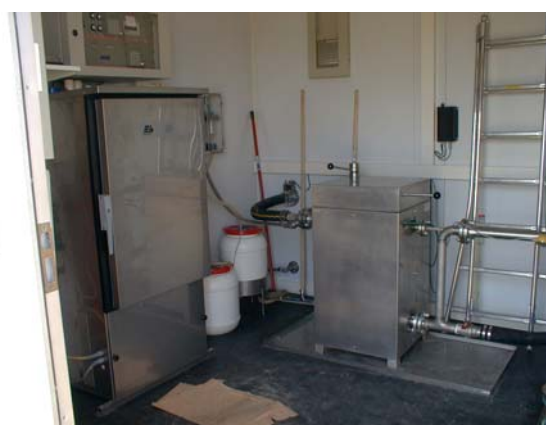
determine the level of radioactivity.

The photograph on the right shows the detector in its casing (cylinder) and the parallelepipedal tube containing the active carbon cartridges (on the right).



TELERAD also has 6 **river stations** which continuously measure the gamma radioactivity of river waters. These stations are 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.



Inside is the gamma spectrometry unit (NaI crystal coupled to a two 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.

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.

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 opposite 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.

1.3 TELERAD: METEOROLOGICAL INSTRUMENT



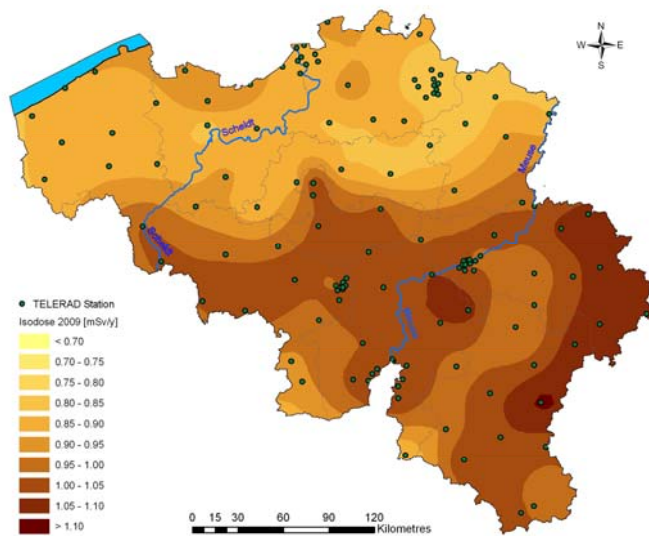
Along the borders and around nuclear sites, TELERAD also has 9 meteorological measuring instruments (wind speed and direction) installed on 10 m masts. There are also 4 additional 30 m meteorological masts located near the nuclear sites (wind speed and direction, pluviometry, sunshine) – photograph on 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 12 transportable stations for the measurement of ambient gamma radioactivity. These stations can be installed in places to be subjected to more detailed examination.

1.4 TELERAD: INSTRUMENT FOR CALCULATING THE EXTERNAL EXPOSURE DOSE RATE

Since the TELERAD network measures a dose rate ($\mu\text{Sv/h}$) 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.

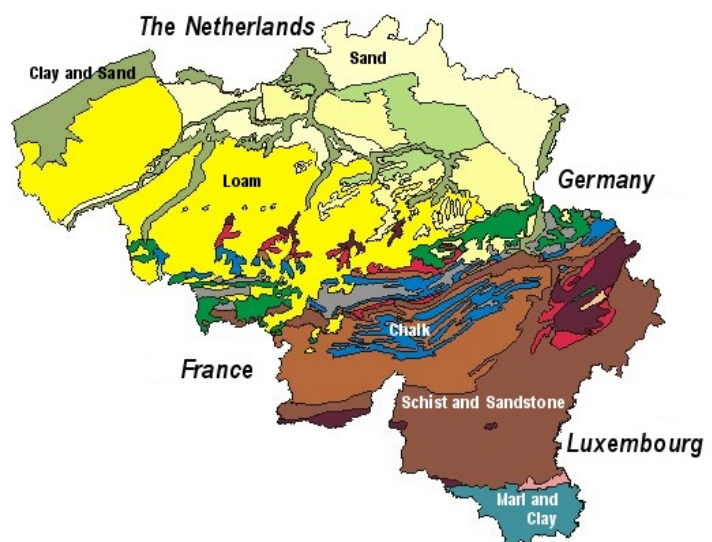


The map on the left shows the outcome of such processing which results in the construction of an illustrative map (because build up on basis of relatively limited detectors) of the natural background radiation due to gamma radioactivity. This background noise represents the annual exposure expressed 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 1mSv/year, that it varies from 0.7 mSv/year in the north to 0.9 mSv/year overall in Flanders and 1.1 mSv/year overall 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 Condruz 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 $^{7,10}\text{Be}$, $^{32,33}\text{P}$, ^{22}Na , ^{35}S , ^{39}Cl , ^{26}Al , ^{14}C and ^3H .

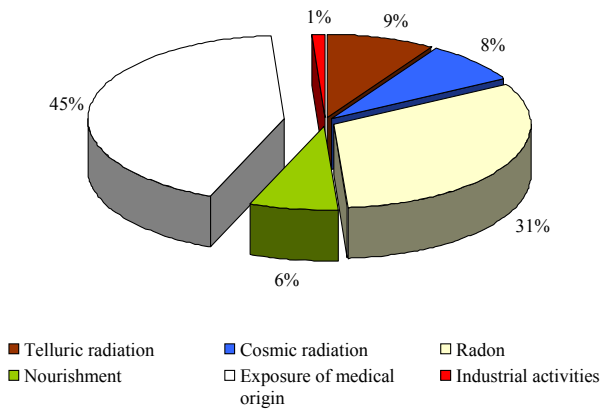
This natural radioactivity also has a terrestrial component: *telluric radiation* which is generated by natural radioelements present in the ground and underground water such as:

- The primary constitutive elements of the solar system, i.e. namely radioelements with very long physical periods or half-lives (time required for half of the radioactivity to disappear) such as $^{235,238}\text{U}$, ^{40}K , ^{232}Th , ^{187}Re , ^{138}La , ^{147}Sm , ^{190}Pt ;
- The elements 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’ elements referred to previously, generated by the cosmic radiation itself).

In addition to this natural radioactivity, there is artificial 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 such as the factory producing feed phosphates at Tessenderlo;
- 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).

Annual average exposure to ionizing radiation in Belgium – Annals BRA: 33(1), 26-27 (2008)



The entirety of this radioactivity is responsible for the overall exposure of people living on the territory of Belgium (4,65 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 sectors of the NORM industry.

The article 72bis of the RGPRI 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, as well as the 2000/473/EURATOM² 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.

The future incorporation into national regulations (GRPIR) of Council Directive 98/83/CE dated 3rd November 1998 on the quality of water intended for human consumption, the technical “radioactivity” annexes of which are being finalised, will force Belgium to face very quickly the obligation of monitoring a very large number of springs, sources, etc used for the production of drinking water, especially in the Walloon Region.

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, 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

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

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.

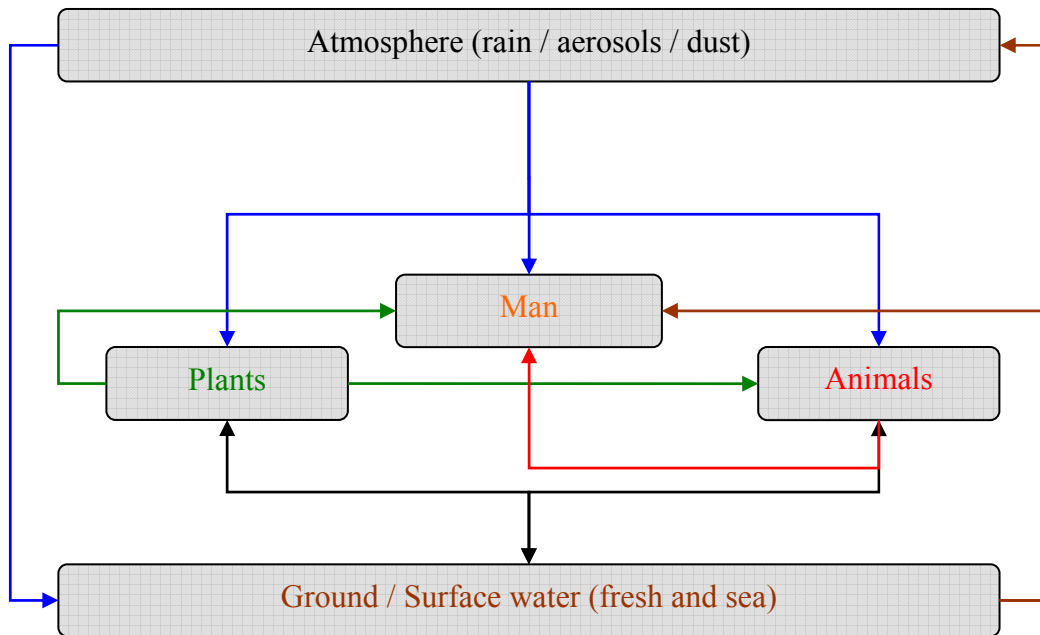
Finally, the conferences of environmental protection specialists on ionising radiation held at the International Atomic Energy Agency (IAEA) since the end of 2001 have confirmed the trends expressed above once again.

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 elements, 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).

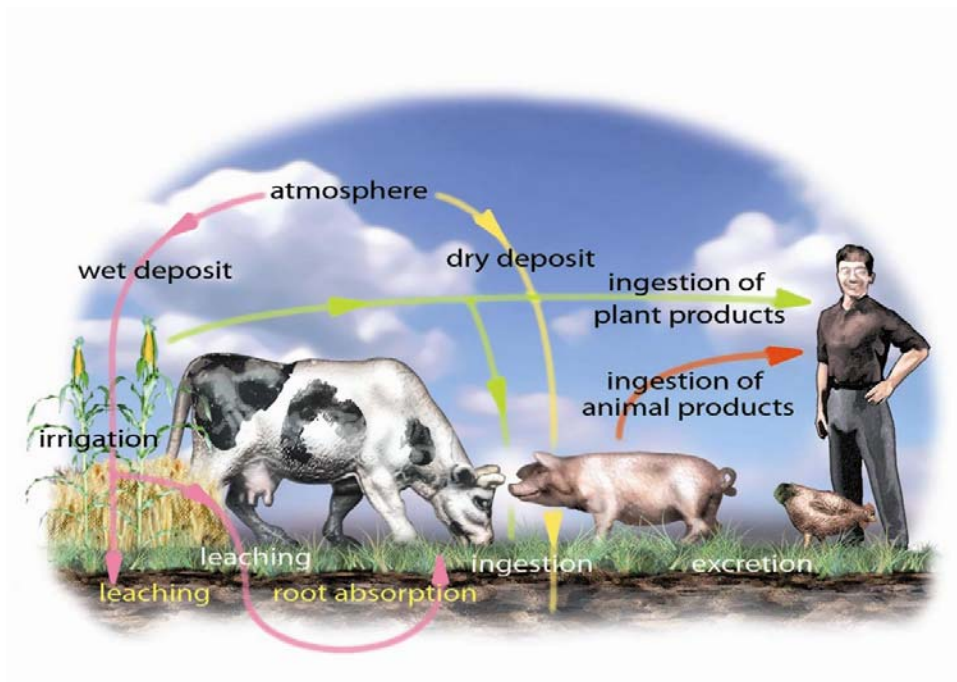
As already explained, the radiological monitoring of the territory is carried out through a programme of radiological surveillance relying on sampling and analyses (measurements of radioactivity) as well as the automatic TELERAD network, which essentially conducts measurements of dose rates at fixed points, supplemented by those carried out via thermoluminescent dosimeters (TLDs) located in urban areas close to the nuclear sites. 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 elements 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 elements 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 Molve Nete: transuranic elements – $^{234,235,238}\text{U}$, $^{238,(239+240)}\text{Pu}$, ^{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 basin: ^{226}Ra by virtue of this stream draining the waters of the Grote Laak and Winterbeek where the Tessenderlo factory producing feed phosphates (NORM industry) discharges 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 elements – $^{234,235,238}\text{U}$, $^{238,(239+240)}\text{Pu}$, ^{241}Am , in addition to the usual array of gamma emitters (including radiocaesiums), ^{90}Sr , ^{99}Tc and organic ^3H 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” radioelements such as (cosmogenic) ^7Be 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

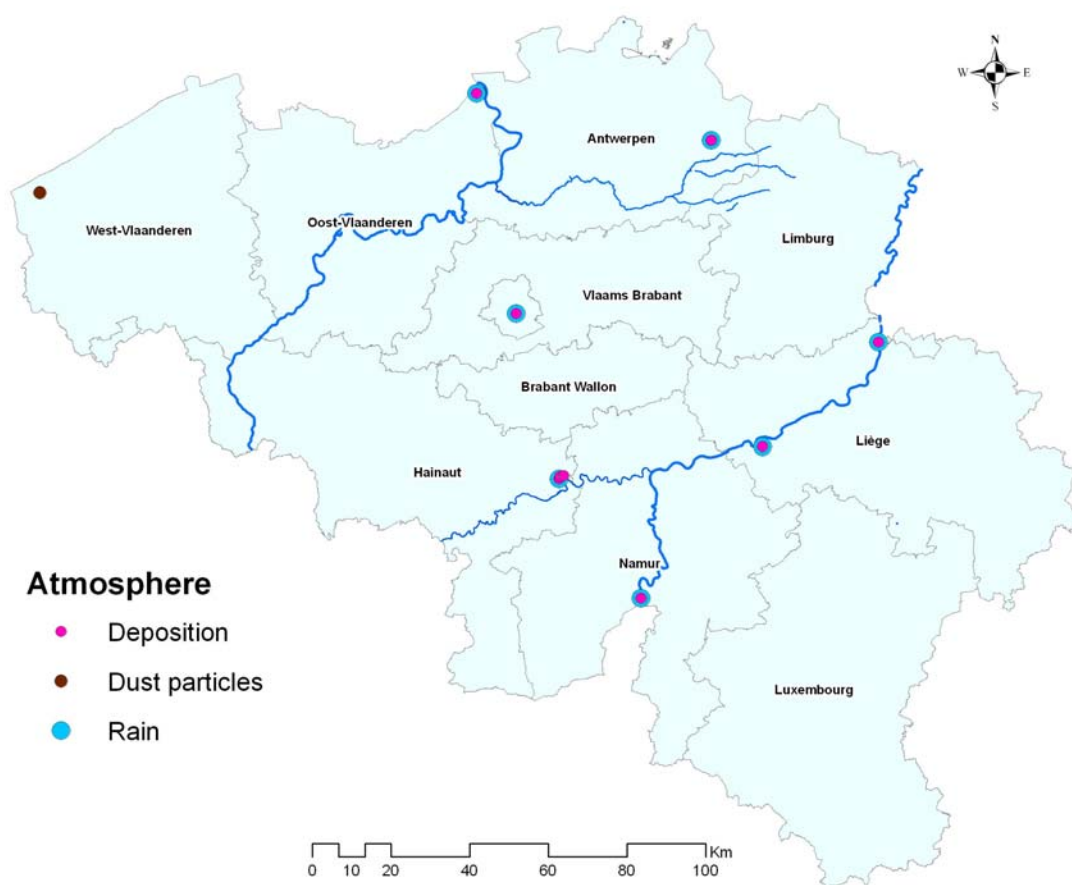
The monitoring network comprises a series of zones, i.e. locations where samples are taken and subsequently brought to the laboratory to be prepared and then measured to determine their level of radioactivity. More than 5,300 samples are taken each year on which around 32,000 radioactivity analyses are conducted.

2.4.1 The main lines of the network:

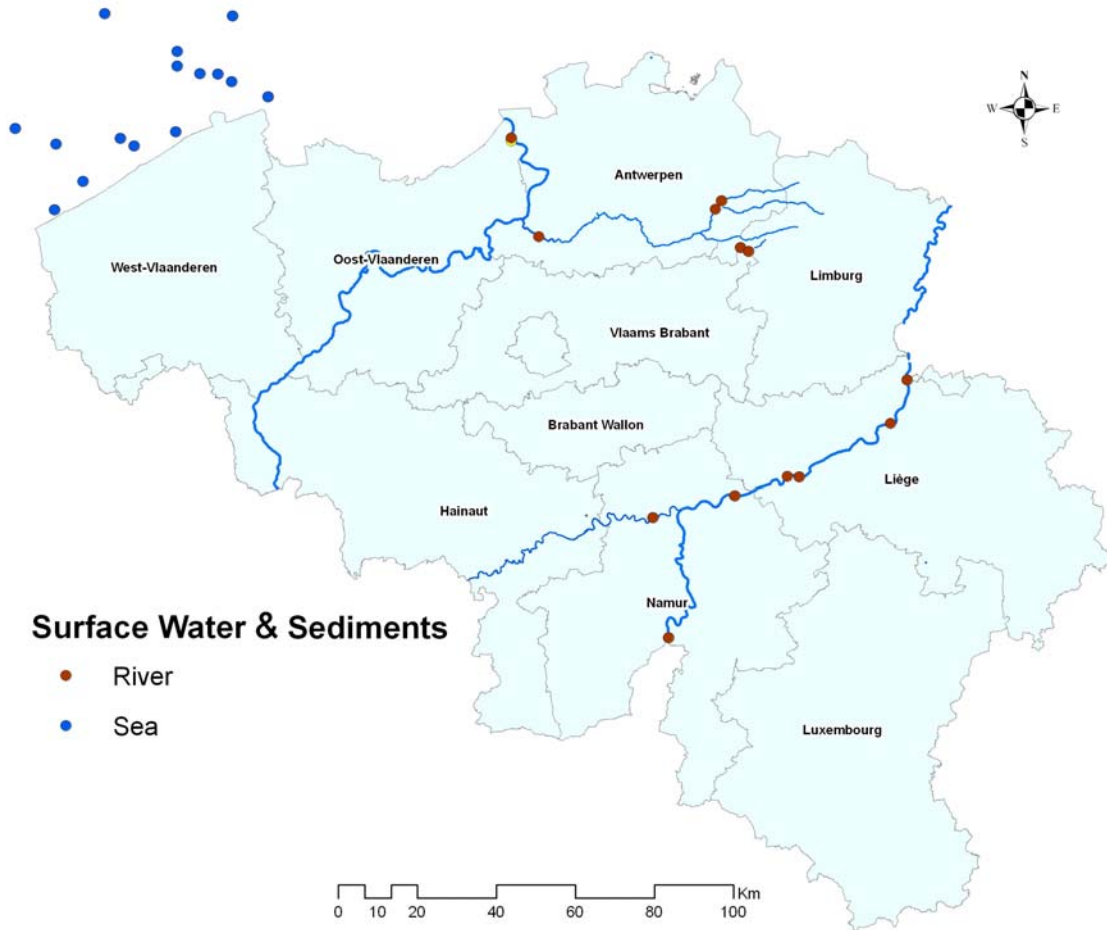
The main lines of the radiological monitoring network relate to:

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

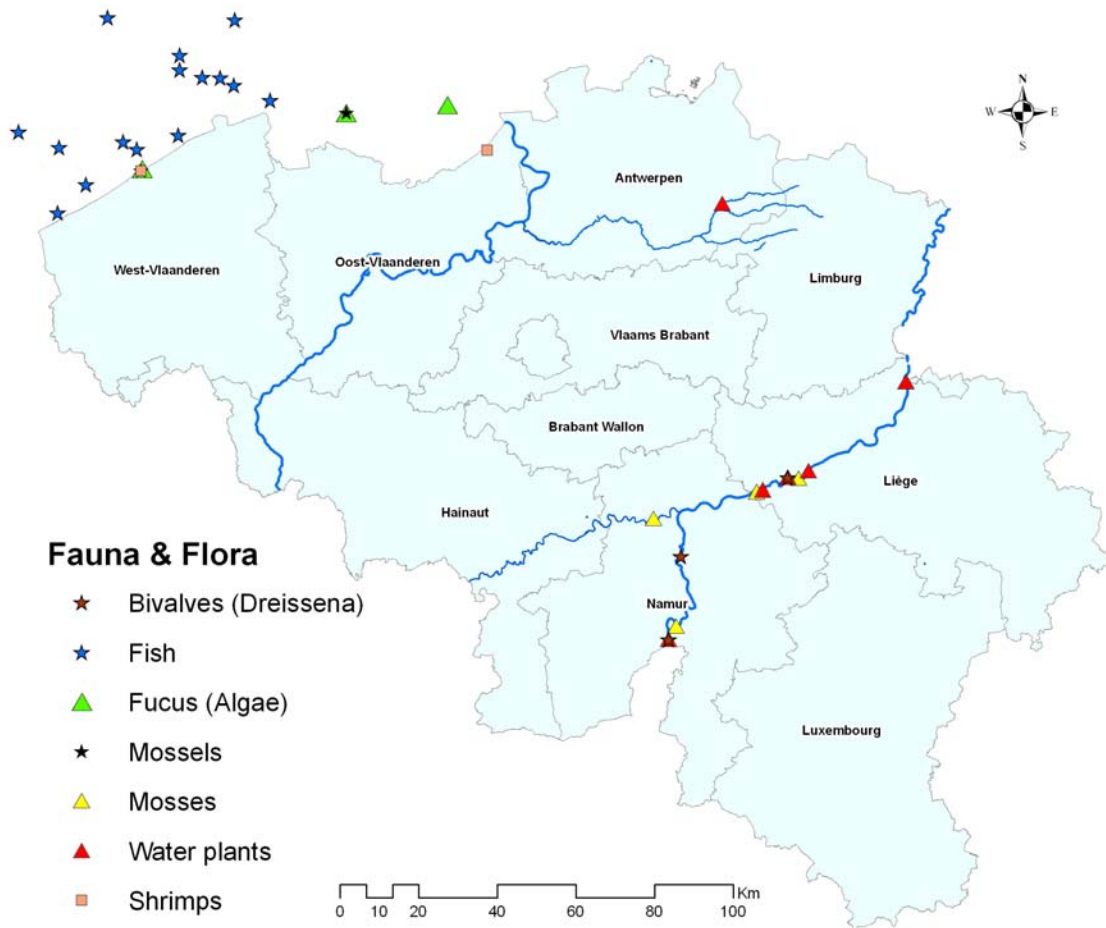
Sampling points for air dusts (red) and precipitations (blue)



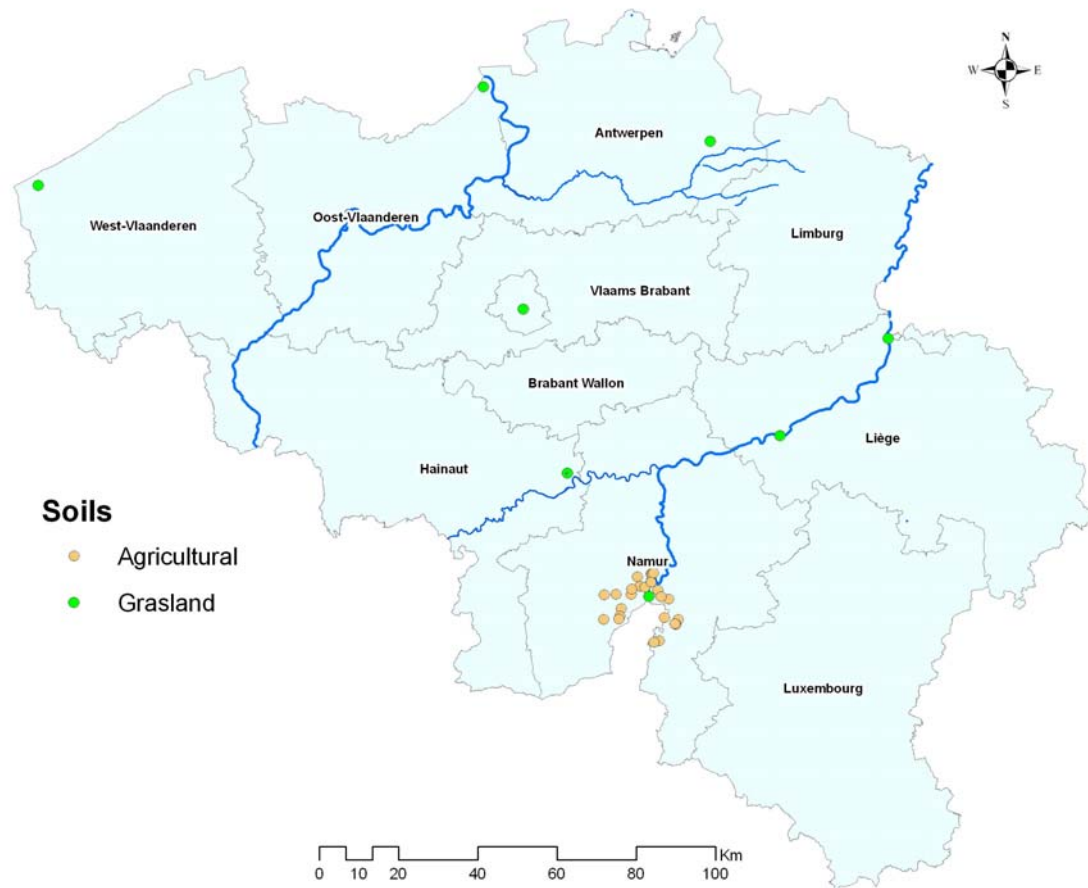
- Monitoring surface water and sediments in fresh – rivers (Sambre, Meuse, Grote Laak, Winterbeek, Molsse Nete, Ruppel and Scheldt) and marine water – North Sea;



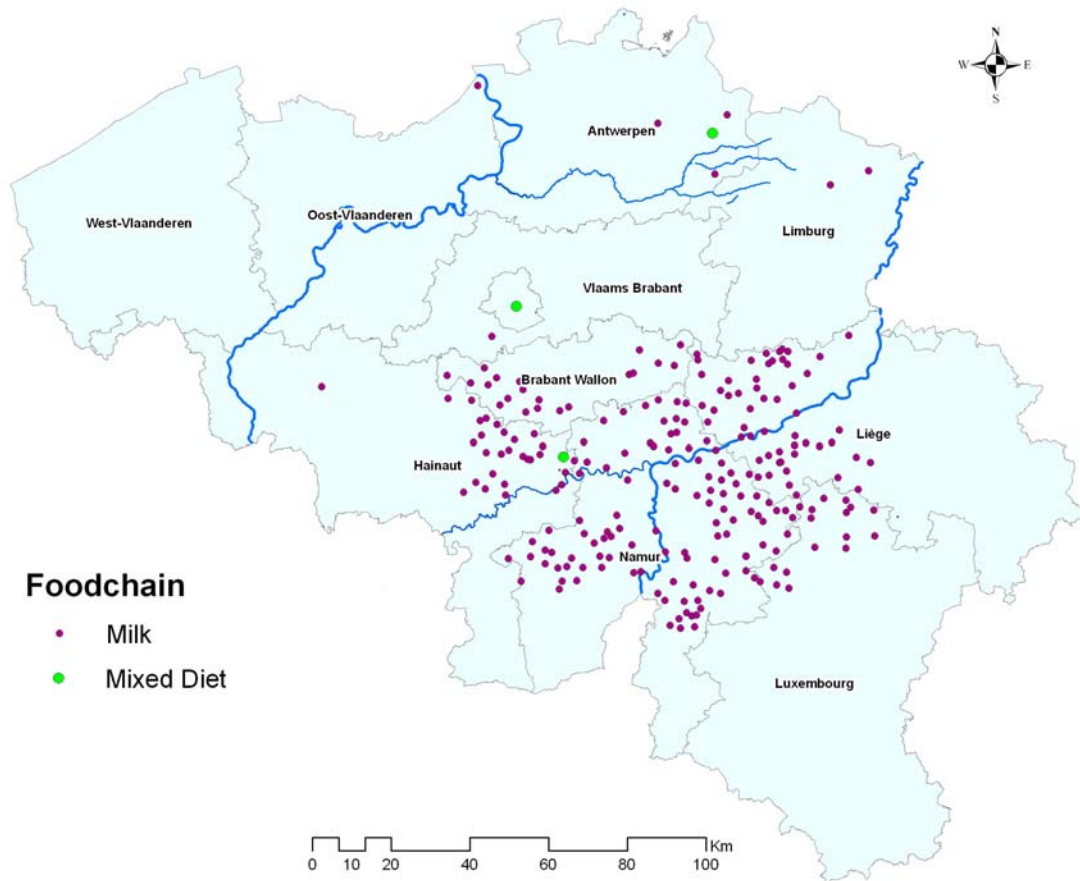
- Monitoring the living environment by searching for radioactivity in aquatic fauna and flora in fresh and salt water (bio-indicators of the presence of radioactivity);



- Monitoring terrestrial zones, i.e. soils sampled in the immediate vicinity of nuclear sites and certain control regions (sea coast, Ardennes, Brussels Capital region);



- Monitoring the food chain by checking milk (supermarkets and dairies which collect from a large number of farms, especially in Wallonia), drinking water and foodstuffs, with samples taken from markets and retail outlets;

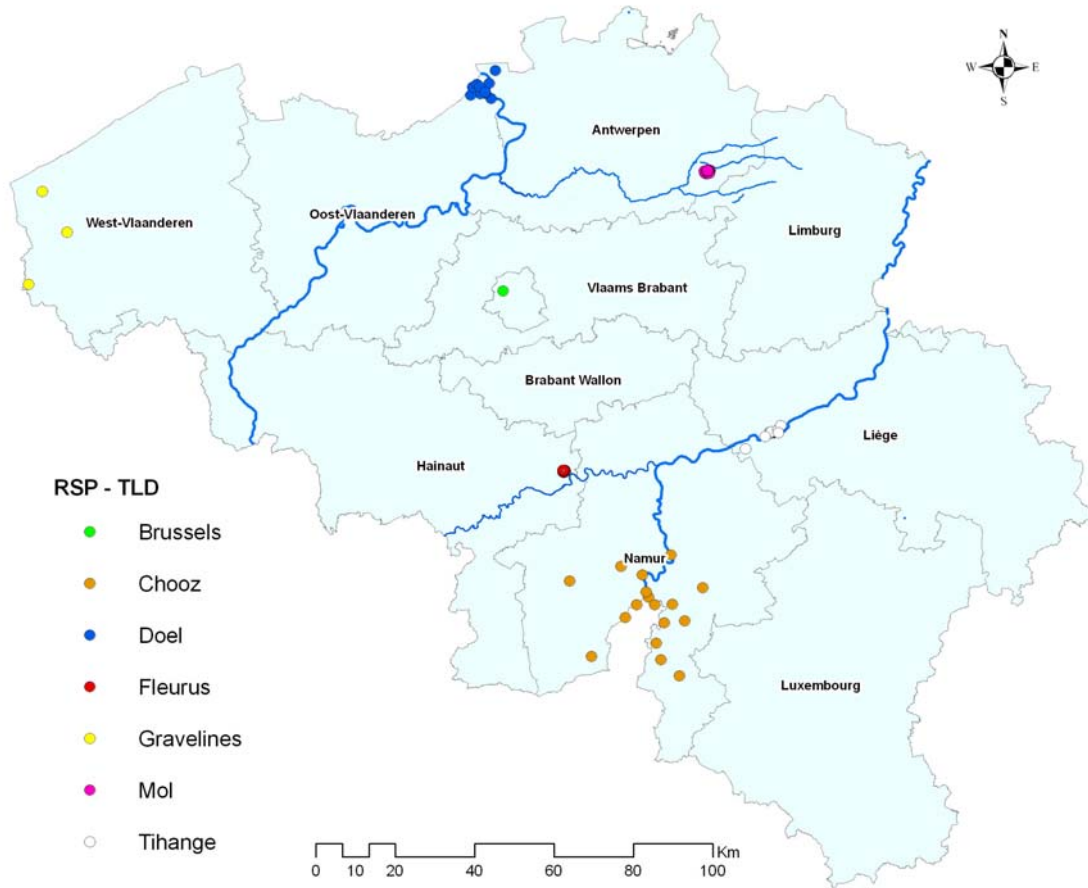


Milk sampling points

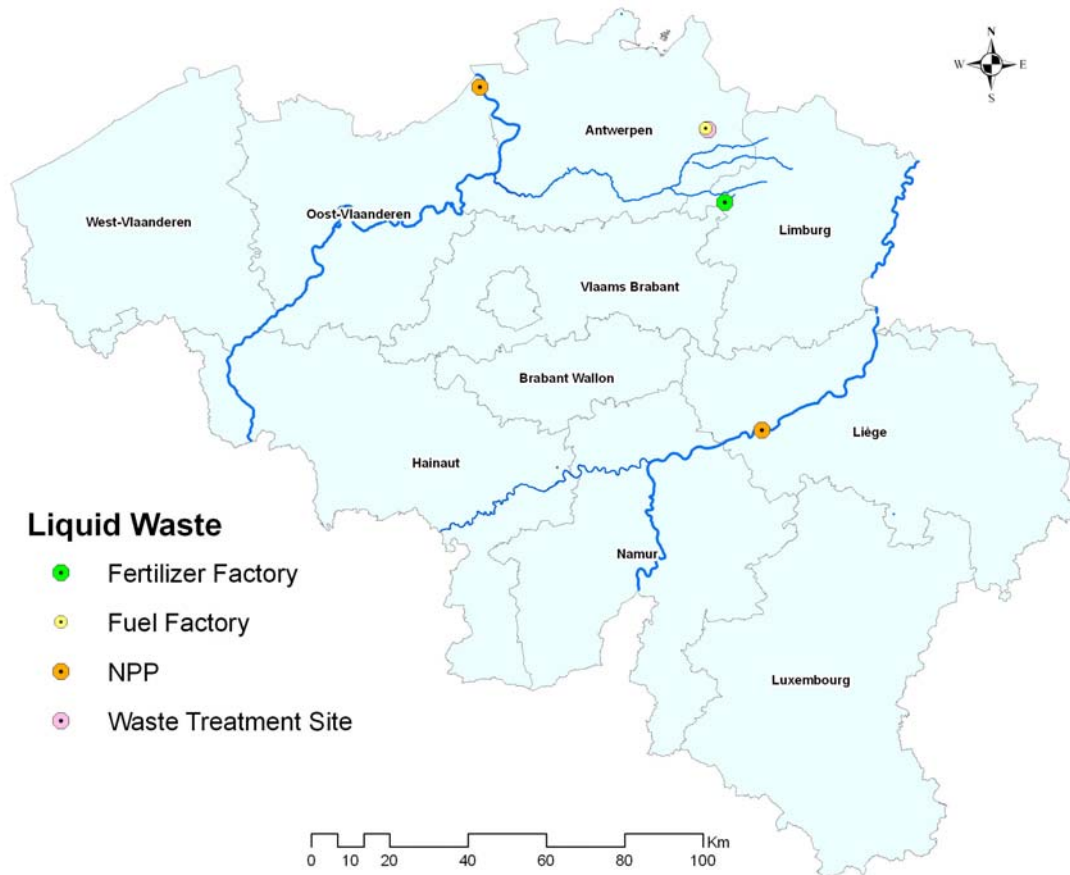


Drinking water sampling points

- Ambient dosimetry via the installation of thermoluminescent dosimeters – TLDs – placed in urban areas around nuclear sites on a monthly basis;



- Monitoring the atmospheric and liquid discharges of nuclear facilities (nuclear power stations, Mol-Dessel site) and NORM industries (Tessenderlo - 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 Aampsin,
 - ◇ the IRE site at Fleurus close to the Sambre,
- *Non-nuclear sites:*
 - ◇ Hospitals of major urban areas such as Namur and Liege.

1,700 samples are taken from the overall basin, on which more than 12,700 measurements are conducted for radioactivity.

Radiological monitoring programme for the Sambre – Meuse basin

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

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

Zone	Basin and location of sampling points		Type of measurement	Frequency of sampling	
	Sambre	Meuse			
Soil	permanent meadow (superficial soil – 5 cm + grass cut short)	close to the IRE site (Fleurus)	close to the Chooz site	Spectrometry γ : ^7Be , $^{134-137}\text{Cs}$, $^{(57)-58-60}\text{Co}$, ^{54}Mn , ^{65}Zn , $^{110\text{m}}\text{Ag}$, ^{40}K , $^{226-228}\text{Ra}$, ^{228}Th	Annually
			close to the Tihange site	^{131}I close to IRE	
			Lixhe		
	agricultural soils		around the boot of Chooz (soils: 24 points) (plants: 25 points)	Spectrometry γ , α , ^{90}Sr , ^{226}Ra	Annually
	agricultural plant production			Spectrometry γ , ^{90}Sr , ^3H , ^{14}C	
River	water	Floriffoux	Heer-Agimont, Andenne, Huy, Ampsin, Monsin, Lixhe	Spectrometry γ : ^7Be , $^{134-137}\text{Cs}$, $^{141-144}\text{Ce}$, $^{103-106}\text{Ru}$, ^{95}Zr , ^{95}Nb , ^{226}Ra	every 4 weeks
				Spectrometry β total, total α ^3H , ^{40}K , (^{131}I near to the IRE)	weekly
	sediments	Floriffoux	Heer-Agimont, Andenne, Ampsin, Lixhe	Spectrometry γ : ^7Be , $^{134-137}\text{Cs}$, $^{(57)-58-60}\text{Co}$, ^{54}Mn , ^{65}Zn , $^{110\text{m}}\text{Ag}$, ^{40}K , $^{226-228}\text{Ra}$, ^{228}Th , (^{131}I close to IRE)	every 4 weeks
	aquatic plants, mosses, bivalves	Floriffoux	Heer-Agimont/Hastière/Waulsort, Andenne, Huy, Ampsin/Amay, Flémalle, Monsin, Lixhe	Spectrometry γ : ^7Be , $^{134-137}\text{Cs}$, $^{(57)-58-60}\text{Co}$, ^{54}Mn , ^{65}Zn , $^{110\text{m}}\text{Ag}$, ^{40}K , $^{226-228}\text{Ra}$, ^{228}Th ^3H 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, Belgonucléaire and FBFC International at Mol and Dessel,
- *Non-nuclear sites:*
 - ◇ Hospitals of large urban areas such as Antwerp,
 - ◇ Feed phosphates factory near Tessenderlo.

Near 1,060 samples are taken from the overall basin, on which around 5,600 measurements of radioactivity are conducted.

Radiological monitoring programme for the Scheldt – Nete basin

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

Close to 450 samples are taken from the overall maritime zone, on which around 1,700 measurements are conducted for radioactivity.

Radiological monitoring programme for the maritime zone

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

The reference zone

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 one million inhabitants (1/10th of the total Belgian population).

About 400 samples are taken, on which more than 900 measurements are conducted for radioactivity.

Radiological monitoring programme for the reference zone

Zone	Location of sampling points	Type of measurement	Frequency of sampling
Atmosphere	dusts	Brussels (Brussels Capital) Spectrometry γ : ^7Be , $^{134-137}\text{Cs}$, $^{141-144}\text{Ce}$, $^{103-106}\text{Ru}$, ^{95}Zr , ^{95}Nb , (^{131}I near to the IRE)	every 4 weeks
		Spectrometry total β : on paper filters after 5 days decay	daily
	precipitations	Brussels (Brussels Capital) Spectrometry γ (untreated water) : ^7Be , $^{134-137}\text{Cs}$, $^{141-144}\text{Ce}$, $^{103-106}\text{Ru}$, ^{95}Zr , ^{95}Nb , ^{131}I	every 4 weeks
		Spectrometry total β , total α , ^3H , ^{90}Sr (filtered water)	every 4 weeks
		Spectrometry total β , total α (filter deposits)	every 4 weeks
Soil	permanent meadow (superficial soil – 5 cm + grass cut short)	Brussels (Brussels Capital) Spectrometry γ : ^7Be , $^{134-137}\text{Cs}$, $^{57-58-60}\text{Co}$, ^{54}Mn , ^{65}Zn , $^{110\text{m}}\text{Ag}$, ^{40}K , $^{226-228}\text{Ra}$, ^{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 – Directive 98/83/EC) 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 the Chernobyl accident.

Almost 660 samples are taken, on which more than 3,000 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. Around 209 samples and up to 630 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 (Brabant) Liège (Liege) Namur (Namur) Fleurus (Hainaut) Bastogne (Luxembourg) Ghent (East Flanders) Poperinge (West Flanders) Mol (Antwerp) Zepperen (Limburg)	Spectrometry total α & total β , ^3H , ^{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
	dairies/farms	Brussels region (Brabant) 1 farm Fleurus region 75 dairies Tihange region 118 dairies Doel region 1 dairy Dessel region 1 dairy Chooz region 42 dairies	Spectrometry γ : of which $^{134-137}\text{Cs}$, ^{131}I , ^{40}K ^{90}Sr	weekly every 4 weeks
Milk	vegetables	national territory among small and large scale retailers	Spectrometry γ : of which $^{134-137}\text{Cs}$, ^{40}K	4 samples monthly of meat, fish, vegetables
	meat		^{90}Sr	4 samples annually of meat, fish, vegetables
	fish			
Foodstuffs	various (mushrooms, flour, etc.)			
	control meal	company canteens: Mol (SCK•CEN), Fleurus & Brussels (ISP)	Spectrometry γ : of which $^{134-137}\text{Cs}$, ^{40}K ^{90}Sr and ^{14}C	monthly quarterly

Dosimetric control close to nuclear sites

The monitoring programme also implements a network of thermoluminescent dosimeters (TLDs), permanently installed in urban areas in the vicinity of the country's main nuclear sites. These dosimeters incorporate the gamma component of the surrounding radioactivity (as do the TELERAD ambient dosimetry stations). They are positioned 1 m from the ground and are generally replaced every two months in order to carry out the measurement to determine the integrated dose over the period of exposure.

Around 480 dosimetric measurements are carried out.

Radiological monitoring programme for ambient dosimetry (TLD)

Location	Nuclear site concerned	Number of TLDS	Measurement period
border of the site and neighbouring urban areas (Tihange, Amsin, Amay, Solière – between Huy and Andenne, Socolie hydro-electric station)	Tihange power station	30	2 months
neighbouring urban areas (Doel, Kieldrecht, fort Lillo, a refinery, etc.)	Doel power station	10	2 months
border of the site and industrial zoning	IRE site	12	2 months
close to and in the SCK•CEN site	Mol-Dessel site	31	3 months
neighbouring towns: neighbouring urban areas (Heer Agimont/Hastière; East of the boot of Givet: Massembre, Feschaux, Winenne, Felenne, Bourseigne-vieille; west of the boot of Givet: Petit Doische and Vaucelles)	Chooz power station	8	2 months
city of Brussels	Reference zone	1	2 months

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 instructed 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, 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.

More than 330 samples are taken, on which over 6,200 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 : ^7Be , ^{51}Cr , ^{54}Mn , $^{(57)-58-60}\text{Co}$, ^{59}Fe , ^{65}Zn , ^{95}Nb , ^{95}Zr , $^{134-137}\text{Cs}$, $^{103-106}\text{Ru}$, $^{141-144}\text{Ce}$, ^{131}I , $^{110\text{m}}\text{Ag}$, ^{113}Sn , $^{123\text{m}}\text{Te}$, $^{124-125}\text{Sb}$	monthly
FBFC site	Spectrometry β : ^3H Spectrometry total β , total α ^{226}Ra , $^{234-235-238}\text{U}$, $^{238-(239+240)}\text{Pu}$, ^{241}Am	weekly
Mol-Dessel site (Belgoprocess 2)	Spectrometry γ : $^{134-137}\text{Cs}$, ^{54}Mn , $^{(57)-58-60}\text{Co}$, ^{131}I Spectrometry total β , total α ^3H , ^{90}Sr , $^{234-235-238}\text{U}$, $^{238-(239+240)}\text{Pu}$, ^{241}Am	weekly

Monitoring discharges from NORM industries

The discharges of the Tessenderlo Chemie site (fabrication of feed phosphates) in the Winterbeek are regular monitored at the vicinity of the discharge release point and this on a weekly basis.

Around 52 samples are taken, on which more than 360 measurements are conducted for radioactivity.

Radiological monitoring programme for following up discharges from non-nuclear sites

NORM site concerned	Type of measurement	Frequency of sampling
Tessenderlo Chemie	total β & total α spectrometry ^{226}Ra , $^{234-235-238}\text{U}$, ^{40}K	weekly

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 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 Chooz (Heer-Agimont) sites;
- Soil category: sampling near the Tihange and IRE nuclear sites as well as in the Belgian agricultural zones 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:

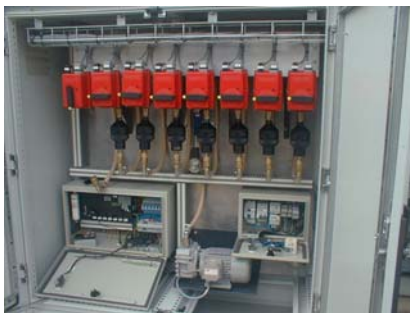
- The air in Belgium and, in particular, around nuclear installations does not present any radiological problem. The levels measured are all lower or close to the – very low – detection thresholds of the measuring equipment;
- The measurements of the radioactivity of rain show that very small quantities of radioactivity (mainly due to natural radioactivity) can be detected by virtue of the very low detection thresholds reached by the measuring equipment;
- The 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) and as far as the other radioelements 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 $> 0.5 \mu\text{m}$), which are one of the forms of atmospheric discharge from nuclear facilities, essentially contain fission products (β 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 and on the right – manual one).



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).



Dusts washed by rains are also collected in pluviometers (photos on the left and 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 and Tihange: atmospheric dusts, rainwater collected in rain gauges and deposit tanks; and in the vicinity of the nuclear site of Chooz (Heer-Agimont): rainwater collected in rain gauges and deposit tanks. A “check” site – Lixhe – located far way of any nuclear installation and nearby the border of The Netherlands has been allocated for performing measurements on dust particles and precipitations.

These controls, conducted close to the IRE, Tihange and Chooz (collectors installed in 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)		Rain (Bq/l)		Deposit tanks (Bq/m ²)	
	measurement	DL	measurement	DL	measurement	DL
γ	NM	$\sim 10^{-5}$	NM	< 1	NM	< 5
		$(0.7 \text{ to } 2.0) 10^{-5}$ \rightarrow ^{134,137} Cs		$0.2 \text{ to } 0.4 \rightarrow$ ^{134,137} Cs		$1.6 \text{ to } 2.3 \rightarrow$ ^{134,137} Cs
		$(0.6 \text{ to } 1.2) 10^{-4}$ \rightarrow ¹⁰⁶ Ru		$2.0 \text{ to } 3.5 \rightarrow$ ¹⁰⁶ Ru		$15 \text{ to } 20 \rightarrow$ ¹⁰⁶ Ru
⁷ Be	$(2 \text{ to } 5) 10^{-3}$		traces 0.5 to 3.7	3.0 to 3.7	NM (traces)	20 to 30
β total	$(0.5 \text{ to } 1.3) 10^{-3}$	$\sim 0.4 10^{-3}$	0.03 to 0.36 (filtrate)	~ 0.03	0.7 to 6.6 (filtrate)	0.7 to 1.0
			0.05 to 0.50 (filter deposit)	~ 0.04	0.5 to 4.5 (filter deposit)	0.9 to 1.1
¹³¹ I					NM Fleurus	~ 4
					NM Tihange, Heer-Agimont, Lixhe	$\sim 20 \text{ to } 24$
³ H	-	-	NM (filtrate)	~ 7.3	NM	distillate : 140 to 160
α total	$(0.8 \text{ to } 5.6) 10^{-3}$ (indicative)	$\sim 1.1 10^{-3}$			NM (filtrate)	~ 0.8
					traces :	~ 0.8
					0.3 to 3.0 (filtrate)	0.9 to 1.0
					traces 0.05 to 0.37 (filter deposit)	0.03 to 0.05
					0.7 to 3.0 (filter deposit)	0.8 to 0.9
					0.5 to 7.5 (filter deposit) Fleurus (IRE)	0.8 to 0.9

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 ⁷Be (cosmogenic natural radioelement) 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/m³;

- 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 alpha and beta emitters (total α and β measurements) – mainly of natural origin – are detectable. These levels are quite in line with those measured in other European countries: total mean annual alpha activities noted for the Paris region lower than $0.15 \cdot 10^{-3}$ Bq/m³ of air;
- In the vicinity of IRE at Fleurus, watersamples taken from the deposit tanks installed on the site close to the Sterigenics building, near building B12 situated further away and at a farm situated a few kilometres outside the site, do not reveal any presence of radioactive iodine (the detection limit is approximately 4.0 Bq/m²);
- 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, Tihange and Chooz nuclear sites 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 site		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
				< 1		< 1
γ	NM	25 to 40	NM		NM	
				2.0 to 4.2 → ¹⁰⁶ Ru		1.2 to 7.7 → ¹⁰⁶ Ru
¹³⁷ Cs	600 to 1,500 120 (Lixhe)	35 to 40	3.6 to 15.0		traces : 0.3 to 4.5	0.1 to 1.0
⁹⁰ Sr			1.5 to 10.0		0.28 to 2.70	~ 0.5
¹⁴ C					0.18 to 0.53 (Bq/g C)	
³ H org.					traces	23 to 38
⁴⁰ K	(3.6 to 5.8) 10 ⁴		400 to 960		130 to 1,700	
²²⁶ Ra	(3.0 to 4.5) 10 ³		30 to 60			
²²⁸ Ra	(2.8 to 4.8) 10 ³					
²²⁸ Th	20 to 30 Bq/kg sec		19 to 57			
²³⁵ U			NM	1.1 to 4.9		
²³⁸ U			17 to 28			
^{238,(239+240)} Pu			NM	0.6 to 0.8		
²⁴¹ Am			NM	0.6 to 1.0		

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 (⁴⁰K 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, ²²⁸Th) are also detected on a regular basis;
- As far as artificial radioactivity is concerned, traces of ¹³⁷Cs 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 radioelement that has been come across is ⁹⁰Sr. This beta emitter (half life of ~ 29 years) is still present in the biosphere as a result of nuclear weapon

tests in the atmosphere. Meadows display greater concentrations (compared to other vegetation) for a given type of soil;

Note also that in 2009, only for 2 of the 25 samples of plants showed traces of ^3H . In 2005, 5 samples of 24 and in the period of 2006-2007, 18 out of 24 showed such traces. In 2008, only 5 samples were positive. 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 23-38 from 2006 to 2009.

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

Campaign	Case of detection of ^3H in plants	Detection limits in case of absence of detection (Bq/kg MS)	Mean of concentrations observed in case of detection (Bq/kg MS)
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

It shows that 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 of dry matter has permitted to measure the tritium content with sufficient accuracy.

It seems that less ^3H has been detected since 2006 whereby the detection limits remained at the same level. One can assume that this illustrates that less tritium is present in the environment.

- Artificial transuranic alpha emitters (Pu and Am) are not measurable.

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, Liège and Charleroi.

The Meuse constitutes, after treatment, 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 imminent application of European Council Directive 98/83/EC dated 3 November 1998 concerning the quality of water intended for human consumption. The technical annexes of this Directive dealing with radioactivity should be published in the near future..



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 elements, 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 (where available) 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 elements. *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*) site incorporates the discharges of Fleurus (IRE) and of Charleroi on the Sambre river;

- The sites of Heer-Agimont (*H-Ag*), Waulsort (*Wau*) or Rivière (*Riv*) 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*) site incorporates 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 Monsin (*Mon*) site, downstream from Liège, incorporates, in turn, the intake from the Liège hospitals;
- 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 (<i>D. polymorpha</i>) (Bq/kg fresh)		Flora (Bq/kg fresh)	
	measurement	DL	measurement	DL	measurement	DL	measurement	DL
γ	NM	≤ 1	NM	< 3	NM	2 to 6	NM	4 to 15
^{137}Cs	NM	0.10 to 0.12	3 to 7 (Flo) 7 to 12 (H-Ag) 7 to 15 (And) 6 to 16 (Amp) 8 to 13 (Lix)	~ 2	NM	≤ 2	NM (mosses) NM (plants)	4 to 7 2 to 3
^{131}I	NM	0.19 to 0.28	NM (Flo, H-Ag, And, Amp) 6 to 40 (Lix)	23 to 44				
^3H	NM (Flo) 8 to 32 (H-Ag) 8 to 34 (And, Huy) 7 to 46 (Amp) 10 to 43 (Mon) 10 to 40 (Lix)	~ 7.5			NM	3 to 9	NM (mosses) NM (plants)	13 to 17

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

total α	traces (Flo, H-Ag. And. Huy. Amp. Mon. Lix)	0.04 to 0.06				
^{226}Ra		30 to 63	3 to 7 (And. Huy, Lix) 10 to 18 (Flo)	~ 3	Mosses : 30 to 170 130 to 310 (And. Flé) 25 to 75 (Flo) Plants : NM	4 to 9
^{228}Ra		30 to 75	NM (And. Huy, Lix) 8 to 12 (Flo)	~ 4	Mosses : 30 to 200 110 to 260 (And. Flé) 15 to 35 (Flo) Plants : NM	8 to 12
total β (résidual)	NM (Flo) 0.05 to 0.12 (H-Ag) NM (And. Huy, Amp. Mon) traces (Lix)	0.05 to 0.06				
^{40}K	0.16 to 0.27 (Sambre) 0.09 to 0.19 (Meuse)	300 to 650	20 to 60	~ 30	230 to 500 (mosses) 220 to 1,350 (plants)	

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 ^3H is detected in the waters on a regular basis: levels of ^3H , which can reach 50 Bq/l, are measured downstream from the nuclear power stations;
- In sediments: ^{40}K fluctuates between 300 and 650 Bq/kg dry, while $^{226-228}\text{Ra}$ ranges between 30 and 75 Bq/kg dry (^{228}Th from 25 to 80 Bq/kg dry);
- Sometimes traces of ^{131}I show up in the sediments taken downstream from big urban areas, which is indicative of hospital discharges;

- In flora and fauna (mosses and *D. polymorpha*): ^{40}K is measured in concentrations from 220 to 1,350 Bq/kg wet in the mosses and aquatic plants, 20 to 60 Bq/kg wet in the bivalves;
- Traces of ^{137}Cs and of ^3H are rarely detected (non significant data) in the samples of mosses (and plants) taken along the river banks.

Summary:

- Natural radioactivity (^{40}K , and to a lesser extent $^{226,228}\text{Ra}$ 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 ^3H is routinely measured in the Meuse water, though it remains at concentrations below the parametric value of 100 Bq/l defined in European Council Directive 98/83/EC of 3 November 1998 concerning the quality of 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 at Mol and Dessel) and non-nuclear sites (hospitals in big urban areas such as Antwerp, feed phosphate factory 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 non-nuclear site of Tessenderlo near the Grote Laak and the Winterbeek, all tributaries of the Grote Nete, itself a tributary of the Ruppel, which flows into the Scheldt:

- 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 Grote Laak, the Winterbeek, the Molse Nete, the Grote Nete, the Ruppel 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 to be subjected to stricter controls on account of the liquid discharges of artificial radioactivity from the Mol-Dessel site and radium discharges from the installations at Tessenderlo (Grote Laak, Winterbeek). The levels of ^{226}Ra (and its concentration in sediments and sludge) needs to be specially monitored for the Grote Laak and the Winterbeek;

More precisely:

- The radioactivity of certain radioelements (including ^3H) 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 as well as in the Grote Nete (and to a lesser extent in the Ruppel) is not negligible. On the other hand, the situation of the hydrographic network of the Nete needs to be monitored very carefully:

- The radiological anomalies observed for ^{226}Ra constitute a greater problem in reality: a high level of pollution through heavy metals. Although the companies discharging into these watercourses have made great efforts to treat their waste water so as to reduce the impact on the ecosystem, the quantities of radioactivity they discharge, which come on top of a “history”, are still not negligible and need to be reduced.

Even though these waters cannot be used as such for human consumption, it cannot be completely ruled out that harmful biological effects may occur through inundating inhabited and agricultural zones (banks, dredging spoil deposit zones, etc.) which may be locally contaminated, especially chemically, with the risk of transfer to the food chain. Significant contamination of the banks has already been observed, in particular, along the Grote Laak and the Winterbeek, the flow of which is almost completely regulated by the liquid effluents of the Tessengerlo complex.

4.1 ATMOSPHERIC RADIOACTIVITY

The following table summarises all the results obtained for the atmospheric categories studied: air dusts, rain collected in pluviometers and 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. ^7Be (a natural cosmogenic radioactive element) 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)		Rain (Bq/m ²)		Deposit tanks (Bq/m ²)	
	measurement	DL	measurement	DL	measurement	DL
γ	NM	$\sim 10^{-5}$	NM	< 1 $0.04 \text{ to } 0.05$ $\rightarrow {}^{134,137}\text{Cs}$ $\sim 0.4 \rightarrow {}^{106}\text{Ru}$	NM	$2 \text{ to } 17$ $1.8 \text{ to } 2.0 \rightarrow$ ${}^{134,137}\text{Cs}$
${}^7\text{Be}$	$(1.0 \text{ to } 3.8) 10^{-3}$		traces 0.4 to 2.0	~ 0.3	13 to 120	~ 10
total β	$(0.2 \text{ to } 0.4) 10^{-3}$	$(0.1 \text{ to } 0.2) 10^{-3}$	0.04 to 0.17 Mol, Doel (filtrate)		4 to 35 Mol (filtrate)	
			0.012 to 0.57 Mol (filter deposit)		1.7 to 5.0 Doel (filtrate)	
			0.012 to 0.18 Doel (filter deposit)		1.0 to 9.0 (filter deposit)	
${}^3\text{H}$			NM	~ 8	NM	700 to 990
total α	$(7 \text{ to } 18) 10^{-6}$ Mol-Dessel	$\sim 4 10^{-6}$	0.002 to 0.015 (filtrate)		0.3 to 1.5 Mol (filtrate)	
			0.001 to 0.007 Mol (filter deposit)		0.2 to 0.8 Doel (filtrate)	
			0.002 to 0.040 Doel (filter deposit)		0.3 to 1.0 Mol (filter deposit)	
					0.3 to 2.2 Doel (filter deposit)	

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 (${}^{40}\text{K}$)

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 ($^{226,228}\text{Ra}$, $^{234,235,238}\text{U}$, ^{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)	DL
	measurement	measurement	
γ	NM	NM	13 to 25
^{137}Cs	420 to 460	400 to 440	~ 25
^{40}K	(24 to 27) 10^3	(9 to 10) 10^3	
^{226}Ra ^{228}Ra	(1,4 to 1,5) 10^3	400 to 560	
^{228}Th	(1,4 to 1,6) 10^3	420 to 460	
^{235}U ^{238}U		NM 280 to 420	~ 20
$^{238,(239+240)}\text{Pu}$		NM	15 to 20
^{241}Am		NM	~ 15

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 radioactive contamination of the soils;
- In the Mol-Dessel region, only natural radioactivity (uraniums) is detectable. There is no evidence of detectable quantities of heavy elements 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 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 receive the discharges of the site manufacturing feed phosphates at Kwaad-Mechelen and Tessenderlo (discharges of ^{226}Ra); the Grote Nete, into which all these watercourses flow; the Ruppel, where the Grote Nete ends and, 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, Belgonucléaire, 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:

$$2,5 [\alpha \text{ total}] + 0,4 [^{90}\text{Sr}-^{90}\text{Y}] + 2,5 \cdot 10^{-5} [^3\text{H}] + [^{60}\text{Co}] + 1,5 [^{134}\text{Cs}] + 1,5 [^{137}\text{Cs}] + 0,1 [\beta] \leq 25 \text{ GBq/month} \\ (150 \text{ GBq/year maximum with a concentration limit of } 15 \text{ MBq/m}^3) \text{ in the river Molse Nete.}$$

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

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*), shrimps (*Crangon sp.*) and crustaceans, 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 Winterbeek (*Win*) near the Tessenderlo chemie discharge channel;
- On the Grote Laak (*GLa*) near the Tessenderlo chemie discharge points;
- On the Molse Nete (*MNe*) near the discharge point of the outlet channel of Belgoprocess 2 at the Mol-Dessel site;
- On the Grote Nete (*GNe*) near Geel, which drains the preceding watercourses;
- On the Ruppel (*Rup*) near Boom;
- On the Scheldt (*Esc*) near Doel;
- Further in the estuary for fauna (shrimps and marine mussels) and flora (algae – *Fucus vesiculosus*): Kieldrecht region near Doel, Kloosterzande and Hoofdplaat 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 ^3H in the Molse Nete.

In greater detail:

- In the waters of the Molve Nete, the artificial radioactivity is due to ^3H , which fluctuates from 9 to 300 Bq/l. Traces of transuranic elements are no longer detected ($^{238, (239+240)}\text{Pu}$ and ^{241}Am) with detection limits in the vicinity of $\sim 10^{-4}$ Bq/l. The natural radioactivity is due to ^{40}K (a few tenths of Bq/l) and to the $^{234, 238}\text{U}$ with concentrations of 0.001 to 0.004 Bq/l, as well as ^{235}U with concentrations of 0.0001 to 0.0002 Bq/l;
- In the sediments, the radioactivity is mainly of natural origin (K and Ra). Radium is easily detectable – especially in the Grote Laak and the Winterbeek (discharge points) with concentrations of 140 to 700 Bq/kg dry matter. The levels decrease further into the basin towards the Scheldt. Recent sediments of the Molve Nete displays traces of artificial radioactivity (mainly ^{137}Cs with concentrations of 30 to 250 Bq/kg and the transuranic elements – Pu and Am with 1 to 70 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 . The presence of ^{137}Cs is measured (4 to 11 Bq/kg) in the Molve Nete (mosses and aquatic plants). 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 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 fresh)		Flora (Bq/kg fresh)	
	measurement	DL	measurement	DL	measurement	DL	measurement	DL
γ	NM	≤ 1	NM	< 3	NM (Estu)	< 3	NM	< 3 (MNe) 1 to 6 (Estu)
^{60}Co			0.5 to 10.0 (MNe)	~ 4				~ 3 (MNe)
			0.2 to 5.0 (GNe)	~ 1	NM (Estu)	~ 2	NM	~ 2 (Estu)
			0.9 to 1.7 (Esc)	~ 1				
^{137}Cs	NM	0.1 to 0.2	traces : 3 to 10 (Win. GLa) 30 to 250 (MNe)	~ 2	NM (Estu)	~ 2	4 to 11 (MNe)	~ 2
			10 to 70 (GNe)				NM (Estu)	
			8 to 11 (Esc)					
^{131}I			40 to 1,100 (Win)	~ 10				
			NM (GLa)	~ 12				
			3 to 60 (GNe)	~ 7				

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 fresh)		Flora (Bq/kg fresh)	
	measurement	DL	measurement	DL	measurement	DL	measurement	DL
total α	0.4 to 1.1 (Win. GLa)	~ 0.5						
	0.01 to 0.03 (MNe)	~ 0.01						
	0.03 to 0.05 (GNe)	~ 0.02						
	0.08 to 0.14 (Esc)	~ 0.09						
^{238,(239+240)Pu} ²⁴¹ Am	NM (MNe)	~ 8.0 10 ⁻⁵	1 to 39				NM (MNe)	~ 0.05
	NM (Esc)	(9 to 10) 10 ⁻⁵	5 to 70 (MNe)		NM (Estu)	0.08 to 0.10	NM (Estu)	0.11 to 0.14
²²⁶ Ra	0.02 to 0.09 (Win. GLa)	0.02	200 to 700 (Win)					
	0.006 to 0.012 (MNe)	0.005	140 to 260 (GLa)				traces (MNe)	~ 5
	0.0014 to 0.0024 (GNe)	0.0014	20 to 80 (MNe)		traces (Estu)	4 to 5	6 to 20 (Estu)	
	0.005 to 0.015 (Rup)	0.005	20 to 65 (GNe)					
	0.009 to 0.023 (Esc)	0.005	46 to 56 (Esc)					
total β	0.5 to 1.0 (Win)	~ 0.9						
	1.0 to 8.7 (GLa)	~ 0.5						
	0.2 to 0.5 (MNe)							
	0.16 to 0.24 (GNe)							
	2.0 to 5.8 (Esc)							
³ H	9 to 300 (MNe)	~ 7					~ 27 (MNe)	
	4 to 100 (GNe)	~ 3			NM (Estu)	13 to 14	NM (Estu)	12 to 15
	6 to 16 (Esc)	~ 10						
⁹⁰ Sr			NM (MNe)	~ 6	NM (Estu)	~ 4	traces (MNe)	~ 5
							NM (Estu)	5 to 6
⁹⁹ Tc							NM (Estu)	~ 65

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

	Waters (Bq/l)		Sediments (Bq/kg dry)		Fauna (Bq/kg fresh)		Flora (Bq/kg fresh)	
	measurement	DL	measurement	DL	measurement	DL	measurement	DL
⁴⁰ K	0.4 to 0.8 (Win)							
	0.5 to 8.0 (GLa)		200 to 340 (Win. GLa)		120 to 300 (shrimps)		400 to 1,000 (MNe)	
	0.2 to 0.3 (MNe)		150 to 250 (MNe)		300 to 400 (mussels)		800 to 1,300 (Estu)	
	0.14 to 0.22 (GNe)		200 to 300 (GNe)					
	1.4 to 4.1 (Esc)		500 to 620 (Esc)					

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

Summary:

- Natural radioactivity (⁴⁰K and to a lesser extent ²²⁶Ra and ²²⁸Th) is mainly responsible for the level of radioactive contamination 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 Molsse Nete is 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 elements (tritium and caesium among others), 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.

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 North Sea Mathematical Model Management Unit). Sixteen 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 elements, 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 categories monitored are:

- Land category: taking of soil samples (meadows) near Coxyde;
- Marine category: 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 artificial radioactivity (^{137}Cs and transuraniums in fish) are sometimes 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.

Atmosphere radioactivity measurements (air) of the Belgian coast

Air dust particles (Bq/m ³)		
	measurement	DL
γ	NM	$\sim 10^{-5}$ $\sim 0.2 \cdot 10^{-5}$ (^{134,137} Cs) $\sim 2 \cdot 10^{-5}$ (¹⁰⁶ Ru)
⁷ Be	$(0.6 \text{ to } 1.3) \cdot 10^{-3}$	
total β	$(0.13 \text{ to } 0.21) \cdot 10^{-3}$	$\sim 0.02 \cdot 10^{-3}$
⁴⁰ K	NM	$\sim 3 \cdot 10^{-5}$

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. ⁷Be is monitored very closely (natural cosmogenic radioactive element).
- This aspect of control 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 are taken at Coxyde once a year. 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 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 ($^{226,228}\text{Ra}$, ^{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 artificial transuranic alpha emitters (^{241}Am) are not measurable.

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	13 to 50
^{137}Cs	280 to 320	
^{40}K	(9 to 10) 10^3	
^{226}Ra ^{228}Ra	(0.33 to 0.37) 10^3	
^{228}Th	(0.35 to 0.39) 10^3	
^{241}Am	NM	~ 15

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

Sixteen 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).

The measurements taken relate to monitoring the levels of alpha, beta and gamma emitting radioactive elements, 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 , ^{60}Co , $^{238, (239+240)}\text{Pu}$) are revealed in the marine sediments and the 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	NM	0.4 to 6.0
^{137}Cs	NM	0.1	0.8 to 1.3	~ 0.8
^{60}Co	NM	0.10	NM	~ 0.7
total β	10 to 11			
^{40}K	~ 12		200 to 350	
$^{226,228}\text{Ra}$	7 to 10			
$^{238,(239+240)}\text{Pu}$	NM	~ $1.0 \cdot 10^{-4}$	traces	~ 0.43

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 fresh)		Fauna (mussels and shrimps) (Bq/kg fresh)		Fauna (flat fish) (Bq/kg fresh)	
	measurement	DL	measurement	DL	measurement	DL
γ	NM	~ 0.2	NM	0.1 to 0.2	NM	0.3 to 0.6
^{137}Cs	NM	~ 0.2	NM	~ 0.11	traces	~ 0.4
^{60}Co	NM	~ 0.2	NM	~ 0.13	NM	~ 0.4
^{131}I	0.6 to 6.1		NM	~ 0.13	NM	~ 300
^{90}Sr	NM	~ 1.6	NM	~ 1.0	NM	~ 1.1
^{40}K	200 to 300		40 to 100		110 to 130	
^{99}Tc	NM	~ 75				
^{228}Ra	1.0 to 3.0	~ 0.5	NM	0.5 to 0.6	NM	~ 1.7
$^{238,(239+240)}\text{Pu}$	NM	~ 0.12	NM	0.05 to 0.09	NM	~ 0.09
^{241}Am	NM	~ 0.15	NM	0.05 to 0.09	NM	~ 0.09

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;
- The fish contain traces of ^{137}Cs , $^{238,(239+240)}\text{Pu}$ and ^{241}Am (transuranic elements 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 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 its 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, rain collected in pluviometers and deposit tanks.

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

		Air dusts (Bq/m ³)		Rain (Bq/l)		Deposit tanks (Bq/l)	
		measurement	DL	measurement	DL	measurement	DL
γ	NM		$\sim 10^{-5}$ $0.3 \cdot 10^{-5}$ (^{134,137} Cs) $2.7 \cdot 10^{-5}$ (¹⁰⁶ Ru)	NM	< 1 ~ 0.1 (^{134,137} Cs) ~ 0.7 (¹⁰⁶ Ru)	NM	< 1 ~ 0.08 (^{134,137} Cs) ~ 0.7 (¹⁰⁶ Ru)
⁷ Be	(2.8 to 5.6) 10 ⁻³			traces 0.8 to 1.3	~ 1.2	0.4 to 12.0	~ 0.6
		Rain (Bq/m ²)				Deposit tanks (Bq/m ²)	
total β	(0.3 to 0.5) 10 ⁻³			0.8 to 10.5 (filtrate)		0.4 to 4.2 (filtrate)	
				0.4 to 4.5 (filter deposit)		0.1 to 16.6 (filter deposit)	
⁴⁰ K				0.14 to 0.47 (filtrate)		0.2 to 1.7 (filtrate)	
³ H				traces 200 to 400 (filtrate)	~ 190	traces (filtrate)	~ 90
total α				0.4 to 2.5 (filtrate)	~ 0.2	0.2 to 1.6 (filtrate)	~ 0.1
				0.1 to 3.0 (filter deposit)		0.1 to 8.5 (filter deposit)	

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 (ISP site) 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. ^7Be (a natural cosmogenic radioactive element) 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 ISP 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:

- 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 ($^{226,228}\text{Ra}$, ^{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.

Summary:

- Natural radioactivity (^{40}K , $^{226,228}\text{Ra}$, ^{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 lower.

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

ISP (Brussels) site (Bq/m ²)		
	measurement	DL
γ	NM	6 to 30
¹³⁷ Cs	130 to 220	~ 10
⁴⁰ K	(6 to 10) 10 ³	
²²⁶ Ra ²²⁸ Ra	370 to 730	
²²⁸ Th	400 to 900	

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

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

From 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 $^{103,106}\text{Ru}$, 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:



7800 Bq/litre in ^3H , 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 $^{226,228}\text{Ra}$, 0.1 Bq/litre in ^{232}Th , 4 Bq/litre in $^{234,238}\text{U}$, 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 deals 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 are still in the process of being finalised.

On the other hand, the directive specifies two parametric values to be complied with: **100 Bq/litre in tritium** (^3H) 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 ^3H , potassium ^{40}K , radon ^{222}Rn or daughter elements 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.

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 will 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 radioelements (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).

- The second approach, the so-called “*specific analyses of radionuclides*” approach, is based on the measurement of a certain number of radioelements (uranium; in β : ^{14}C and ^{90}Sr ; in α : $^{239+240}\text{Pu}$ and ^{241}Am ; in γ : ^{60}Co , $^{134-137}\text{Cs}$ 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, especially in small Walloon communities, will have to put a general plan in place for monitoring its water so as to be able to apply and abide by this new directive.

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: Brabant (Brussels), Liege (Liege), Namur (Namur), Hainaut (Fleurus), Luxembourg (Bastogne), East Flanders (Ghent), West Flanders (Poperinge), Antwerp (Mol) and Limburg (Zepperen).

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

Analysis of the table shows:

- Only ^3H 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.

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 element 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 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. Ideally, the source should be traced in order to identify the collecting point(s) at the origin of these excessively high concentrations of radium.

Radioactivity measurements for drinking water

	Radioactivity of the water (Bq/l)	DL (Bq/l)	“Screening” value (Bq/l)
^3H	NM (Bastogne. Fleurus)	~ 7	100
	9 to 13 (Namur)	~ 7	
	NM (Mol. Zepperen. Poperinge)	~ 7	
	NM (Liège)	~ 2	
	6 to 10 (Brussels)	~ 2	
	7 to 20 (Ghent)	~ 2	
total β (residual) *	NM (Bastogne)	0.04 to 0.05	1
	traces : 0.06 to 0.14 (Fleurus. Namur)		
	0.04 to 0.23 (Mol)		
	0.03 to 0.05 (Zepperen)		
	0.09 to 0.35 (Poperinge)		
	0.02 to 0.04 (Ghent. Brussels. Liège)		
^{40}K	0.04 to 0.08 (Bastogne. Fleurus)	NA	
	0.09 to 0.20 (Namur)		
	0.10 to 0.13 (Mol)		
	0.25 to 0.35 (Zepperen. Poperinge)		
	0.08 to 0.12 (Ghent. Brussels)		
	0.02 to 0.03 (Liège)		
total α	NM (Mol)	0.01 to 0.06	0.1
	0.04 to 0.07 (Zepperen)		
	0.15 to 0.48 (Poperinge)		
	0.03 to 0.05 (Bastogne. Namur)		
	0.17 to 0.24 (Fleurus)		
	0.05 to 0.08 (Ghent)		
	0.06 to 0.10 (Brussels)		
	0.07 to 0.13 (Liège)		
^{226}Ra	NM (Ghent. Zepperen. Brussels. Liège)	~ 0.017	0.1
	0.07 to 0.15 (Poperinge)		
	0.03 to 0.25 (Fleurus)		

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

** total β residual: total β apart from ^{40}K*

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 , $^{134,137}\text{Cs}$ 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 47-58 Bq. The other artificial radionuclides are practically 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		DL (Bq/l)
	National mixture	Fleurus, Tihange regions	Chooz region	Mol – Dessel region	Doel region	
measurement (Bq/l)						
$^{134,137}\text{Cs}$	NM	NM	NM	NM	NM	0.1 to 0.4
^{131}I	NM	NM	NM	NM	NM	0.1 to 0.7
^{90}Sr	NM	0.03 to 0.08	0.03 to 0.10	NM	NM	0.03 to 0.05
^{40}K	48 to 53	47 to 53	48 to 51	49 to 58	50 to 57	

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

Summary:

- Artificial radiation cannot be measured for $^{134,137}\text{Cs}$ 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 is greater by far.

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.

Common staple vegetables are collected: lettuce, leeks, celery, cauliflowers, Brussels sprouts, white cabbages, red cabbages, broccoli, beans, carrots, chicory, tomatoes, cucumbers, peppers, salsifies, turnips, potatoes, cultivated mushrooms, etc.

Common staple of fruits are also collected: pears, appels, nectarines, kiwis, mangos, melons, oranges, bananas, etc.

Meat is also analysed from markets and abattoirs: beef, veal, horse, pork, poultry (chicken and turkey), rabbit, lamb, venison in season. The organs concentrate radionuclides differently in the same animal. These differences are linked to the metabolic paths taken by the radioactive elements 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 fresh)

	Vegetables & fruits		Sea fish		Fresh water fish	
	measurement	DL	measurement	DL	measurement	DL
¹³⁴ Cs	NM	~ 0.2 to 0.3	NM	0.3 to 0.9	NM	~ 1.0
¹³⁷ Cs	NM	~ 0.2 to 0.4	traces (~ 1.1)	0.3 to 0.9	NM	~ 1.0
⁹⁰ Sr	NM	~ 0.03	NM	0.4 to 0.5		
⁴⁰ K	50 to 130		70 to 110		50 to 120	

	Red meat (beef, veal, horse, pork)		White meat (poultry)	
	measurement	DL	measurement	DL
¹³⁴ Cs	NM	0.7 to 1.1	NM	0.8 to 1.0
¹³⁷ Cs	NM	0.7 to 1.1	NM	0.7 to 0.9
⁹⁰ Sr	NM	0.6 to 1.2	NM	0.5 to 0.6
⁴⁰ K	80 to 130		95 to 130	

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

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;
- The authors of this report refer the reader to the reports specific to the food chain made available in French or Dutch to the public on the FANC website: <http://fanc.fgov.be/fr/page/surveillance-radiologique-de-la-belgique/700.aspx>, entitled “Surveillance radiologique du territoire – Rapport de synthèse des données de la chaîne alimentaire, années 2000 to 2009”; or in the Dutch language: <http://fanc.fgov.be/nl/page/radiologisch-toezicht-in-belgie/700.aspx>, entitled “Radiologisch toezicht op het grondgebied – Syntheseverlag van de gegevens met betrekking tot de voedselketen, jaren 2000 to 2009” (Radiological monitoring of the territory – Summary report on the data concerning the food chain 2000 to 2009);

The 2009 report contains the data obtained within the framework of the monitoring of the territory, **in addition to** those provided by the Federal Agency for the Safety of the Food Chain; up to 470 samples of foodstuffs were consequently checked and the data analysed and interpreted;

The main conclusions of this (these) report(s) are summarised below:

*This strengthened monitoring programme highlights the fact, as was already the case in previous years, that the **influence of nuclear installations** (Doel and Tihange nuclear power stations, nuclear sites of Mol-Dessel and IRE at Fleurus) **is not perceptible** in relation to foodstuffs.*

The radiological state of the foodstuffs checked is excellent with artificial radioactivity hardly ever discernible - despite particularly low detection limits as far as the detection of radioactivity is concerned.

In general, the 470 samples measured in 2009 show no detectable artificial radioactivity.

*Analysis of the data makes it possible **to conclude** that there is **no significant artificial radioactivity founded in analysed foodstuffs**. A “pessimistic” and therefore conservative approach confirms these results.*

It can thus be stated on the basis of the routine control carried out that the consumer’s health is definitely not placed in danger by consuming foodstuffs distributed on Belgian territory.

7.4 RADIOACTIVITY OF CONTROL MEALS

Samples of “control” meals are taken from company restaurants or canteens 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 (ISP)		Wallonia (Fleurus)		Flanders (SCK•CEN)	
	measurement	DL	measurement	DL	measurement	DL
^{134,137} Cs	NM	~ 0.09	NM	~ 0.12	NM	~ 0.33
⁹⁰ Sr	NM	~ 0.3	traces (0.04 to 0.07)	~ 0.03	NM	~ 0.5
⁴⁰ K	25 to 60		35 to 60		30 to 50	
¹⁴ C	NM*	~ 1*	0.26 ± 0.27*	< 0.1*	NM*	~ 1*

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

* expressed in Bq ¹⁴C / 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. CONTROL OF DOSIMETRY CLOSE TO NUCLEAR SITES

Dosimetry is conducted by means of TLDs (thermoluminescent dosimeters) positioned about 1 m from the ground at various points of the territory located in the immediate vicinity of nuclear sites and neighbouring urban areas in order to obtain a realistic picture of the ambient dose received by the population (photo on the right). They are generally replaced every 2 months to enable them to be measured.



These dosimeters essentially measure natural telluric and cosmic gamma radiation (as do the TELERAD ambient dosimetry stations). The annual dose varies according to the nature of the rocks; it is generally higher in ancient terrains composed of crystalline rocks. These dosimeters also register exposure to Radon, a natural radioactive gas given off by some soils (notably in rocky soils as in the Ardennes).

On the whole, dosimetry shows that the doses generally remain lower than or equal to 1 mSv/year.

The doses recorded in the areas around the nuclear sites are thus due to a natural origin – telluric and cosmic natural radiation – as confirmed by the results of continuous measurements obtained by the TELERAD network, with doses slightly higher than 1 mSv/year in the Ardennes and from 0.7 to 0.9 mSv/year in Flanders (Chapter 1, point 1.4 of this report).

From this, it can be concluded that the nuclear installations have no dosimetric impact on their surroundings.

The following table summarises the results obtained.

Average ambient dosimetry measurements (TLD) expressed in mSv/year

IRE site	Tihange site	Tihange region	Doel region	SCK•CEN Site	Chooz region	Brussels site
				0.73 ± 0.12 (in general)		
	0.84 ± 0.29			1.23 ± 0.36 (waste depot area)	0.81 ± 0.08 (7 points)	
0.73 ± 0.64	0.86 ± 0.08 (near of the waste building)	0.83 ± 0.09	0.77 ± 0.07	3.02 (old waste depot of Eurochemic – BP2 site)	1.34 (Felenne)	0.96
				1.00 (BR2)		
				1.43 (BR3)		

Summary:

- The ambient dosimetry around IRE is conducted at 12 points by means of TLDs read every 2 months and placed on the fence. The doses recorded fluctuate around 0.73 mSv/year. This level of background radiation has no incidence on the ambient dose;
- The ambient dosimetry around the SCK•CEN site is carried out at 31 points with the help of TLDs taken every three months. The doses recorded average 0.73 mSv/year. This level of background radiation confirms no site has no incidence on the ambient dose. Nearby the buildings for radioactive waste storage, the recorded doses are locally higher but this has no consequences at greater distance;
- The dosimetry around Tihange is conducted by means of TLDs read every two months and placed at 25 points around the Tihange site (on the edge of the site at the level of the fences), as well as in various urban areas or places located in the vicinity of the nuclear site: Tihange, Ampsin, Amay, Solière (located between Huy and Andenne) and the Socolie hydroelectric station;

For the nuclear site, the doses recorded are around 0.84 mSv/year. In the urban areas located on terrains composed of crystalline rocks, the doses recorded are sometimes slightly higher (according to the nature of the rocks richer in natural radioactivity);

The doses are systematically lower for Socolie, the station located downstream from the power station on the banks of the Meuse, averaging 0.49 mSv/year. This decline in background radiation has to be seen in relation to the nature of the subsoil (backfill and concrete of the banks) as well as the presence of substantial masses of water (the river itself) in the immediate vicinity.

From this, it can be concluded that the Tihange nuclear power station does not give rise to any increase in the ambient dose;

- The ambient dosimetry around Doel is conducted by means of 10 TLDs read every 2 months and placed at several points situated at various locations around it (Doel, Kieldrecht, Lillo fort, a refinery, etc.);

The doses recorded are around 0.77 mSv/year. This level of background radiation confirms that the power station, as at Tihange, has no incidence on the ambient dose.

- The dosimetry around Chooz is conducted by means of TLDs read every 2 months and placed at 8 points around the site in different urban areas of Belgium (located on a straight line between 5 and 8 km from the French power station): Heer-Agimont, for the east of the boot of Givet at Massemble, Feschaux, Dion, Winenne, Felenne, Bourseigne-Vieille and for the west of the boot of Givet at Petit Doische and Vaucelles: the measured values fluctuate around 0.81 mSv/year;

The doses recorded are of the same order of magnitude than those recorded in the Tihange region (0.83 mSv/year): this dose is directly in relation to the nature of the rocky subsoil, the French power station does not give rise to any increase in the ambient dose;

- The dosimetry carried out in the urban area of Brussels (1 TLD) shows that the 2009 dose is about 0.96 mSv/year.
- As a whole, these results confirm the data provided by the TELERAD network (chapter 1, point 1.4 of this report).

9. 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).

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 any liquid radioactive waste in the environment. Historically, it has not been included in this monitoring. The Agency will receive – in a very near future – a precise reporting of the atmospheric releases operated;
- Tessenderlo NORM industry (production unit for feed phosphates), which discharges ^{226}Ra into the Grote Laak and the Winterbeek. The follow-up of these discharges was integrated into the general surveillance program of the Belgian territory. Furthermore, other NORM sites or historically contaminated sites are also followed, either through measurements performed by the utility or through punctual interventions by the FANC.

Generally, the analysis of atmospheric and liquid discharges from the nuclear sites indicates that all these installations adhere to the limits imposed on them and more, in that the discharges are very much lower than the limits in question.

Only the discharges of tritium are significant, mainly the liquid ones, which represent around 36 % (Tihange) and 51 % (Doel) of the maximum authorised values. It should be noted that these levels are on the decline compared with those of the 1985-1990 period, when they were at a maximum of 47 % for Tihange and 67 % for Doel.

The liquid discharges into the Mulse Nete are less negligible and make it particularly necessary to monitor this eco-system. The presence of a chemical industry at Tessenderlo and its discharges of ^{226}Ra strengthen the obligation to monitor the radio-ecological status of this region.

9.1 ATMOSPHERIC DISCHARGES OF NUCLEAR INSTALLATIONS

Atmospheric discharge is produced by the following sites:

- Nuclear power plant sites (nuclear power plants of Doel and Tihange);
- Sites of Mol-Dessel (SCK•CEN, Belgoprocess and FBFC International).

9.1.1 Nuclear Power Plants:

There are no noticeable radiological problems: all of the emissions remain largely below the prevailing limits, especially with regard to the rare gases, iodines and aerosols.

The following table gives an overview of the results available:

Measurement of the radioactivity present in the atmospheric discharge produced by the nuclear power plants of Tihange and Doel, expressed in a percentage of the legally specified yearly limits

	Tihange		Doel	
	Percentage	Limit	Percentage	Limit
Rare Gases	0.56	2.22 10 ⁶ GBq	0.00053	3.00 10 ⁶ GBq
Aerosols (β-γ)	0.0011	1.11 10 ⁵ MBq	0.0057	1.50 10 ⁵ MBq
Iodines	0.20	1.48 10 ⁴ MBq	0.41	1.50 10 ⁴ MBq
³ H	13.49	5.55 10 ⁴ GBq	3.30	8.90 10 ⁴ GBq

Summary: on the basis of these results, it may be stated that there are no noticeable radiological problems.

9.1.2 Other Nuclear Sites:

site of SCK•CEN:

The atmospheric discharges of alpha, beta and gamma emitters, iodine, tritium and rare gases produced by the installations of the SCK•CEN, are controlledly released through several chimneys: « nuclear reactors BR1, BR2 and BR3 (in dismantling), high and medium activities laboratory LHMA, laboratory of Pu warm chemistry and laboratory of Low activity L.Sch, the building of temporary radioactive waste storage CBZ».

More in detail:

The data obtained are summarized in the table below.

Measurement of the radioactivity present in the atmospheric discharge produced by the nuclear site of the SCK•CEN, expressed in kBq per year (% of the limit)

	Total α	Total β-γ	¹³¹ I	HTO	Rare gases
BR 1		98.8 (0.0010)	608 (0.0021)		
BR 2	4.56 (0.0027)	40.5 (0.0026)	1080 (0.0534)	2.17 10 ⁹ (0.17)	< 44.1 10 ⁹ (7.25)
BR 3		70.6 (0.0016)			
LHMA	2.35 (0.0012)	11.9 (0.0007)			
Pu	3.44 (0.0014)	15.0 (0.0002)			
L.Sch	10.20 (0.0026)	120.0 (0.0036)			
CBZ	1.56 (0.0031)	5.91 (0.0030)			

Summary: there are no noticeable radiological problems. Monthly limits are likewise applicable and are also largely complied with.

Site of Belgoprocess:

The atmospheric discharges of alpha and beta emitters and of tritium produced by the installations of Belgoprocess, are controllably released through several chimneys, mainly: « AD, FLK, BRE, 280 » of building 2 (BP2) and « 120, 110, 131, 137 and 155 » of building 1 (BP1).

More in detail:

The data obtained are summarized in the table below.

Measurement of the radioactivity present in the atmospheric discharge produced by the nuclear site of Belgoprocess 2 in Mol-Dessel, expressed in kBq per year (% of the limit)

	Total Alpha	Total Beta	Tritium
AD	28.2 (0.148)	60.1 (0.00050)	333 10 ³ (0.00018)
FLK	15.4 (0.037)	58.2 (0.00022)	
BRE	5.3 (0.0143)	10.1 (0.000046)	
280	12.5 (0.134)	60.7 (0.00303)	283 10 ³ (0.71)

Measurement of the radioactivity present in the atmospheric discharge produced by the nuclear site of Belgoprocess 1 in Mol-Dessel, expressed in kBq per year (% of the limit)

	Total Alpha	Total Beta	Tritium
120	6.42 10 ³ (0.584)	1.11 10 ³ (0.0010)	
110	11.5 (1.173)	39.6 (0.015)	
137	35.2 (1.76)	3.37 10 ³ (0.034)	301 10 ³ (0.03)
131	5.7 (0.0057)	17.7 (0.0018)	
155	8.6 (0.0215)	51.2 (0.00171)	

Summary: there are no noticeable radiological problems. Monthly limits are likewise applicable and are also largely complied with.

Site of FBFC International :

The atmospheric discharges of *FBFC International*, a nuclear fuel and MOX assembly factory, are released through two chimneys situated on buildings 2 and 5 of the site. Its alpha emission is subject to the following licenses:

- Building 2: 190 kBq/year;
- Building 5: 320 kBq/year.

With an instant volumic limit of 0.013 Bq/m³ (GRPIR).

More in detail:

The data obtained are summarized in the following table.

Measurement of the radioactivity present in the atmospheric discharge produced by the nuclear site of FBFC International in Mol-Dessel, expressed in kBq in total alphas

	Total discharge	Limit	Percentage of the limit
Building 2	29 ± 9	190	15.26 ± 4.74
Building 5	72 ± 18	320	22.50 ± 9.47

Summary: there are no noticeable radiological problems.

9.2 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 Molve Nete).

9.2.1 Nuclear power stations:

The liquid discharge limits set for the *Tihange site*, three reactors with a total capacity of 2985 MWe, are 1.48 10⁵ GBq in ³H and 8.88 10⁵ MBq in beta-gamma emitters; for the *Doel site*, four reactors of a total capacity of 2817 MWe, they are set at 1.04 10⁵ GBq in ³H and 1.50 10⁶ MBq in beta-gamma emitters.

In greater detail:

- For the Tihange nuclear power station: the most significant liquid discharges in terms of activity are made up of tritium: in the order of 36 % of the authorised limit. The beta-gamma emitter discharges are, however, mostly lower than the limit, i.e. around 1 % of said limit;
- For the Doel nuclear power station: the most significant liquid discharges in terms of activity are made up of tritium, representing 51 % of the limit. The beta-gamma emitter discharges are, once again, mostly lower than the limit, i.e. around 0.2 % of said limit.

The following table summarises the available data.

Radioactivity measurements for liquid discharges from the Tihange and Doel nuclear power stations, expressed in a percentage of the legally specified yearly limits and quantities discharged

	Tihange		Doel	
	Percentage	Limit	Percentage	Limit
³ H	36.1	1.48 10 ⁵ GBq	51.1	1.04 10 ⁵ GBq
total β-γ	0.62	8.88 10 ⁵ MBq	0.23	1.50 10 ⁶ MBq
	Quantity (MBq)		Quantity (MBq)	
total β	0		0	
total α	1.27 10 ⁻³		0	

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

9.2.2 Other nuclear sites:

Mol-Dessel site:

The liquid discharges from the Mol-Dessel nuclear site enter the Molve Nete via the installations of Belgoprocess 2. These discharges have to adhere to a limit set at 25 GBq/month and a maximum of 150 GBq/year according to the following weighting formulae:

$$2,5 [\alpha \text{ total}] + 0,4 [^{90}\text{Sr}-^{90}\text{Y}] + 2,5 \cdot 10^{-5} [^3\text{H}] + [^{60}\text{Co}] + 1,5 [^{134}\text{Cs}] + 1,5 [^{137}\text{Cs}] + 0,1 [\beta] \leq 25 \text{ GBq/month}$$

(150 GBq/year maximum with a concentration limit of 15 MBq/m³) in the river Molve Nete.

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

The discharges from the site into the Molve 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 data show that the total weighted discharges represent 0.19 % of the annual limit;
- Measurements conducted on the gamma and beta emitters of the effluents discharged show that radioactive elements such as ¹³⁷Cs (from 1.0 to 4.0 Bq/l), ³H (from 3.5 10² to 4.0 10⁵ Bq/l), ⁹⁰Sr (from 0.3 to 0.8 Bq/l) and ⁶⁰Co (0.2 to 1.6 Bq/l);
- The discharges in total alpha range from 0.2 to 3.0 Bq/l, with those in total beta around 1.3 to 35.0 Bq/l;
- As far as the transuranic elements are concerned, traces of ²⁴¹Am are detected (for limits of the order of 0.9 to 1.0 Bq/l). ^{239,240}Pu are routinely detected at levels below or close to 0.3 Bq/l (mostly between 0.01 and 0.10 Bq/l). The same observation can be made for ²³⁸Pu.

The following table summarises the data obtained.

Radioactivity measurements for liquid discharges from the Mol-Dessel nuclear sites, expressed in percentages of the statutory limits and in quantity (GBq) – Belgoprocess 2 discharges

	Percentage	Weighted quantity (GBq)	Annual discharge limit
Weighted total	0.189	0.284	150 GBq
total α		0.040	
^{90}Sr - ^{90}Y		0.008	
^3H		0.057	
^{60}Co		0.009	
^{134}Cs		0	
^{137}Cs		0.144	
total β		0.026	

Summary: the site fully complies with the discharge limit.

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 Molsse Nete. They are nevertheless monitored regularly (every month).

In greater detail:

Measurable quantities of alpha emitters are discharged every month: from 0.4 to 1.0 Bq/l (a decrease is recorded compared to 2001-2002 when the measurements recorded reached a few Bq/l). It should be noted that the detection limits are of the order of 0.2 Bq/l, which indicates that these discharges are barely measurable. The site can't discharge more than 20 Bq/l in total alpha (GRPIR).

The following table summarises the data obtained.

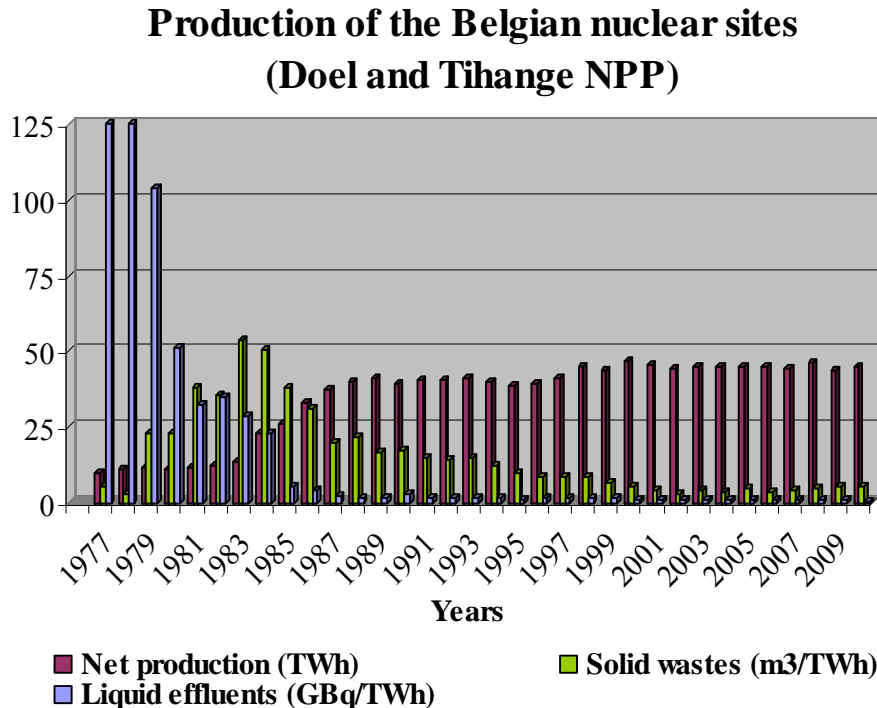
Radioactivity measurements for liquid discharges from the FBFC International Mol-Dessel nuclear site expressed in Bq/l (DL: detection limit)

Radioactive element	measurement	DL	Total discharge (MBq)
total α	0.4 to 1.0	0.08	3.31
total β	0.5 to 0.8	0.10	
^{234}U	0.3 to 0.7	0.001 to 0.007	
$^{235,236}\text{U}$	0.014 to 0.044	0.002 to 0.013	
^{238}U	0.06 to 0.15	~ 0.002	
^{241}Am	traces ($1 \cdot 10^{-4}$ to $48 \cdot 10^{-4}$)	~ $1.8 \cdot 10^{-4}$	
^{238}Pu	traces ($1 \cdot 10^{-4}$; a peak of $7 \cdot 10^{-2}$ in February)	~ $1.8 \cdot 10^{-4}$	
$^{239+240}\text{Pu}$	traces ($0.7 \cdot 10^{-4}$ to $47 \cdot 10^{-4}$)	~ $1.7 \cdot 10^{-4}$	

Summary: no radiological problem to report.

9.2.3 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).



While the total production of electricity has remained more or less constant at around 45 TWh in recent years, the quantity of radioactivity discharged in the liquid effluents has sharply declined from around 42 GBq in 2003 and 2004, to reach 21 GBq in 2009 (or 0.47 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 are around 5.38 m³/TWh.

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.

9.3 NORM INDUSTRIES AND HISTORICALLY CONTAMINATED SITES

Belgium accounts for several active NORM industries, including the sector of feed phosphate 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 m³ - the 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 by past activities – one speaks about historically contaminated sites or

legacy sites. Besides those sites related to the NORM industry – like the historical disposal sites for phosphor gypsum-, one should also take into account the sites related to the past activity of radium extraction.

9.3.1 NORM industry in activity:

In the area of enhanced natural radioactivity (NORM industry), two companies – both active in the phosphate industry - are subject to environmental monitoring: *Tessenderlo Chemie NV* and *Prayon SA*. Besides these 2 companies, the liquid discharges of a company producing titanium dioxide – *KRONOS NV* – is subject to punctual measurements.

Since 2000, the discharges of *Tessenderlo Chemie* have been measured directly in the discharge channel flowing into the Winterbeek. Trace quantities of alpha emitters are reported (2 to 3 Bq/l total alpha and 0.11 to 0.23 Bq/l ²²⁶Ra).

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

Furthermore, the mono-landfill (Fig. 1), on which the production residues of *Tessenderlo Chemie* are discarded, is being monitored. These residues consist mainly of calcium fluoride with a Ra-226 concentration of slightly over 10 Bq/g. The total alpha concentration in the ground water is followed through sampling 2 piezometers. Between 2004 and 2009, the measurements vary between less than 15 mBq/l and a maximum value of 139 mBq/l. The radon concentration in free air on and around the landfill area is also being monitored (Fig. 2 shows the location of the 14 measurement points: 5 are located on the landfill and 9 are in the direct neighbourhood of it). The table hereafter shows the radon concentrations during the period 2006-2007. One needs to notice that the highest recorded value amounts to 540 Bq/m³, which is over 20 times the normal level in this region.



Fig. 1: Aerial view of the mono-landfill of Tessenderlo Chemie

Table 1: Radon concentration on and around the mono-landfill of Tessenderlo Chemie

	1 st semester 2006	2 nd semester 2006	1 st semester 2007	2 nd semester 2007
<i>A. On the landfill</i>				
1	145	155	150	165
2	175	255	260	340
3	380	480	410	540
4	45	35	55	50
15	65	135	90	60
<i>B. In the neighbourhood</i>				
5	35	25	40	30
6	20	15	35	30
7	40	20	40	40
8	25	15	45	30
9	30	25	55	30
10	60	25	55	40
11	205	205	110	145
12	35	45	70	45
13	35	30	45	30

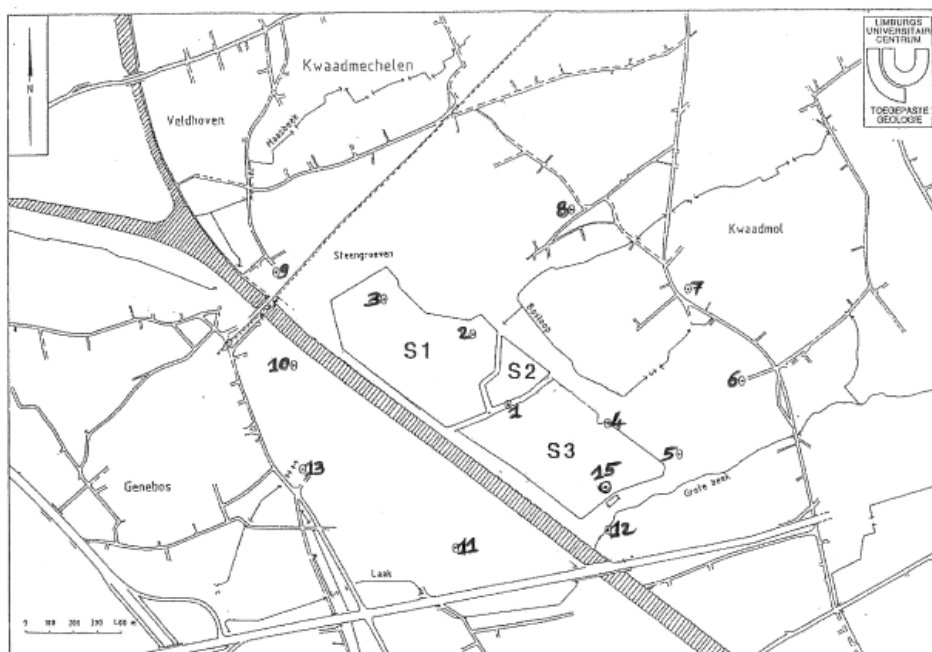


Fig. 2: Location of the radon measure points on the mono-landfill of Tessenderlo Chemie

Next to its production site at Engis, *Prayon SA* possesses also a mono-landfill on which the surplus of phosphor gypsum - originating from the production process – is stored. The Ra-226 content of the groundwater is followed here using 6 piezometers. The values measured between 2001 and 2009 vary between 2 and 49 mBq/l. This is the same order of magnitude as the natural concentrations.



Fig. 3: aerial view of the mono-landfill of *Prayon SA*

KRONOS NV, a producer of TiO_2 located near Ghent, discharges its effluents in the canal Ghent-Terneuzen. The Ra-226 and Ra-228 concentrations in these effluents have been verified between July 2007 and January 2008. The Ra-226 concentration varied between 0.4 Bq/l and 1 Bq/l. The Ra-228 concentration was between 0.2 and 0.6 Bq/l. To compare, these values are significantly lower than the general discharge limits as published in the Belgian regulations for authorised practices (ARBIS section 2.2.1).

In conclusion: the current radiological impact of the active NORM industries in Belgium is limited. Notwithstanding this, the activity levels of the residues on the mono-landfill of *Tessenderlo Chemie* and the increased radon concentrations at its surface make that the radiological surveillance of this site becomes necessary. More precisely will – at the end of the exploitation – every new allocation of the site require a detailed evaluation of its radiological impact.

9.3.2 Historically contaminated sites:

9.3.2.1 Historical NORM sites

In 2009 FANC performed radiological measurements at the following 2 ‘historical’ NORM sites:

- the old landfill for phosphor gypsum ‘Hoeykens’ at Puurs: this disposal site has a surface of approximately 14 ha and contains about 2.1 million m^3 of phosphor gypsum. This phosphor gypsum originates of the past production of phosphor acid by Prayon-Rupel. This landfill is one of several phosphor gypsum disposal sites in the region. The average radium concentration in the phosphor gypsum is around 0.5 to 0.6 Bq/g. Measurements of the radon concentration in the soil – at the level of the gypsum layer – have been conducted (Fig. 4). The average level of the radon concentration rise to 372 kBq/m^3 for a normal value in this region of about 20 kBq/m^3 . A radon exhalation measurement was also performed and resulted in a radon flux of 62 $\text{mBq}/(\text{m}^2\text{s})$. This is significantly higher than what is being measured in the high radon risk area of the Ardennes, where between 30 and 40 $\text{mBq}/(\text{m}^2\text{s})$ is being measured.

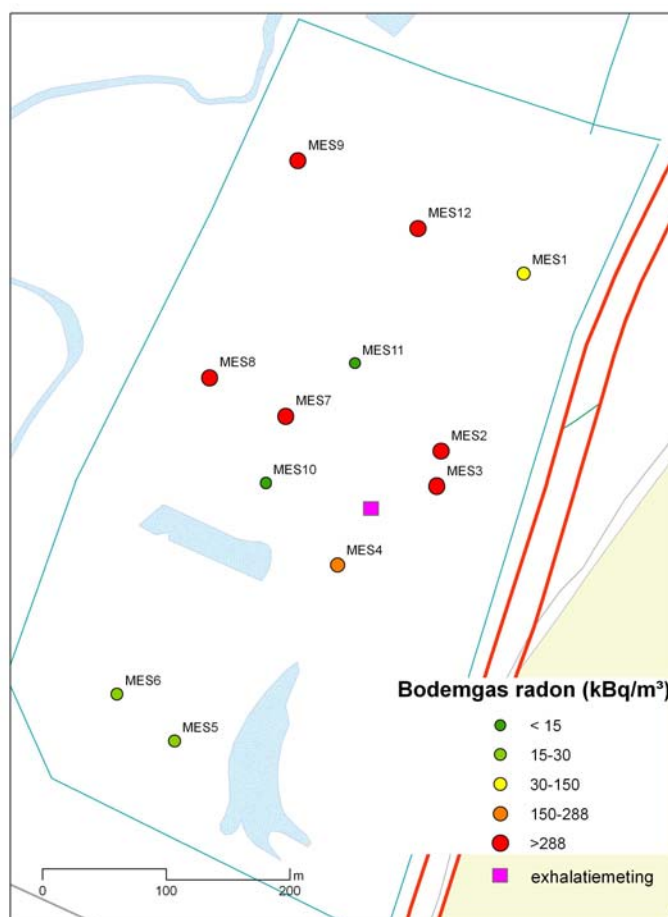


Fig. 4: radon concentration measurements in the soil of the phosphor gypsum disposal site ‘Hoeykens’

- the landfill of the old Forges de Clabecq, a steel factory located in Tubize, that ended operations at the beginning of the years 2000, was also monitored briefly during 2009. The discarded residues contain slag and sludges from the smoke washing. Dose rates at the surface of the site were measured yielding values in the order of 2 to 3 times the natural background. Samples of the soil indicated only a moderate elevation of the Th-232 concentration (highest value recorded: 0.17 Bq/g). A radon exhalation measurement was also performed yielding a radon flux of 0.94 mBq/(m²s). This can be explained by the high density of the slag material.

Furthermore, abnormally elevated uranium concentration (up to 400 µg/l) were measured during a routine control of the groundwater at Ukkel (within the District of Brussels) during 2009. The concerned ground water was for sanitary purposes used by 2 neighbouring schools. One of these schools disposes of a pond where a concentration of 150 µg/l of uranium was measured. The origin of these relatively high concentrations was not clearly identified: a link with discarded waste from the glass industry during the previous century is expected. As long as this water is not used for consumption, the radiological risk remains however limited.

In conclusion: although the current radiological impact of the historical NORM sites remains limited, it could become significant in case a new allocation would be given to these sites in future. Especially the risks related to the high radon concentrations that were observed on the historical landfills for phosphor gypsum are important.

9.3.2.2 Other historical sites

Between 1922 and 1969 the metallurgic factory of *Union Minière* (nowadays *UMICORE*) at Olen (province Antwerp) was performing extraction of radium and production of radium sources. Next to the extraction of radium, the company was also active in the production of other metals, amongst which cobalt.

Part of the residues of the production process (tailings, radium needles ...) and the waste from dismantling the radium extraction unit are stored in an authorised storage installation: the UMTRAP (*Uranium Mill Tailings Remedial Action Plan*).

Between 2006 and 2008 clean-up operations were performed at the banks of the Bankloop river, which was contaminated as a result of the activities of the company. The material that was produced during these clean-up operations is stored in another authorised installation.

These 2 authorised installations are submitted to a radiological monitoring programme. The radon concentrations in open air and the concentrations in the surface waters are being measured around both installations.

The following table shows the lowest and highest values measured for these concentrations during 2009. The values vary between as a function of the location of the measurement point and the season.

	UMTRAP			Bankloop		
	# measure points	Min	Max	# measure points	Min	Max
Concentration Rn-222, free air (Bq/m ³)	3	56	105	6	24 (=background)	199
Concentration Ra-226, surface water (mBq/l)	2	13,3	20,9	2	8,2	240
Concentration Ra-226, ground water (mBq/l)	4	6,2	19,5	4	13	380
Concentration Ra-226, percolation (mBq/l)	0	-	-	1	175	398

Besides the material stored in these 2 authorised installations, there are on and around the site of the company several terrains that show a radium concentration that cannot be neglected and that still need to be remediated.

More precisely, specific waste from the production process and some waste from dismantling the radium extraction unit were disposed off on 2 landfills: D1 and S1. The landfill D1 shows

the highest contamination levels: the Ra-226 concentration averaged over the entire landfill (217000 m³) is around 20 Bq/g, with some hotspots reaching 1 kBq/g. Analyses of the ground water performed in 2008 present concentrations in the filtered ground water up to 220 mBq/l of U-238 and 409 mBq/l of Ra-226. In the past the radon concentration was also measured at different points in the upper layer of the D1 landfill. These were clearly elevated and varied between 180 and 1330 Bq/m³ at 0.5 m.

Radium contaminations can also be found outside of these 2 landfills, a.o. in some streets of neighbouring communities.

In conclusion: the current radiological impact of the sites contaminated by historical activities of radium extraction does not require urgent countermeasures. This impact could however become important if new allocations for these terrains would be considered. The FANC forces itself, together with all stakeholders, to develop and to implement a general solution guaranteeing a permanent and safe management of the radiological risk.

10. OVERALL CONCLUSIONS

The revision of the entire programme for the radiological monitoring of the territory – which was implemented from 2003 to 2004 and was based on an effort to harmonise the libraries of radioelements measured for the overall territory as well as taking account of 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) – has enabled the different regions of the country to be better monitored while taking account of their specific features. Comparisons between sections of each region and between regions themselves have been made easier.

An analysis of the results obtained within the framework of the radiological monitoring of the Belgian territory of 2009 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 ^7Be) 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 elements on the environment and consequently on humans: “traces” of artificial radioactivity, considerably lower than natural radioactivity, are routinely detected.

Although this situation is reassuring at the health level, 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).

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 feed phosphate industry in the Tessenderlo region. This means that the sediments of the Molve Nete contain a significant level of fission products (^{137}Cs) and heavy artificial radionuclides in the form of traces of transuranic elements ($^{239+240}\text{Pu}$, ^{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 and feed phosphate production has nevertheless declined sharply in recent years.

The Federal Agency for Nuclear Control have decided to install in 2010 new automatic and continuous measuring stations for gamma radiation present in surface water. Continuous data will be used among others to demonstrate more fully more fully that Belgium is meeting its national and international obligations under the OSPAR convention and Articles 35/36 of the EURATOM (EC) Treaty.