MISSION REPORT 2018

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

Moving nuclear security forward

Radiological report of the French environment from 2015 to 2017

réseau national
Réseau national de mesures de la radioactivité de l'environnement

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Gamma spectrometry system for measuring atmospheric aerosol filters

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RADIOLOGICAL MONITORING OF THE ENVIRONMENT

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RADIOLOGICAL MONITORING OF THE ENVIRONMENT

1.1. THE PURPOSE OF THE RADIOLOGICAL MONITORING OF THE ENVIRONMENT

Many operators help to monitor the radiological composition of the French environment:

- operators of nuclear facilities (ANDRA[1], CEA[1], EDF[1], ILL[1], the French Navy[1] and Orano[1]). All of these operators monitor local levels in the immediate vicinity of their nuclear sites as per regulatory requirements. In general, requirements relating to environmental monitoring for civilian nuclear facilities are defined in ASN (French nuclear safety authority) decision no. 2013-DC-0360 dated 16 July 2013 on controlling disturbances and the effects of basic nuclear facilities on health and the environment, amended by ASN decision no. 2016-DC-0569 dated 29 September 2016. If necessary, this programme can be detailed and adapted to match local particularities in the form of site-specific ASN decisions. The monitoring programme applicable to former mining sites is defined as a prefectoral decree;
- IRSN[1], ASN[1], French Ministries (health, DGAL[1], DGCCRF[1], etc.), government services and other public operators responsible for monitoring throughout France, or which conduct tests or monitor specific sectors (e.g. food for the French Ministries of agriculture and consumers);
- associations approved for monitoring air quality (AASQA[1]), local authorities, associations (CLI[1], environmental protection associations), which monitor this parameter independently to public authorities.

As highlighted above, monitoring is shared between many different entities with, on the one hand, IRSN and the public authorities monitoring radioactivity at regional and national level, and, on the other hand, nuclear facility operators monitoring their sites. Other public authorities and associations additionally contribute to and boost the credibility of the overall monitoring network. They particularly check the consistency of the measurements taken.

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Alpha spectroscopy

1. See glossary in chapter 8.4.

The different purposes of the radiological monitoring of the environment

Purpose no. 1

Help to improve our knowledge of the radiological composition of the environment and variation in this composition. This is achieved by measuring the different radionuclides in the different components, quantifying radioactivity levels and monitoring geographic variation and change over time in order to detect any increases in artificial radioactivity, even down to several magnitudes less than fluctuations in natural ambient radioactivity.

Purpose no. 2

Help to evaluate radiological exposure to protect the health of the local populations and the environment, particularly by evaluating doses and improving our knowledge of the radiological composition of the different environmental components: air, soils, waters, food, etc.

Purpose no. 3

Detect any abnormal increase in environmental radioactivity as early as possible, monitor levels and identify the cause of the variation (natural or anthropic) and the specific source facility for spurious discharges.

Purpose no. 4

Ensure compliance with all provisions applicable to nuclear facilities by determining the type and source of the substances in question if the predefined thresholds are exceeded. Help to check that the radiological impact of the facilities remains below regulatory limits.

Purpose no. 5

Improve transparency and the quality of information provided to the public by distributing the results of monitoring programmes, approving laboratories and involving several entities.
While each single measurement taken separately will not necessarily cover all five purposes, the combined measurements taken by the different operators will directly and indirectly contribute to ensuring the five purposes of environmental monitoring are covered. Each contributor organises several types of monitoring (e.g. routine monitoring and expertises), each designed to meet specific targets. The immediate environments of nuclear sites are monitored in addition to effluent monitoring by operators. The environment must be monitored in addition to effluent monitoring, the latter alone is insufficient.

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Sampling aquatic plants in the Vienne region downstream from the Civaux NPP

1.2. RADIOLOGICAL MONITORING DEVICES USED FOR THE ENVIRONMENT

Two complementary approaches are used for the radiological monitoring of the environment in France:

- continuous *in situ* monitoring using independent systems (remote monitoring systems) with the real-time transmission of results. These systems (figure 1A) are mainly used to trigger an alert if a major accident occurs. These systems include:
  - networks of ambient gamma dose rate sensors (e.g. IRSN Téléray network, site operator sensors),
  - IRSN's Hydrotéléray network, used to monitor the main rivers by gamma spectrometry, downstream of all nuclear facilities and before a river crosses a national border;
- samples taken from the various types of environment near to facilities authorised to discharge radionuclides are processed and measured in a laboratory. Samples are taken using two methods:
  - ad hoc environmental samples. These samples are taken for a wide range of source matrices: water (rain, fresh surface water, ground water or seawater), biological indicators (mosses, algae), soils and sediments, and food (milk and dairy products, meat, fish, molluscs, shellfish, cereals, etc.);
  - continuous sampling systems. These samples are mainly taken in view of atmospheric (aerosols, measuring specific radionuclides in the air such as tritium and carbon-14) and surface water (sampling *via* water sampling systems) measurements.

The type of monitoring selected will depend on the final aim, expected performance levels and any limitations for the analyses (interfering factors, sampling time, etc.).

The sampling and measuring systems used, and the types of analysis carried out in France by the many contributors to the radiological monitoring of the environment sometimes differ substantially for this reason. Some systems are suitable for the targets assigned to nuclear operators as part of the regulatory monitoring of their facilities, while other operators use far more advanced analysis techniques and sampling gear, allowing them to reach much lower decision thresholds (see chapter 1.4) to meet different priorities. This means that the RNM database includes results from various sources, obtained using a range of different analytical procedures.

A detailed presentation of the various sampling systems and analysis techniques used by the different laboratories in France is therefore required to help understand the wide range of results included in this radiological report.

Monitoring the atmosphere

The atmosphere is monitored using two types of systems: firstly, continuous measuring systems and, secondly, continuous sampling systems (air, gas, rainwater) with subsequent laboratory analyses.

Continuous measurements of the ambient gamma dose rate

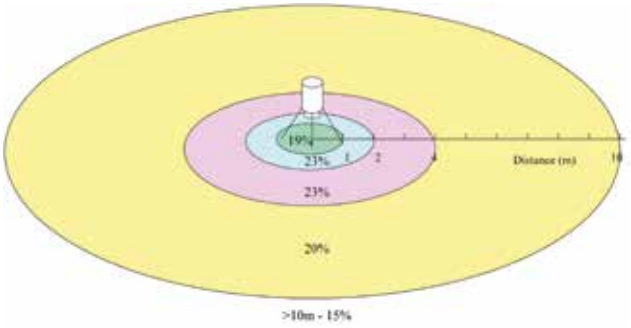
The ambient gamma dose rate measuring networks represent the main continuous measuring networks for exposure to ionising radiation in France. These systems are configured with pre-alarm and alarm thresholds and connected to supervision and stand-by systems able to trigger an alert if a major accident occurs at a nuclear site. The situation and any developments can be instantaneously assessed using these systems. These sensors (see figure 1) are deployed by IRSN throughout France and French overseas territories, however the network is far denser in the immediate vicinity of nuclear sites. Operators (EDF, CEA, Orano, ANDRA, the French Navy, ILL, etc.) monitor an area with a radius of between 0 and 10 km, while IRSN completes the monitoring network within a radius of 10 - 30 km.

FOCUS ARTICLE

THE MAIN FACTORS WITH AN IMPACT ON GAMMA DOSE RATE RESULTS

The dose rate triggered by a source of radiation decreases rapidly as the distance from the source increases.
On this basis, most of the gamma radiation reaching a detector placed 1 m above the ground, with homogeneous activity levels, is emitted within a circle with a radius of approx. 10 m. The following figure gives an example, showing the source of the gamma radiation detected 1 m above the ground containing ^{137}Cs: 19% of the radiation detected is sourced from the ground area with a radius of 1 m directly under the detector, 65% from an area with a radius of 4 m, and approx. 15% from a radius of over 10 m.
These contributions can vary depending on the energy radiated by the radionuclide in the ground. However, the key factor to remember is that any local topography, such as embankments or a construction, or if the detector is located in a dip, can substantially affect these contributions. The detector may be more directly exposed to sloped, or even vertical, surfaces, in the immediate vicinity. A wall can also act as a shield for radiation sourced behind it, or, on the contrary, radiation from a wall can dominate the radiation sourced from the ground.

In addition, radiation is attenuated by the ground itself, which acts as a shield (see chapter 5), and this effect will be more proportionally noticeable if the energy radiated is weak. On this basis, in the above case, the thickness of the ground contributing to the radiation reaching the detector will also depend on the energy radiated by the radionuclide in the ground. However, for most radionuclides of interest, this depth will be approximately 10 - 20 cm.



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Téléray sensor (left) and field gamma spectrometry system (right)

Passive environmental dosimetry

In France, the real-time monitoring systems mentioned previously can be completed with monitoring based on passive dosimetry (see figure 1B) using ThermoLuminescent Dosimeters (TLD) or RadioPhotoLuminescence glass dosimeters (RPL) set up within the grounds of nuclear sites (for operators) or throughout France as part of the recently-installed IRSN RPL network. The aim is to ensure compliance with regulations *a posteriori* (data is integrated on a monthly-to-quarterly basis and later analysed at a laboratory).

FIGURE 1 / **AMBIENT GAMMA DOSE RATE CONTINUOUS MEASURING SYSTEM, PART OF THE IRSN TÉLÉRAY NETWORK (photo 1A) AND RPL DOSIMETER SET UP AT THE CADARACHE SITE (photo 1B)**

1A

© A. Bouisson/MEDDTL/IRSN

1B

© DR

Atmospheric aerosols

IRSN manages the radiological monitoring of aerosols at national level in France. Nuclear operators and associations also contribute to monitoring at local level. Monitoring is based on aerosol samples collected at filters on a daily or weekly basis, and the subsequent laboratory analysis of the filters.

Various types of sampling methods are used at national level (see figure 2) depending on priorities and target performance levels. The main difference is air intake flowrates. A flowrate of 4 - 80 m^3/h (low to medium flow) is maintained at most stations and sampling devices for higher flowrates (100 - 700 m^3/h) are fitted at around twenty-odd stations (IRSN, CEA, the French Navy).

Nuclear operators measure the gross beta activity index using daily filter samples as well as, for some sites, measuring the gross alpha radioactivity index, as required by regulations. This index[2] is used to detect any significant air activity anomaly and trigger complementary investigations on this basis.

In addition, according to regulations, the gross beta activity index in air must not exceed a specific limit due to normal facility discharges.

On this basis, if the value of the gross beta activity index exceeds 2 mBq/m^3 in air, a gamma spectrometry analysis is required as per regulations. Gamma spectrometry will be used to determine which radionuclides are responsible for the excess radiation and, if these radionuclides are artificial, to identify the source and assess the inherent radiological consequences.

IRSN and some nuclear operators systematically carry out gamma spectrometry on aerosol filters. Performance levels mainly depend on intake flowrate and the duration of sampling. To give just one example, a station with a low flowrate can be used to measure cesium-137 activity in the air of approx. 5 mBq/m^3; a station with a high flowrate can detect levels of 0.00005 mBq/m^3 with reference to IRSN stations with a flowrate of 700 m^3/h. Such stations with high flowrates can be used to measure residual background radiation for cesium-137 in the air, which represents approx. 0.0002 mBq/m^3 (see chapter 2), and therefore to detect any increase in this background radiation, however small.

FIGURE 2 / **EXAMPLES OF ATMOSPHERIC AEROSOL SAMPLING DEVICES**

700 m^3/h sampler shown on the left; 80 m^3/h in the centre; 10 m^3/h sampler on the right.

© DR

2. The gross beta (or gross alpha) activity index is used to detect any increase in the ambient radioactivity of a given environment (air, water or biological matrix) potentially caused by a spurious discharge from a nuclear facility. The gross beta (or alpha) activity index does not correspond to the total activity of the beta-emitting (or alpha-emitting) radionuclides contained in the sample analysed and cannot be used to determine which radionuclides are present.

Special case: radon-222 daughter isotopes with short lives; measuring Potential Alpha Energy (PAE)

Radon-222 released from rocks has migrated across the ground to the atmosphere and then decays to polonium-218, lead-214, bismuth-214 and polonium-214 (see chapter 2) atoms successively. These radionuclides are present in the atmosphere as solid particles (aerosols), and may or may not be attached to the atmospheric aerosol. These aerosols, rather than the radon itself, as radon is an inert gas with a short half-life (3.8 days), can, if inhaled, settle in the respiratory tracts and release significant amounts of energy to the cells as they successively decay. These doses are generally considered as radon radiation.

The Potential Alpha Energy by volume or PAEv is used to quantify the energy which can potentially settle in the respiratory tracts in physical terms. This value is used to monitor workers and mining sites. It is expressed in J/m^3 (joules per cubic metre)

If total equilibrium is reached, where the activity of each of the daughter isotopes is equal to that of the radon, for 1 Bq of radon-222, the PAE is equal to 5.66 10^{-9}J. This factor can also be used to express the potential alpha energy by volume as an Equilibrium Equivalent Concentration (EEC), in Bq/m^3.

Figure 3 shows one example of a PAE measuring device. This device measures integrated PAE in the atmosphere over the periods of exposure selected by the operator based on the purpose defined.

Gases: tritium (^3H) and carbon-14 (^{14}C)

Tritium and carbon-14 are the main radionuclides discharged into the air by nuclear facilities.

Samples of atmospheric tritium are taken by bubbling air sucked in into containers, or bubblers, filled with water (see figure 4). Atmospheric tritium content is determined by analysing the tritium in the bubbler water. Two types of systems are used for the continuous monitoring of facilities: systems with two bubblers, exclusively used to measure atmospheric tritium as water vapour (tritium HTO), and systems with four bubblers, which are used to measure tritium HTO (first 2 bubblers) and other forms of atmospheric tritium, including gaseous HT, in the first 2 bubblers downstream of an oxidation furnace. Such monitoring is mainly implemented by nuclear operators based on

FIGURE 3 / **POTENTIAL ALPHA ENERGY MEASURING SYSTEM**

© IRSN

FIGURE 4 / **BUBBLERS FOR TAKING ATMOSPHERIC TRITIUM OR ^{14}C SAMPLES**

© DR

weekly liquid scintillation analyses (see figure 5). Results generally oscillate between 0.05 and 1.5 Bq/m^3 (background atmospheric tritium varies between 0.005 and 0.01 Bq/m^3; see chapter 2).

Samples of carbon-14 are taken by bubbling air sucked in into sodium hydroxide in order to trap CO_2 as carbonates. In addition to the CO_2 trapped in

the first 2 bubblers, these systems with 4 bubblers also trap other forms of carbon in the air (CH_4, etc.) in the 2 bubblers fitted after a catalytic heater. Various carbon-14 analysis techniques are used. The main technique involves measuring the different forms of carbon-14 using liquid scintillation. Data for activity by volume obtained based on the measurements taken using these weekly-to-monthly samples are generally between 0.02 and 0.1 Bq/m^3 (background atmospheric carbon-14 in France is approximately 0.02 - 0.06 Bq/m^3; see chapter 2).

For both tritium and carbon-14, some of the entities involved in radionuclide measurements use methods which can reach or approximate background radiation, particularly if suitable sampling times and analysis methods are used. The decision thresholds[3] obtained by other contributors, particularly during routine measurements, are, however, consistent with the purpose of monitoring nuclear facilities.

Other radionuclides in the atmospheric discharges of some facilities are also sampled and analysed, such as atmospheric iodine (gaseous and particulate) and krypton-85 (a noble gas mainly discharged by the Orano La Hague plant).

The measurements for these radionuclides are also forwarded by operators to the RNM. Atmospheric tritium and carbon-14 (and krypton-85 near to La Hague) analyses are used to assess the exposure of local residents near to some sites.

FIGURE 5 / **LIQUID SCINTILLATION MEASURING DEVICE**

© IRSN

3. The decision threshold is the lowest value of a sample measurement when the metrologist can decide whether or not activity and therefore a measurement exists. Below this value, the activity of the sample is too low to be estimated. This decision threshold depends on performance and ambient radiation around the measuring devices used (see p. 27).

FOCUS ARTICLE

PASSIVE SAMPLERS: A NEW SAMPLING TECHNIQUE FOR TRITIUM CONTAINED IN THE AIR

Current sampling systems for atmospheric tritium used for monitoring purposes require a power supply and regular heavy-duty maintenance to function properly. This is particularly the case for the bubblers shown on page 11. For this reason, these devices are little used for routine monitoring, despite the fact that tritium is the radionuclide the most frequently found in the effluents discharged by the nuclear industry.

On this basis, IRSN developed a device which can be used in far more operating configurations, at a much lower cost. This passive trap is based on the molecular diffusivity of gases and mainly comprises adsorbent material, which will preferentially sample water (H_2O) and the tritiated water vapour (HTO), and a patented sampler (figure A). The sampler consists of a lid and an internal tapered perforated structure. The two components maintain a constant sampling rate based on the availability of ambient water vapour (H_2O and HTO). The sampler comprises adsorbent material (a molecular sieve) which acts as a pump (as in "active" systems) and collects the tritiated water vapour. The molecular sieve is more generally known as zeolite (aluminosilicate). This sieve adsorbs gas molecules selectively, particularly tritium.
Test results and comparisons with other devices, particularly bubblers, were satisfactory, and a patent was granted to E2SInnovation for the sale of this device in France and Europe (figure B). Cooperation agreements with various partners were concluded to develop this sampler: CEA, CERN, EDF, the French Navy, Orano.

FIGURE A / **GEOMETRY OF THE PASSIVE PASSIF SAMPLER (IRSN patent no.: WO2014037461), LOCATION IN THE ENVIRONMENT AND MAIN CHARACTERISTICS**

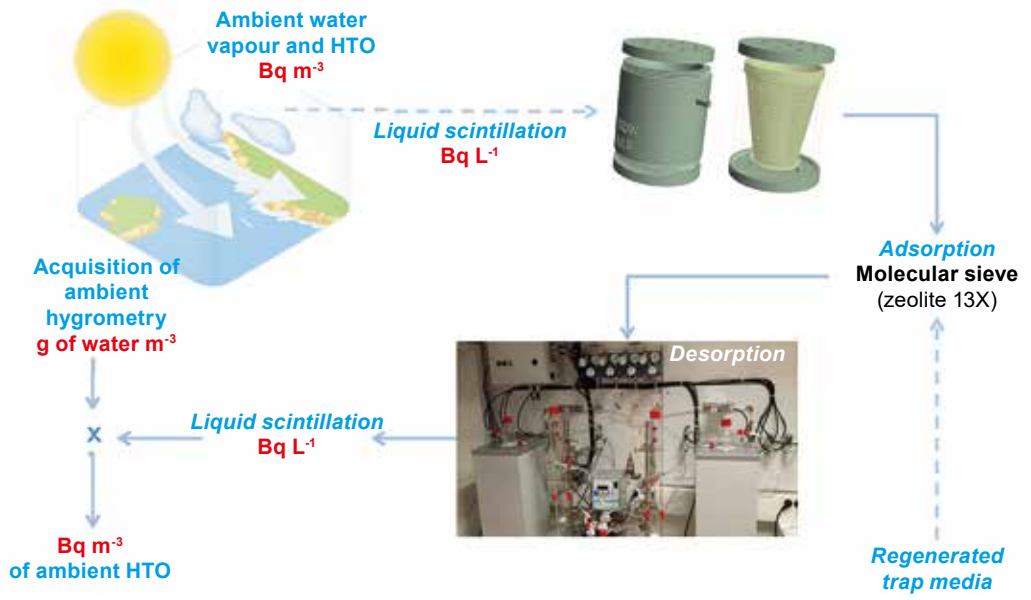


FIGURE B / **AVAILABLE VERSION SOLD BY E2SINNOVATION**

Tribase: passive sampler and recording system for the environmental parameters required to calculate the activity of atmospheric tritium.

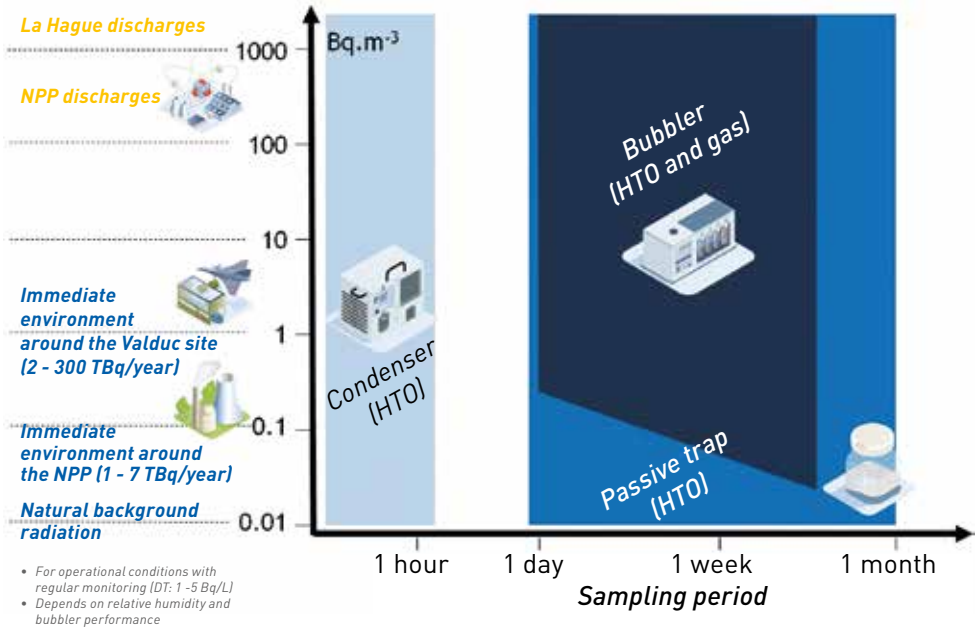
Characteristics of the molecular sieve	
Quantity of molecular sieves	180 g
Maximum sampling capacity	30% by weight
Diameter, height	94 and 111 mm
Operating time	from 24 hours to 30 days
Operating temperature	– 10 °C to 35 °C
Relative humidity	30-100%

© IRSN

Figure C shows the operating envelope for this passive sampler, and highlights that sampling periods can range from less than 1 day to over a month, with a decision threshold of 1 Bq/L (0.01 Bq/m³) for a standard liquid scintillation sample analysis. However, this device can only be used to collect tritium in atmospheric water vapour. Note: this form of tritium is the one directly transferred to flora and fauna in the environment and is the main contributor to human exposure.

IRSN started using this device, which is easy to deploy and relatively low-cost, for monitoring. No specific premises or power supply are required. When combined with routine monitoring, this passive sampler is ideal for radiological mapping as part of reinforced local monitoring policies.

FIGURE C / **OPERATING ENVELOPE OF THE PASSIVE TRITIUM SAMPLER**



Rainwater

Atmospheric radionuclides are leached from the atmosphere by rain, and subsequently precipitated on the ground. On this basis, rainwater is sampled and analysed to complement atmospheric monitoring. Collectors (see figure 6) continuously collect water during rainy episodes and samples are taken either weekly or monthly.

FIGURE 6 / **RAINWATER COLLECTOR**

© P. Demail

Rainwater is generally analysed to determine tritium activity. Such analyses are frequently carried out at the same time as determining gross alpha and total beta activity indexes (see footnote on p. 11), or even as gamma spectrometry, as part of monitoring policies at nuclear sites.

Monitoring the aquatic environment

Water and total suspended solids

As the receiving environment for liquid discharges from nuclear facilities and any potential input from runoff, water acts as a direct vector of contamination for the aquatic environment. Water (fresh water, seawater) is monitored using various sampling and analysis systems. The extent of the monitoring required will vary depending on the conditions at each site, particularly hydrogeological characteristics, background radiation and the potential presence of radionuclides emitted in the past. IRSN's Hydrotéléray network (see figure 7) is set up on the 7 main rivers downstream from all unclear facilities, and is designed to trigger an alarm if the level of activity measured in the environment is likely to be the outcome of a large-scale accidental discharge. Gamma spectrometry measurements are taken at each station, and integrated over two hours, giving an approximate water flowrate of 5 m^3/h. The measurements taken give decision thresholds of approx. 0.5 to 1 Bq/L for ^{137}Cs, ^{60}Co and ^{131}I. Data are automatically analysed, stored and retransmitted to the IRSN site control centre in Vésinet.

FIGURE 7 / **HYDROTÉLÉRAY STATION**

© DR

Water is also monitored using water sampling systems, which take semi-automatic water samples (see figure 8). These systems can take continuous or sequential samples. Sampling and analysis frequencies vary depending on the sites (daily to monthly). A settling tray is sometimes added to this system to collect the suspended solids in the water.

FIGURE 8 / **WATER SAMPLING SYSTEM**

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Finally, many ad hoc (instantaneous) surface water samples are taken throughout France by all contributors, mainly using manual equipment (see figure 9). These ad hoc samples complement the semi-automatic samples. To give one example, EDF must systematically take a river water sample during each discharge of liquid effluents ("mid-discharge" sample), particularly to analyse tritium.

According to regulations, ground water must also be monitored by operators in the form of ad hoc samples. The main aim is to check that no effluents are directly discharged into the ground water and to track any variation in former radiological contamination, for example. Ground water is pumped out using specially designed structures: piezometers. Samples may be taken on a monthly to annual basis.

FIGURE 9 / **AD HOC WATER SAMPLING USING A HORIZONTAL KEMMERER SAMPLER**

© DR

The water samples taken are generally analysed to determine tritium, gross alpha and gross beta activity. These measurements are complemented by determining uranium isotope levels or quantifying content for specific radionuclides (gamma spectrometry, alpha spectrometry, etc.) at some nuclear sites. Analytical procedures can also be extremely extensive for water measurements. To give just one example, decision thresholds for tritium vary between 2.5 and 10 Bq/L for most operators (background tritium in fresh water with no discharges varies from less than 1 to 3 Bq/L). Thresholds of less than 1 Bq/L can be reached as part as some appraisal programmes using other sampling and analysis techniques. By conducting tritium analyses on river water samples taken downstream of nuclear facilities, the potential exposure of local residents to doses by ingestion can be quantified. Decision thresholds for water measurements obtained by gamma spectrometry vary between 0.0001 and 0.5 Bq/L in France according to the different laboratories and set targets.

Sediments

Radionuclides with low solubility and a long half-life can integrate sediments on a long-term basis. For this reason, ad hoc sediment samples are taken upstream and downstream of nuclear facilities (see figure 10). Most samples taken for monitoring programmes include surface sediments and are intended to quantify any radionuclides due to recent discharges.

These samples are taken at frequencies between monthly and five yearly. The sediment samples taken are generally subjected to gamma spectrometry and gross alpha and gross beta activity analyses. Complementary analyses (alpha spectrometry, tritium, ^{14}C, ^{90}Sr) are also carried out depending on the specific spectrum of the effluents discharged at each site. The analysis methods used must ensure that the analytical results achieved meet the set targets (regulatory monitoring, radio-ecological studies, etc.).

FIGURE 10 / **AD HOC SEDIMENT SAMPLING USING A BERTHOIS CONE**

© DR

Aquatic fauna and flora

Sampling runs are also completed alongside of the monitoring of the aquatic environment for products eaten by humans (fish, shellfish, molluscs) and bio-markers (aquatic plants) in order to assess the effects of these effluents from the facilities.

Radionuclides can accumulate in aquatic plants and reach high concentration factors. Such factors rapidly respond to variations in radionuclide activity in the water and are considered as "front line" markers. Fish samples are selected based on what they eat and mobility trends. Sedentary and grass-eating species are preferred when possible.

In general, the minimum requirements of regulations imply annual fish samples. However, some operators carry out radio-ecological studies in addition to meeting regulatory requirements in terms of monitoring. Ad hoc and recurrent (annual, ten-year) sampling for these studies mainly focus on key environmental matrices (algae, bryophytes and aquatic phanerogams, fish, molluscs).

IRSN and other contributors to monitoring (ACRO, etc.) also run monthly, quarterly, six-monthly and annual sampling campaigns for aquatic sediments, fauna and flora at a series of fresh water and seawater stations, specifically as part of their monitoring programmes for nuclear facilities and in France in general. The results of the periodic radio-ecological studies focusing on one or several regions (radiological observations) are combined with such regular monitoring.

Samples are generally taken upstream and downstream of nuclear facilities (see figure 11) in the continental aquatic environment. Samples are taken in the immediate vicinity and further away from facilities at sea. Sea stations are located in positions based on potential sources of discharges and likely dispersal routes at sea (currents, tides, etc.).

Gamma spectrometry is systematically carried out on these matrices to check for any radioactive products (^{58}Co, ^{60}Co, ^{54}Mn, ^{110m}Ag, etc.) and fission products (^{131}I, ^{129}I, ^{137}Cs, ^{106}Ru, etc.). The spectrum of the radionuclides analysed will depend on the liquid effluents discharged from the facility monitored and any other nearby facilities upstream or in the vicinity. Some monitoring contributors also focus their strategy on analysing radionuclides with a dominant effect on dosimetric impact (generally ^{14}C and ^{3}H).

Additional measurements (^{90}Sr, Pu, Am, U, ^{99}Tc) are sometimes taken near to specific sites affected by these radionuclides, either due to current liquid discharges, or due to former radiological levels. IRSN also monitors residual radioactivity from fallout from atmospheric testing.

FIGURE 11 / **SAMPLING AQUATIC PLANTS (creeping water primrose) IN THE VIENNE REGION DOWNSTREAM FROM THE CIVAUX NPP**

© DR

FIGURE 12 / **FOOD SAMPLING**

© DR

Monitoring the terrestrial environment

Terrestrial plants and soils

Mosses, lichens, tree leaves and grass are used as bio-markers, indicating the presence of radionuclides suspended in the air, due to their ability to capture aerosols and dust raised from the ground and suspended. These bio-markers provide information on short-term and long-term variation in radionuclide activity in the environment, which food analyses could not necessarily contribute.

Soils can integrate radionuclide deposits with a sufficiently long half-life (a few years), which will progressively migrate to deeper locations. It is frequently difficult to estimate the contribution of a facility to soil activity due to the presence of radionuclides from nuclear weapon atmospheric test fallout and the Chernobyl accident (particularly ^{137}Cs and ^{90}Sr).

Grass samples (on a monthly or quarterly basis), and topsoil samples (yearly sampling) are taken at most nuclear sites. The analyses performed on these samples will vary depending on the radionuclides in the effluents discharged from the facilities. Gamma spectrometry is practically systematic. Gamma spectrometry is then occasionally complemented by ^{3}H, ^{14}C, ^{90}Sr, plutonium, americium uranium analyses. Institutional monitoring (IRSN, DGCCRF) networks also contribute to regular monitoring programmes. Additional analyses on terrestrial vegetation (tree leaves, mosses) and soils are also carried out as part of specific, ad hoc or recurrent radio-ecological studies.

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Analysing water from Toulon bay

Food: dairy products, meat, fruit and vegetables

Radionuclides (aerosols or gases) can settle directly onto the leaves of terrestrial plants. Such radionuclides reach the highest activity levels recorded. Only part of the activity deposited onto the leaves is transferred from the leaves to the other parts of the plant (fruit, seeds, roots or tubers). The percentage transferred varies depending on the radionuclide.

Radionuclides mainly transfer to livestock when the animals ingest contaminated food. The degree of transfer to meat and dairy products (milk, eggs) will vary depending on the product and the radionuclide. However, the activity transferred will systematically be less than, frequently significantly less than, the activity in the plant.

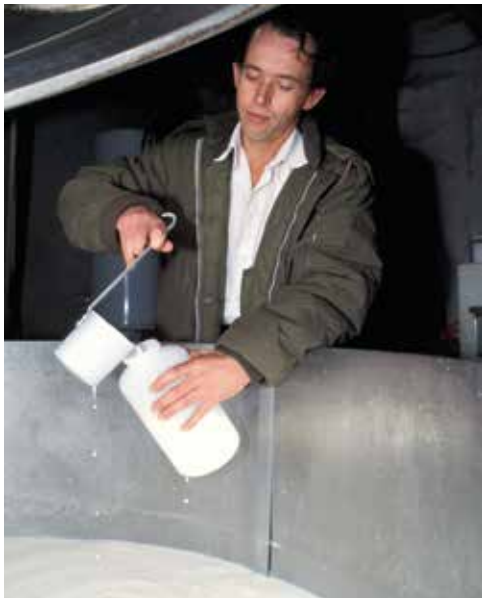
Food analyses are therefore carried out as part of most monitoring programmes (run by operators, institutions and associations), in order to confirm monitoring data for the effluents discharged and help to estimate the doses absorbed by the public.

The main food samples taken by nuclear operators include milk (see figure 13) and cereals. Food samples (cereals, mushrooms, fruit, vegetables, meat, honey, eggs, cider, wine, olive oil, etc.), sampling intervals and types of analysis all vary substantially depending on site locations and operators.

IRSN regularly monitors food radioactivity at departmental (French administrative départements) level. A network of plant crop (cereals, vegetables, fruit, mushrooms, etc.) and livestock (milk, meat, game, fish) samplers was deployed throughout France with contributions by the local services of DGAL, DGCCRF and France Agrimer. Finally, the radiological status of areas which are not affected by discharges from nuclear facilities is also determined using very low level measurements taken during specific studies or radiological observations.

The measurements taken can be compared with those taken for terrestrial plants (gamma spectrometry is performed on all samples, occasionally for operators and more systematically for institutions, for ^{3}H, ^{14}C, ^{90}Sr, plutonium, americium and uranium measurements). As is the case for all samples taken for the purposes of the radiological monitoring of the environment, the measuring performance levels adopted must be suitable for the set targets (regular facility monitoring, radio-ecological studies, etc.) and can lead to variation in decision thresholds by a factor of between 10 and 100 depending on the type of analysis used.

FIGURE 13 / **SAMPLING COW'S MILK**



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Summary of the strategic criteria applied and the sampling and measuring devices used to monitor the radiological properties of the different environmental components

The following tables summarise the various methods used to monitor the atmosphere and aquatic and terrestrial environments, as well as the strategic criteria applied to the samples taken and *in situ* analyses.

TABLE 1 / **THE ATMOSPHERE**

The atmosphere	Strategic criteria applied to measurements and sampling in this component	Measuring and/or sampling systems
Air	The receiving environment for atmospheric discharges. The radioactive gases and particles in the air are passed on to humans via external and internal (if inhaled) exposure.	Continuous measurement sensors (ambient gamma dose rate)
		Passive environmental dosimeters
Atmospheric aerosols		Continuous measuring and/or sampling systems for aerosols
		Continuous sampling systems for aerosols (with subsequent laboratory measurements)
Gas		Bubblers (^{3}H, ^{14}C), noble gas monitors (^{85}Kr), activated carbon cartridges (iodines)
Rainwater	Wet aerosol deposition (which potentially includes radioactivity) as the column of air passed through by the droplets of rainwater is leached.	Rainwater collectors

TABLE 2 / **TERRESTRIAL COMPONENT, INCLUDING FOOD**

Terrestrial component and food	Strategic criteria applied to measurements and sampling in this component	Measuring and/or sampling systems
Terrestrial plants (grass, leaves, mosses, etc.)	Mosses, lichens, tree leaves and grass are used as bio-markers for atmospheric contamination, due to their ability to capture aerosols and dust raised from the ground and suspended.	Ad hoc (manual) sampling
Soils	Soils can integrate radionuclide deposits with a sufficiently long half-life (a few years), which will progressively migrate to deeper locations. Soils can also contaminate vegetables, fruit and grasses via their roots.	• Ad hoc sampling (manual) • On-site gamma spectrometry
Plants (cereals, vegetables, fruit, wine, etc.)	Plants are contaminated when radionuclides settle on aboveground parts or are absorbed by their roots. Fauna eating contaminated plants can also be contaminated.	Ad hoc (manual sampling or collection by growers) sampling
Livestock (milk, meat, eggs, etc.)	Radioactive feed will lead to the transfer of radionuclides to products of animal origin, including milk, a significant vector for radionuclides (caesium, strontium, iodine, etc.).	Ad hoc (manual sampling or direct collection by growers or slaughterhouses) sampling

TABLE 3 / **AQUATIC COMPONENT**

Aquatic component	Strategic criteria applied to measurements and sampling in this component	Measuring and/or sampling systems
Water	As the receiving environment for liquid discharges from nuclear facilities and any potential input from runoff, water acts as a direct vector of contamination for the aquatic environment.	• Continuous measuring and sampling systems (IRSN Hydrotéléray network) • Water sampling systems • Ad hoc sampling
Total Suspended Solids (TSS)	TSS are the main support base for radionuclides. TSS are mobile and help to ensure the presence of radionuclides on river banks, beaches and land after flooding.	• Settling trays combined with water sampling systems • Water samples are filtered in a laboratory
Sediments	Sediments can effectively integrate radionuclides and desorb radionuclides from the aquatic environment.	Ad hoc (manual or mechanical) sampling
Aquatic plants (algae, mosses, phanerogams)	Aquatic plants can very effectively and rapidly fix some radionuclides. Radionuclide activity by mass can be compared at different locations thanks to the wide geographic distribution of aquatic plants. Some plants, such as marine algae, react rapidly to variations in the radionuclide composition of water.	Ad hoc (manual) sampling
Molluscs	Both filter-feeding and grazing marine molluscs are effective long-term bio-markers thanks to their nutritional habits.	Ad hoc (manual sampling or direct collection by growers) sampling
Shellfish **Fish**	Fish effectively integrate radionuclides thanks to their position at the end of the food chain. Fish are also extremely popular with humans. Thanks to the geographic distribution of the species sampled, the activities by mass measured at different sampling locations in France can be compared.	Ad hoc (fishing or direct collection by professionals) sampling

© DR

IRSN's gamma spectrometry room at Orsay can be used to measure very low activity levels

1.3. FROM SAMPLING PLANS TO MEASURING RESULTS

All of the analysis and sampling techniques described below are used by RNM contributors as per the relevant provisions of NF or ISO standards, particularly NF EN ISO/IEC 17025.

Analysis and sampling plans

Regulatory monitoring of the environment of basic nuclear facilities is adapted to each type of facility (nuclear powerplant, plant, laboratory). Predefined plans dictate the analyses carried out on each sample based on the effluent discharged (type of effluent, radionuclides and level of activity discharged) and past events (previous incidents and discharges). Analysis and sampling plans are included in chapter 3, for each site, after a description of the effluents discharged.

Preparing samples

Upon receipt at the laboratory, the samples are processed and packaged as necessary for the planned radiological analyses. The initial phase of radioactivity analysis on a sample taken from the environment involves preparing the sample. This phase ranges from simply placing the sample in a standardised container to more sophisticated processes such as drying, calcination or freeze drying to concentrate the sample (see figure 14). In general, the different techniques used to treat the samples aim to concentrate as much radioactivity as possible in the smallest possible volume in order to detect radionuclides at low, or very low, levels. In some cases, the sample starts the concentration process from sampling thanks to the specific systems used (e.g. aerosol samples, TSS samples, etc.).

In most cases, only part of the sample is used for analysis. The sample is homogenised prior to testing to ensure that the partial sample does not lead to biased or non-representative measurements. Most parties involved in monitoring also archive some of the samples analysed (filters, soils and dried sediments, samples of dried or calcinated fauna and flora), in view of potential analyses in the future using complementary or more advanced equipment.

Laboratory facilities are required in order to concentrate the sample or extract the radionuclides to be measured, to ensure the highest possible quality levels for all or part of the phases involved in characterising the radionuclides in a sample.

Radiological analyses

Determining the activity of a radionuclide (see chapter 4) in a sample involves estimating the amount of radiation emitted by measuring the radiation absorbed by a detector. The main detection methods used are based on the fact that radiation will excite (transmit energy to atoms) and ionise (separate electrons from atoms) the materials which absorb it. These temporary effects of radiation are recorded by the detector and amplified to allow for measurement. The number of pulses per second absorbed by the detector can then be compared with the radiation emitted by the sample, and therefore its activity, by considering the performance of the measuring device. Several measuring techniques and devices can be used, mainly depending on the large differences in the distances potentially travelled by the different types of radiation (see chapter 4):

- gamma spectrometry can be used to identify the radionuclides and measure activity for most gamma emitting radionuclides, in fresh, dried, or incinerated samples (^{137}Cs, ^{134}Cs, ^{60}Co, ^{125}Sb, ^{110m}Ag, ^{131}I, ^{129}I, ^{40}K, ^{210}Pb, etc.);
- due to the very short distance travelled by the alpha radiation and the fact that the radiation is absorbed by the sample itself (reducing the amount of radiation leaving the sample, which can then be measured), radiochemical treatment is required before the alpha emitting radionuclides (plutonium, uranium, polonium, etc.) can be measured and counted, mainly by alpha spectrometry. The aim is to remove the radioactive atoms in question from the sample by eliminating all or part of the surrounding sample;

- radiochemistry is also required prior to measuring some beta emitters such as strontium-90;
- finally, for radionuclides emitting beta particles with very low energy levels, such as tritium or carbon-14, the sample is placed in a solution and mixed directly with the liquid scintillator used to detect them.

Tracers are used, or control sources with specific references in terms of activity, density and type, to ensure the quality of the measurements taken.

FIGURE 14 / **THE MAIN PHASES OF A RADIOACTIVITY ANALYSIS ON ENVIRONMENTAL SAMPLES (from sampling to archiving)**

1. Take a grass sample

2. Oven dry

3. Freeze dry

4. Crush and homogenise

5. Calcinate

© IRSN

6. Radiochemistry

7.1. Detect alpha radiation

7.2. Detect beta radiation

7.3. Detect gamma radiation

8. Archive

© IRSN

After samples have been taken in the field **(1)**, they must be rapidly packaged to avoid any modification to their properties and then transported to the laboratory for various types of treatments. The characteristics of the sample are recorded upon arrival at the laboratory to ensure traceability throughout processing.

The initial phase of radioactivity measurements for a sample involves physically preparing the sample. This phase ranges from simply placing the sample in a standardised container to more sophisticated processes such as oven drying **(2)**, freeze drying **(3)**, crushing **(4)** and calcination **(5)** to concentrate the radioactivity of the sample.

More intensive processes **(6)** are sometimes required in order to concentrate the sample or extract the radionuclides to be measured. These processes generally concentrate or separate the selected radionuclides.

After this phase, the samples are measured using various types of counters depending on the selected radionuclides **(7)** (proportional alpha-beta counters, alpha counters with photomultipliers, liquid scintillation counters, gamma detectors, etc.). Samples are then archived **(8)**.

1.4. DETAILS OF THE PRESENTATION AND USE OF MEASURING RESULTS FOR THE 2015-2017 RADIOLOGICAL REPORT

Data sources and units

All of the data shown in this report in graphic or table format were taken from monitoring results in the RNM database on 31 December 2017 and cover the period running from January 2015 to December 2017. However, earlier data can be used to improve our understanding of variation over time based on recurrent input. The data used are also obtained from IRSN results for specific studies, such as radiological observations or radio-ecological monitoring on behalf of nuclear operators (EDF or Orano). Finally, the chapter on former mining sites describes and comments on the Potential Alpha Energy (PAE) measurement results acquired by Orano at and near to these sites. These data were considered to be sufficiently pertinent and reliable to be included in this report, with the agreement of ASN and MSNR, despite the lack of current approval.

Table 4 shows the different types of measuring results shown and used in this report, with units.

With carbon-14, if the activity added around a facility, at local level, is too low to be differentiated from background radiation using activity measurements by mass in Bq/kg fresh, specific activity measurements in Bq/kg of carbon can be used to quantify the extra activity representing a few percent of the background radiation (see chapter 2). The activity by mass corresponding to the mean carbon content of the food tested can be calculated using these specific added activities. The conversion method used is described in chapter 8 of the appendices.

Three types of tritium analysis results for biological matrices (food or biological indicators) are used in this radiological report: total tritium measurements as Bq/kg fresh, Organically-Bound Tritium (OBT) measurements as Bq/kg fresh of OBT or Bq/L of combustion water, and free tritium activity (HTO) as Bq/kg fresh of free tritium or Bq/L of drying water (see focus article in this chapter pp. 29-31). The conversion ratios between the different values and units are provided in chapter 8 of the appendices.

TABLE 4 / **THE DIFFERENT TYPES OF MEASURING RESULTS SHOWN AND USED, WITH UNITS**

Dose rates	Sv/h (sub-multiples: µSv/h and nSv/h)
Air activity	Bq/m^3 (sub-multiples: mBq/m^3 and µBq/m^3)
Potential Alpha Energy	J/m^3 (sub-multiple: nJ/m^3)
Water (rain, rivers, seawater, etc.) activity	Bq/L (sub-multiple: mBq/L)
Soil activity	Bq/kg (sub-multiple: mBq/kg)
Activity levels for biological markers	Bq/kg (sub-multiple: mBq/kg)
Food activity	Bq/kg fresh (sub-multiple: mBq/kg fresh) Bq/kg of carbon for carbon-14 Bq/L of combustion water for organically-bound tritium (OBT) Bq/L of drying water for free tritium (HTO)

Decision thresholds, insignificant results, metrological uncertainties and rounding

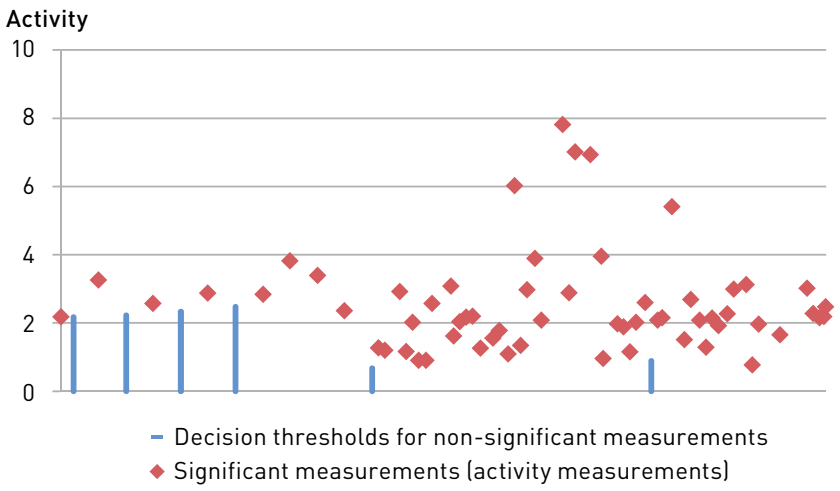
Even if the sample to be measured is not radioactive, radiological measuring devices can provide measuring results for external radiation, particularly the natural radiation (see chapter 2) to which the detector is exposed, and background noise from the device itself. This metrological background radiation fluctuates. If the activity of the sample is very low, it is also difficult to differentiate between the radiation added by the sample and fluctuations in metrological background radiation. In some cases, the metrologist will decide that the measuring result for the activity of the sample is insignificant (the activity measured cannot be definitively attributed to the sample). In this case, the metrologist will declare that the activity of the sample is "below the decision threshold": ≤ DT. On this basis, the decision threshold is the lowest value of a sample measurement when the metrologist can decide whether or not activity exists. Note: the value of this decision threshold only depends on the measuring device (or metrological background radiation), rather than the activity of the sample.

The activities of some radionuclides in the environment are very low, therefore the series of measurement results frequently includes results which are below the decision threshold. These results are also qualified as "insignificant" results. In this case, a "significant" result or "significant measurement" refers to activity above the decision threshold.

Insignificant results are shown on the charts as vertical bars running from the x-axis to the DT. "< DT" appears in the legend. Significant results are shown as colour symbols as per the legend provided (figure 15).

"Nm" in the table refers to a "not measured" parameter or radionuclide.

FIGURE 15 / **EXAMPLE DIAGRAM USED TO DIFFERENTIATE BETWEEN LOWER AND UPPER MEASUREMENTS AT DECISION THRESHOLDS**



Activity cannot be precisely measured, mainly due to fluctuating metrological background radiation. A metrologist will systematically indicate the metrological uncertainty for analysis results. The metrological uncertainty is, however, very low compared with the uncertain representativeness of the sample with respect to the environmental component sampled, which is additionally much more complex to determine. Just how representative is a litre of water sampled at a precise location of a river, or more precisely, of the river water over a day or a week? How representative is the activity of a lettuce sampled at a given location of average activity for lettuces in the entire field? For this reason, and to avoid giving the misleading impression that results are precise, the uncertainties indicated by the metrologist are not shown on the charts and tables published in this report.

Results expressed as mean values are rounded to two significant figures to reflect the uncertainty for the data. If the third significant figure is between 0 and 5, the second figure is rounded down. If the third significant figure is between 5 and 9, the second figure is rounded up. For example, if the result is equal to 23.12548 Bq/L, a value of 23.1 Bq/L will be indicated.

Mean values and other statistical indicators

A mean value is used as the statistical indicator for this report, calculated using significant analysis results (> DT) and insignificant analysis results (< DT) subject to the DT if specific conditions are met. The reasons for selecting this indicator, the method used and the different potential scenarios are described in chapter 8 of the appendices.

Box plots are used in chapter 2 to show the range of activity levels recorded in the environment for the different background radiation radionuclides. The information shown in these box plots and its specific meaning are described in chapter 8 of the appendices.

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Crushing and adjustment of the geometry of a dried grass sample

FOCUS ARTICLE
ANALYSING ORGANICALLY-BOUND TRITIUM (OBT) IN SOLID AND LIQUID ENVIRONMENTAL MATRICES (EXCLUDING WATER)

The following radionuclides co-exist in the organic matter in environmental matrices:

- free water tritium in the sample (dewatering tritium, DT), in the form of HTO molecules;
- Organically-Bound Tritium (OBT), replacing hydrogen atoms bound to atoms of organic matter.

The 1st stage of analysing OBT is to separate the tritium from the free water of the OBT in the matrix in question. Freeze drying is generally used for this purpose.

The OBT fraction can be separated into two parts: (i) exchangeable organically-bound tritium (E-OBT), where the tritium atoms are bound to nitrogen, oxygen or sulphur atoms with labile bonds and (ii) the non-exchangeable organically-bound tritium (NE-OBT) where the tritium atoms are bound to carbon atoms with covalent bonds. Only the OBT analysis is confirmed for analytical purposes based on current knowledge.

OBT activity can be measured by:

1. tritium measurement in water obtained by liquid scintillation analysis;

2. calculation after measuring helium 3 (the daughter of tritium) using mass spectrometry

1. Tritium measurement in water obtained by liquid scintillation analysis

Dehydrated samples are subjected to combustion to remove the hydrogen from the organic matter as H_2O.

Various combustion systems exist:

- automated combustion with a flow of oxygen (Oxidiser type combustion);
- combustion in a contained system with pressurised oxygen (Parr pump type combustion);
- combustion with a flow of oxygen in a tube furnace (Pyroxidiser type combustion)

The tritiated water vapour obtained from the combustion gases is collected after the combustion phase, in the form of water, using a cold trap. This water is then analysed by liquid scintillation (LS).

Oxidisers and tube furnaces are the most frequently used systems in French laboratories.

2. Calculation after measuring helium 3 (the daughter of tritium) using mass spectrometry

The dehydrated samples are placed in isolation containers (glass tanks, metal pots) with the lowest possible helium leakage rate once closed.

The containers are then placed on a vacuum degassing line ($P < 10^{-5}$ Torr).
This degassing process must eliminate all dissolved gases in the sample, particularly helium. It effectively "resets" the helium before closing the container.

After degassing, the containers are closed, sealed and stored prior to measuring.

Isolating the samples allows the tritium to decay to helium-3. The isolation period (t) is determined based on the mass of the sample, the expected tritium activity and target uncertainty and generally lasts for a few weeks to a few months.

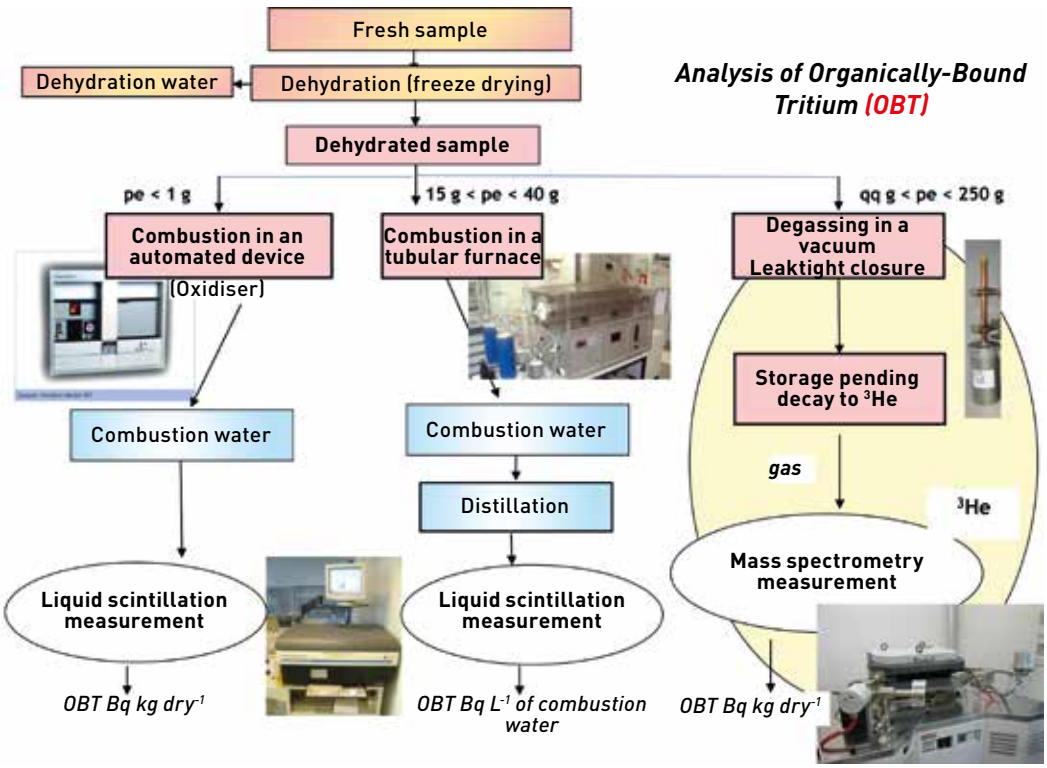
After the storage period, the containers are placed on a feeder line for a mass spectrometer specifically designed to measure noble gases (static operation).

As the number of helium-3 atoms produced in the sample during the isolation period can be determined by mass spectrometry, the number of tritium atoms initially present and therefore the tritium activity of the sample at the start of storage can be calculated.

Figure A shows the different OBT analysis techniques.

FIGURE A / **THE DIFFERENT OBT ANALYSIS TECHNIQUES**

(pe = mass of the dehydrated sample)



The selected analysis technique will depend on many factors, such as the type of matrix, the mass of the available dehydrated sample, the purpose of the measurement in terms of response time and analytical performances (decision threshold, uncertainty).

For example, for a matrix containing 80% water and 6.2% hydrogen (plant matrix), table A lists the results generally achieved by laboratories for the different techniques.

TABLE A / **LIMITATIONS AND RESULTS FOR THE DIFFERENT PREPARATION METHODS**

	Automatic combustion system (oxidiser)	Tube furnace	^{3}He mass spectrometry
Mass of a fresh sample	2.5 g	100 g	500 g
Mass of a dehydrated sample	0.5 g	20 g	100 g
Mass of the combustion water counted	0.25 g*	10 g	-
Detection performance	30 - 40% tritium window 1-2 mL water/ 10 mL scintillator	20 - 25 % tritium window 10 mL water/ 10 mL scintillator	-
Duration of counting	120 min	120 min	-
Isolation period (decay to ^{3}He)	-	-	5 months
Decision threshold	50 Bq/kg of dry matter	5 Bq/L of combustion water 2.5 Bq/kg of dry matter	0.025 Bq/kg of dry matter 0.05 Bq/L of combustion water

* This mass is not measured experimentally in automatic mode.

Results will be obtained (see figure A) either in Bq/kg dry, or Bq/L of combustion water depending on the selected operating procedure. The percentage by mass of hydrogen measured in the dehydrated sample can be used to convert the result into the other unit.

Recommendations

Isotopic exchanges with water vapour in ambient air should be limited during the different phases of OBT analysis (preparation, storage, aliquoting, conservation, handling, treatments) due to the physical and chemical properties of hydrogen isotopes. In particular, all sample handling phases must be carried out in a suitable location and as rapidly as possible.

FOCUS ARTICLE

ANALYSING CARBON-14 IN ENVIRONMENTAL MATRICES CONTAINING CARBON

Carbon-14 can be found in the air, mainly as carbon dioxide (CO_2).
The properties and transfer of carbon-14 are an indissociable part of the carbon cycle. Carbon-14 is incorporated into organic matter in plants during photosynthesis, and subsequently into the fauna eating the plants. Just like stable carbon, carbon-14 is a component of organic matter.

Carbon-14 activity in environmental matrices can be determined using:
1. Liquid Scintillation (LS);
2. Accelerator Mass Spectrometry (AMS).

The sample must be dehydrated prior to analysis for all measuring techniques. Freeze drying is generally used for this purpose. The carbon (including carbon-14) contained in the carbon dioxide sample must then be converted by combustion or oxidation.

Various combustion systems exist, e.g.
- combustion in a contained system with pressurised oxygen (Parr pump type combustion);
- automated combustion with a flow of oxygen (Oxidiser type combustion);
- combustion with a flow of oxygen in a tube furnace (Pyroxidiser type combustion)

With liquid scintillation analysis, the carbon dioxide obtained is:
- either trapped in a specific CO_2 absorber, such as Carbosorb®E, before liquid scintillator is added;
- or chemically converted into an organic form which can be mixed with the liquid scintillator (benzene synthesis method).

After the CO_2 has been routed to and trapped in cold traps, benzene is synthesised in the following phases:

1. carbide production (750 °C): $2\ CO_2 + 10\ Li \rightarrow Li_2C_2 + 4\ Li_2O$;
2. hydrolysis of lithium carbide: $Li_2C_2 + H_2O \rightarrow C_2H_2 + Li_2O$;
3. trimerisation of acetylene into benzene (Cr catalyst): $3\ C_2H_2 \rightarrow C_6H_6$.

Butyl PBD (2-(4'-t-butylphenyl)-5-(4-biphenylyl)-1,3,4-oxadiazole) and bis-MSB (1.4-bis-(2-methylstyryl)-benzene) scintillators are added to the synthetic benzene for measurement purposes.

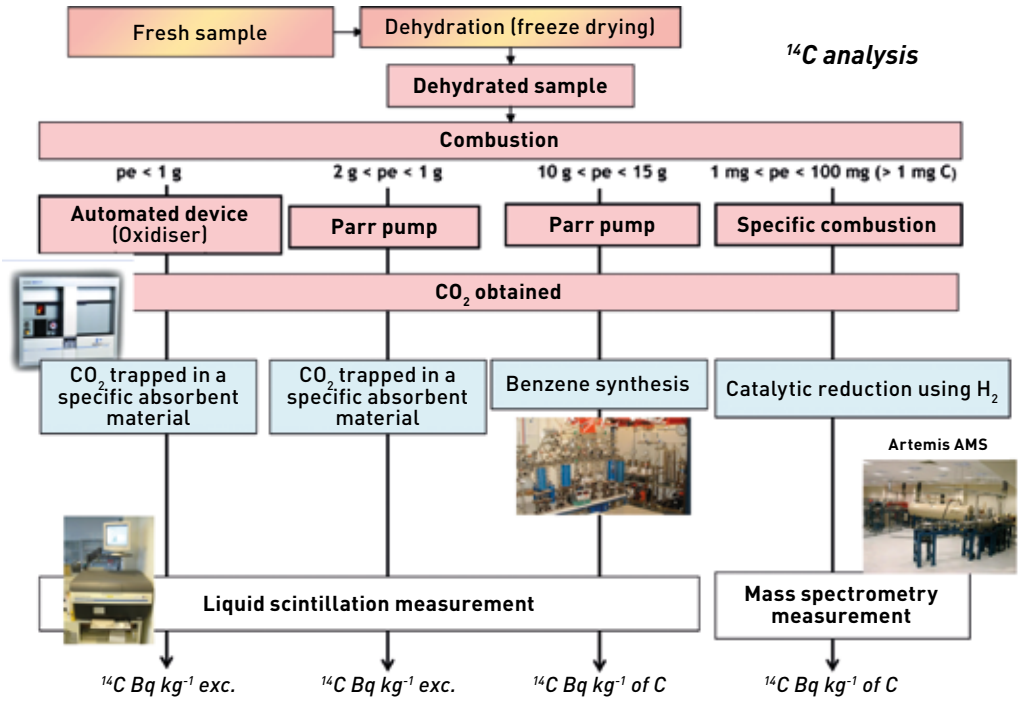
If AMS is used, after the carbon dioxide is combusted and collected, a graphite source is obtained by catalytically reducing CO_2 using H_2, with iron powder as a catalyst. This reaction occurs at 600°C with excess H_2 ($H_2/CO_2 = 2.5$). The resulting carbon-iron powder is compressed into a pellet for measurement purposes.

The selected analysis technique will depend on many factors, such as the type of matrix, the mass of the available dehydrated sample or the purpose of the measurement in terms of analytical performances, and response times (see table A on the next page). Parr pump analysis techniques are suitable for matrices containing at least 10% carbon, which is enough to trap a sufficient amount of CO_2 for the rest of the analysis. On this basis, only AMS is feasible for sediments (due to the very low percentage by mass of carbon).

Figure A shows the different carbon-14 analysis techniques.

FIGURE A / **THE DIFFERENT ^{14}C ANALYSIS TECHNIQUES**

(pe = mass of the dehydrated sample)



Results will be obtained (see figure A) either in Bq/kg of dry sample, or Bq/kg of carbon (see chapter 2) depending on the selected operating procedure. The percentage by mass of carbon measured in the dehydrated sample can be used to convert the result into the other unit.

The performance of the different available tools for ^{14}C analysis, in terms of detection limits, is not critical as the activity levels measured are systematically significant. In fact, background radiation (excluding the direct impact of effluents discharged) is currently approximately 227 Bq/kg C. Results will mainly be compared based on the associated uncertainty (table A).

TABLE A / **ANALYTICAL PERFORMANCE LEVELS FOR THE DIFFERENT PREPARATION METHODS**

	Automatic combustion system (oxidiser)	Benzene synthesis	AMS
Associated uncertainty as a % (with a coverage factor k = 2) for activity of 227 Bq/kg C	20	6	2.5
Duration of the analysis (days)	1	5	4

1.5. THE RNM (RÉSEAU NATIONAL DE MESURES / *FRENCH METROLOGICAL NETWORK*) FOR ENVIRONMENTAL RADIOACTIVITY

The reference site for environmental radioactivity measurements in France

The French metrological network for environmental radioactivity centralises all approved monitoring data for environmental radioactivity in France. An approval procedure is applied to ensure data quality and harmonisation.

One of the strengths of this approach is the many sources of available information: measurements are provided by Government services and public sites, nuclear operators and other public & private organisations or associations.

Since 2010, www.mesure-radioactivite.fr has published the 300,000 measurements taken in France each year (representing a total of slightly over 2 million data items in 2017) for the different environmental components (air, water, soil, fauna and flora) and food products to ensure 100% transparent access for all.

The www.mesure-radioactivite.fr initiative is unique in Europe and allows just anybody to understand how the radioactivity in their area is monitored.

Centralisation

The environment is currently extensively monitored by a large number of contributors, focusing on various aspects, as part of the French nuclear segment. The environmental radioactivity data forwarded to the RNM include the results of the analyses conducted:

- by nuclear operators monitoring the radiological composition of the immediate environment of their facility as per regulatory requirements;
- by public authorities, Government services and public sites in charge of health safety checks for food and water;
- by any public or private organisation, or any association contributing to radiological monitoring in France.

The French metrological network collects and centralises these data from various sources *via* a unique database.

Harmonisation

www.mesure-radioactivite.fr can be used to track variation in the radiological composition of a specific environmental component over time and to compare the measurements provided by different contributors. Measurements can be compared thanks to the use of strict and homogeneous measuring methods and data harmonisation criteria such as measurement units.

All measurements to be added to the RNM database must be carried out by laboratories approved by the ASN (Autorité de sûreté nucléaire - French Nuclear Safety Authority). This approval is issued based on the opinion of a multi-party approval committee.

Reliability

Laboratories must meet two combined conditions to guarantee the reliability of measurements:

- comply with International standard ISO/IEC 17025, establishing the general requirements in terms of the skills needed for testing and/or calibration, including sampling;
- obtain results able to satisfy the comparative inter-laboratory tests organised by IRSN. With these expertise tests, the results obtained by the laboratories based on identical samples are compared with a control value.

Presentation

The www.mesure-radioactivite.fr site allows just anybody to understand how the radioactivity in their area is monitored.

The site was fully revamped in 2016 in order to better meet the expectations of the general public by providing a "guided" user mode, as well as the "advanced" user mode intended for well-informed users.

The site has also been available in English since early 2018 to allow non-French-speaking users to access content.

RNM operations

The French network was set up under the aegis of ASN (French nuclear safety authority). IRSN (French national institute of radiation protection and nuclear safety) manages the network.

Other system contributors include representatives of the main Ministries involved, health agencies, public institutes, the nuclear industry, qualified individuals and consumer and environmental protection associations.

RNM committees

The French network is led by a management committee, which is chaired by ASN, and entrusted with defining strategic guidelines for the network. An approval committee also issues an opinion on applications submitted by laboratories for ASN approval. The different RNM contributors are represented within these two bodies.

The Management committee meets twice annually. Management committee meeting reports can be accessed under the "Publications" section. The Management committee will issue its opinions on strategic guidelines for the RNM. The committee is supported by working group input when necessary. The working groups are set up as required to study RNM upgrades.

The approval committee is responsible for ensuring that the measuring laboratories hold the necessary organisational and technical expertise to provide quality measurements to the network. The committee can suggest that ASN propose or refuse, withdraw or suspend approval. ASN will then decide whether or not to issue or refuse approval. This decision will be published in ASN's *Official* bulletin.

IRSN (French national institute of radiation protection and nuclear safety) manages the national metrological network (RNM), as well as overseeing its development, technical operations and general organisation.

Transmitting measuring results to the RNM

Most French contributors to the radiological monitoring of the environment upload their measurements to the RNM.

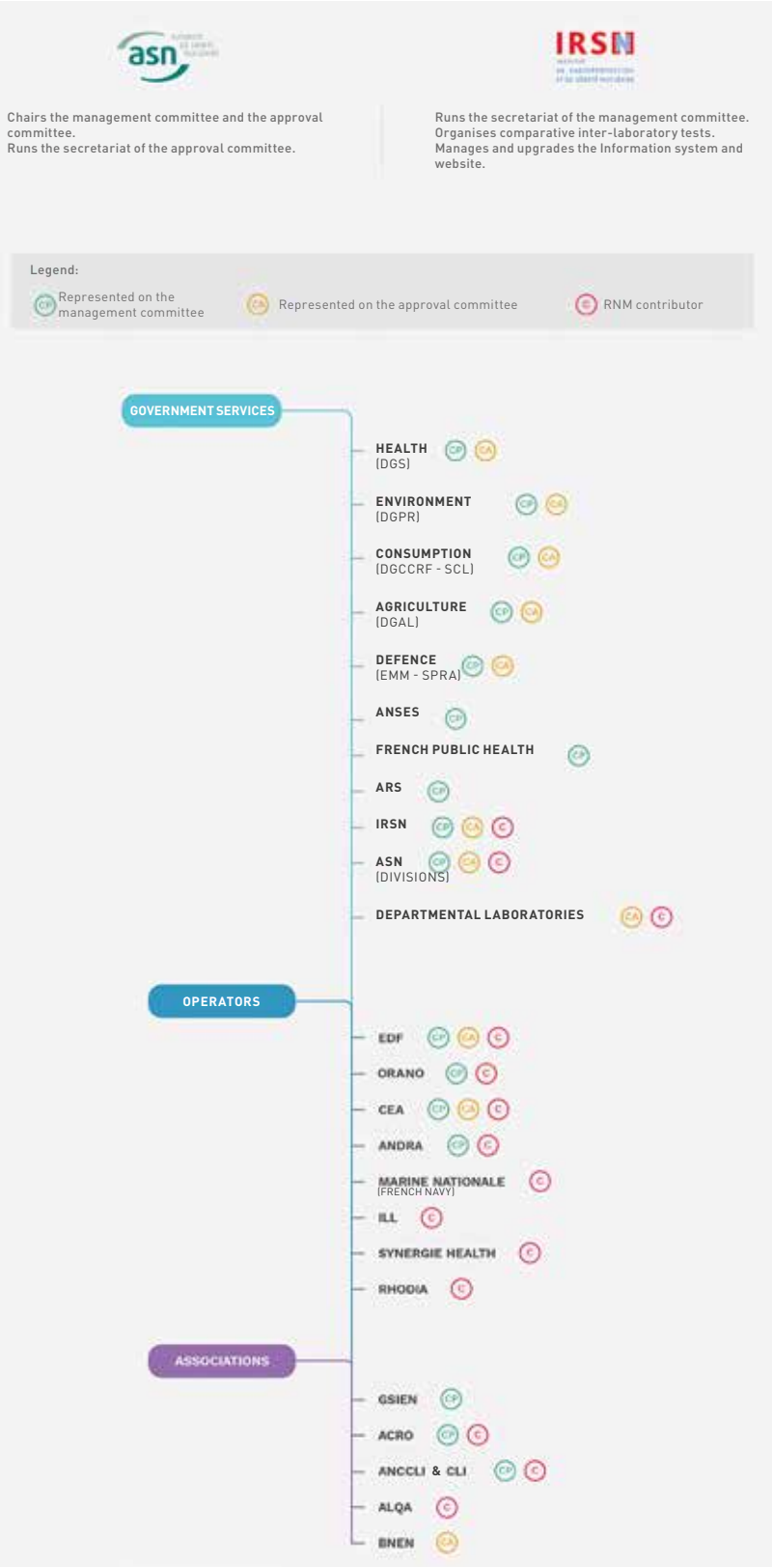
All contributors send their data formatted according to a jointly-defined information exchange protocol *via* the internet using a secure transfer system. To date, 66 contributors upload environmental radioactivity measurements to the French network.

These measurements have been entered into the central database of the RNM since its launch in January 2009. 25,000 measurements are uploaded each month on average.

Using and presenting RNM data

The data centralised in the RNM information system are presented to the public and experts in the form of a map-based web portal (www.mesure-radioactivite.fr). A radiological report on the status of the environment is released every 3 years using this data and input analysis. This report is the second radiological report to be released. The first report was published in 2015 and covered the June 2011-December 2014 period.

FIGURE 16/ **RNM ORGANISATION**



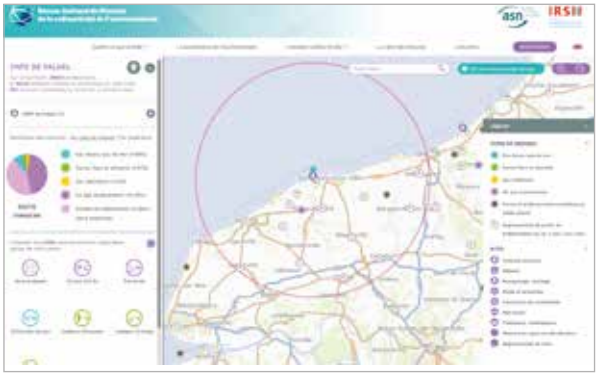
RNM FOCUS ARTICLE
AN ALL-NEW WEBSITE, NOW TRANSLATED INTO ENGLISH

The RNM is continuing to open its activities up to a wider public: after modernising the website in 2016 to ensure easier access for the "general public", non-French-speaking experts should appreciate the English translation.

The RNM website was totally revamped towards the end of 2016. The main aim was to make it more approachable for the general public. The "guided user mode" version provides basic information on the number and type of measurements: e.g. the measurements taken near to the location of the RNM user (geolocation function).

A second level is available for non-specialist users, simply providing access to around a dozen or so of the hundreds of available types of measuring results. These results are preselected to provide both a representative overview and in-depth analysis, hence the term "Landmark".

FIGURE A / **THE GUIDED USER MODE FOR THE NEW VERSION OF THE WEBSITE**

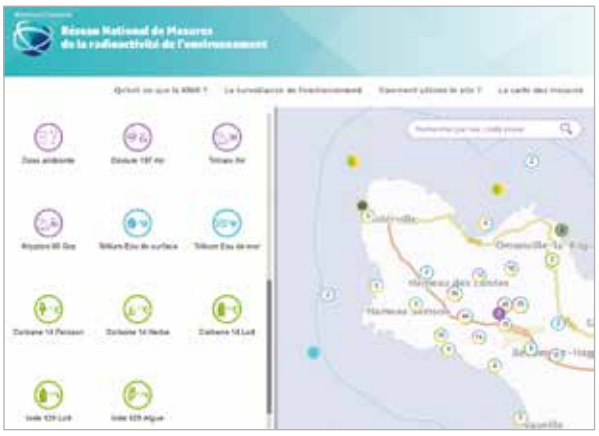


RNM "Landmark" results

Maximum values and the extent of background radiation (values measured in the surrounding environment) are indicated for these "Landmarks" as well as specific items of information (*via* a "did you know?" section).

The selected Landmarks are considered to be representative of radioactivity measurements throughout France (e.g. the ambient gamma dose rate or caesium 137 measurement in aerosols) or of one or several specific nuclear facilities (e.g. iodine-129 measurements in milk, which mainly affects the La Hague facility, or tritium measurements in dairy products reflecting tritium discharged from the Marcoule and Valduc facilties).
A "thermometer" is displayed for each selected Landmark measurement and reflects background radiation in France

FIGURE B / **"LANDMARKS" FOR THE NORTH COTENTIN SITES**



(radioactivity excluding the impact of nuclear facilities) and the maximum value measured in France with an explanation describing the context and providing users with the details they need to understand why this value was measured.

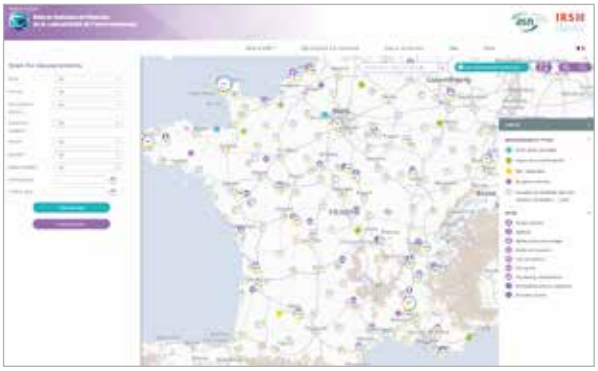
The "expert" version shows all measurements published on the site in the form of time-series for recurrent data.

FIGURE C / **CONTEXT-BASED EXPLANATIONS FOR THE CESIUM-137 CONTROL DATA**

An English site to allow non-French-speaking users to access information in the RNM database.

The website was also modernised in order to expand its potential audience to non-French-speaking users: translating the site into English appeared the natural solution, opening up the 2.2 million data items currently available *via* the site to the English-speaking scientific community. An increase in users in foreign countries was detected *via* an in-depth analysis of the locations of users logging in during "radiological events" (such as when ^{106}Ru was detected from the south Urals in the autumn of 2017). Launching an English version of the website will cover this underlying requirement for information in foreign countries.

FIGURE D / **ENGLISH VERSION OF THE WEBSITE**



Laboratory approval processes

Laboratory approvals for environmental radioactivity measurements as per article R. 1333-26 of the French public health code are issued in the form of an ASN decision.

Laboratories must meet the following requirements prior to approval:

- submit an approval application to ASN listing the requested types of approval and proving that their measuring and sampling techniques satisfy the requirements of standard NF EN ISO/IEC 17025 as applicable to test laboratories;
- satisfy the comparative inter-laboratory tests organised by IRSN on a regular basis.

Approvals are issued based on an ASN decision, with reference to the opinion of the laboratory approval committee, released after considering the approval applications and the results obtained by the laboratories in the comparative inter-laboratory tests organised by IRSN. Approvals are granted with a maximum validity period of five years.

Over sixty laboratories, including one foreign laboratory, have applied for approval for environmental radioactivity measurements since 2003.

The following types of laboratories are approved as part of the RNM:

- laboratories run by nuclear operators, which monitor the environment of the nuclear facilities in application of the regulations in force;
- laboratories run by government institutes or agencies, which measure radioactivity for health safety purposes;
- university laboratories, which can measure radioactivity on behalf of nuclear operators or public authorities (health safety testing for drinking water);
- private laboratories, which mainly invest in radiological testing for drinking water;
- laboratories run by environmental protection associations, which take their own independent measurements and provide a second opinion for their own benefit or that of public authorities;
- foreign laboratories, generally government laboratories working in sectors aiming to protect public health.

Just what are comparative inter-laboratory tests?

The comparative inter-laboratory tests organised by IRSN are intended to prove the technical expertise of the laboratories. With these expertise tests, the results obtained by the laboratories based on identical samples are compared with a control value.

These tests involving measuring artificial alpha-, beta- and gamma-emitting radionuclides, or radionuclides from natural uranium and thorium chains. IRSN is responsible for preparing the samples, delivering them to the laboratories registered for testing, determining the control values and processing the results obtained by the laboratories for statistical purposes.

The samples prepared by IRSN are distributed to the laboratories involved simultaneously in view of parallel measurements. The batch of samples provided by IRSN must be sufficiently homogeneous in terms of radioactive content to ensure that results will not differ due to a heterogeneous sample.

Up to 70 laboratories can participate in each test, including a few foreign laboratories.

IRSN has organised this type of testing for the last 40 years and currently sets up 4 to 5 test runs each year as part of the RNM. The IRSN laboratory organising these tests has held COFRAC (French accreditation body) accreditation since 2006.

The different types of tests proposed as part of the RNM are scheduled for each type of environmental matrix and radioactivity measurement category based on the laboratory approval table defined in appendix to approved and amended ASN decision no. 2008-DC-0099 of 29 April 2008, on the organisation of the RNM for environmental radioactivity, which also defines the laboratory approval procedure.

Environmental matrices:

- 7 groups are defined: water, soil, biological matrices, aerosols, gases, the ambient environment and food;
- 17 radioactivity measurement categories.

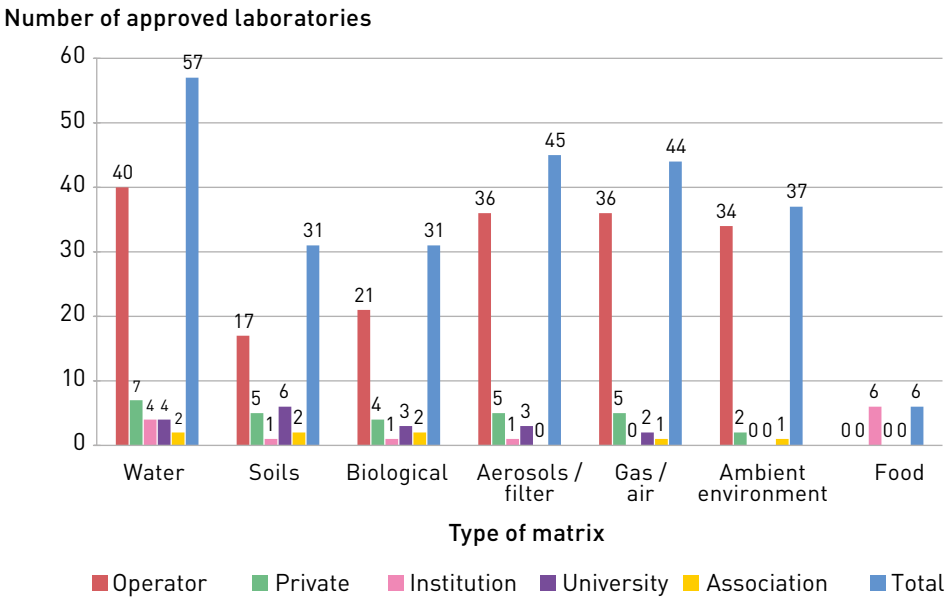
Comparative inter-laboratory tests allow the laboratories involved to prove the quality of the analysis techniques used, provide accreditation bodies with information indicating their level of expertise in the analysis process and obtain ASN approval as per regulations.

Overview of approved laboratories as at 1 January 2018

58 laboratories had been approved for measuring environmental radioactivity on 1 January 2018, including 40 laboratories run by nuclear operators. The other 18 laboratories are run by private operators (6), universities (6), institutions (3) and associations (3). These laboratories hold a total of 880 approvals in 51 approval categories. Since the launch of a new type of approval for gamma-emitting measurements in food as part of health safety tests in 2015, six laboratories (pre-selected by DGAL and DGCCRF) have applied for ASN approval in order to contribute to the RNM. This equivalence will allow these laboratories to upload food data to the RNM.

Most laboratories are approved for monitoring water radioactivity with 57 laboratories holding up to 13 different water monitoring approvals each (see figure 17).

FIGURE 17 / **LABORATORY BREAKDOWN (including IRSN)**



Around fourty laboratories hold approval for biological matrix (food chain), atmospheric dust, air or ambient gamma dosimetry measurements. 31 laboratories are approved for soil measurements. While most laboratories are able to measure gamma emitters in all environmental matrices, only around a dozen laboratories are approved to measure carbon-14, transuranic elements or radionuclides from natural uranium or thorium chains in water, soil and biological matrices.

CILEI - IRSN's comparative inter-laboratory environmental testing website

IRSN has launched a website exclusively for the purpose of exchanging information between laboratories involved in IRSN's inter-laboratory tests for measuring radioactivity in the environment and food: https://cilei.irsn.fr/

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Helium-3 degassing bench for seawater tritium measurements

FOCUS ARTICLE

FEEDBACK ON COMPARATIVE INTER-LABORATORY TESTING AS PART OF THE LABORATORY APPROVAL PROCESS

The comparative inter-laboratory testing organised by IRSN as part of the French metrological network for environmental radioactivity is intended to appraise the quality and reliability of the measurements taken by the various laboratories involved.
With these expertise tests, the results obtained by the laboratories based on identical samples are generally compared with a control value. IRSN is responsible for preparing samples, determining control values and using results for these tests, which are open to both French and foreign laboratories.

Initial comparative inter-laboratory tests were organised by IRSN in April 2003 based on the first regulatory texts governing the monitoring of environmental radioactivity (decree no. 88-715 of 9 May 1988 on harmonising radioactivity measurements for the environment and food intended for consumption, article R. 43-6 of the French public health code, amended by decree 2002-460 and the order of 17 October 2003 on the organisation of a French metrological network for environmental radioactivity).
The laboratory approval committee, established by the order of 17 October 2003, met for the first time on 7 January 2004, and issued positive opinions on 29 approval applications. Approvals are granted with a validity period of 5 years.

ASN decision no. 2008-DC-0099 of 29 April 2008 describes the organisation of the French metrological network for environmental radioactivity and defines laboratory approval procedures. This decision was amended by ASN decision no. 2015-DC-0500 of 26 February 2015, introducing a new type of approval designed to allow laboratories approved by DGAL and DGCCRF to upload their food measuring results obtained as part of health safety tests to the database of the French metrological network (RNM) for environmental radioactivity.

Participating in comparative inter-laboratory tests (ILT) meets both the general requirements specified in standard NF EN ISO/IEC 17025 on the expertise of testing and calibration laboratories and regulations requiring laboratories to submit the results of ILT when applying for approval.
If the ILT results of a laboratory are not sufficiently conclusive, ASN may issue provisional approval for a one- or two-year period, for example, or require additional elements as prerequisites for approval, potentially including further multi-party tests, based on the opinion of the approval committee.

The number of ILT required each year has gradually increased since 2003 to cover the entire range of approvals. IRSN organises 6 ILT each year on average, spread over two semesters. The laboratory approval committee has met twice annually since 2010 in order to appraise the ILT results of laboratories and issue an opinion to ASN on the applications for approval submitted by the laboratories.

IRSN organised 70 ILT between 2004 and 2017, and on 1 January 2018, ASN had issued 880 current approvals to 64 laboratories.

The following table itemises the number of approvals granted to laboratories for each matrix and per year since ILT were introduced.

Starting year for validity	Water	Soils and sediments	Biological matrices	Aerosols	Air	Ambient gamma dose rate	Food
2004	24		5				
2005	76		40				
2006	58	53	26	40			
2007	26		4	2			
2008	17			16	8	18	
2009	151		65		35	20	
2010	62	73	18	17	1	1	
2011	24	57	1	70	1		
2012	14	8	25	1	49		
2013	13	12	38		14		
2014	119	1	74	25	42	40	
2015	87	77	15	26			
2016	76	60		71		5	
2017	25	12	27	7	52		6

According to feedback, the 5-year intervals adopted for each type of ILT, matching the validity of the corresponding approvals, are satisfactory. It would not be appropriate to extend this period as it would not leave enough time to appraise the ability of the laboratories to maintain their performance levels over time based on personnel turnover, structural changes, or new standards and measuring methods likely to occur during the validity period for the approval.

Since the initial ILT, ASN and IRSN have taken note of the improvements for approved laboratory teams: the percentage of satisfactory ILT results has generally increased over time, meaning that the number of two-party tests organised by teams has decreased in relative terms. In fact, each of the 29 two-party testing sessions organised between 2004 and 2012 included up to 4 laboratories. Most of the 16 two-party testing sessions organised between 2013 and 2017 only included one or two laboratories. The number of provisional approvals granted for one or two years, requiring two-party testing or the submission of additional elements to the approval committee, also decreased between 2004 and 2017.

On this basis, since 2003, ASN has considered that the organisation of comparative inter-laboratory testing by IRSN is an effective, reliable and well-tested system which indeed appraises the quality and reliability of the measurements taken by the various laboratories involved. ILT helps to improve the expertise of laboratories and maintain their performance levels over time, guaranteeing the quality of the environmental radioactivity measurements published on the website of the French metrology network for environmental radioactivity: www.mesure-radioactivite.fr.

Carbon-14 measurement bench based on benzene synthesis

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02
BACKGROUND RADIATION IN FRANCE

02
BACKGROUND RADIATION IN FRANCE

Background radiation refers to the activities of the different radionuclides in the environment, excluding any current anthropic contributions (nuclear industry, other industries, hospital waste, etc.). This background radiation is partially emitted by natural sources, and partially residual fallout comprising artificial radionuclides affecting all of France. This fallout is mainly the result of the atmospheric testing of nuclear weapons and the Chernobyl accident. Residents are also exposed to this background radiation. This chapter describes natural background radiation (2.1) and artificial background radiation (2.2), and details the inherent radiological exposure faced by residents (2.3).

2.1. NATURAL BACKGROUND RADIATION

Two sources of natural background radiation exist: telluric radionuclides, which have been present on Earth since it formed, and cosmic radiation, which is permanently emitted by cosmogenic radionuclides.

Cosmic radiation and cosmogenic radionuclides in the environment

Cosmic radiation reaches our planet from the sun and space (other stars and galaxies). Cosmic radiation mainly consists of protons. These protons interact with atoms in the upper atmosphere, which leads to "secondary" cosmic radiation comprising electrons, protons, photons, neutrons, etc., and to the production of "cosmogenic" radionuclides such as, primarily, tritium (^{3}H), carbon-14 (^{14}C), beryllium-7 (^{7}Be) and sodium-22 (^{22}Na).

Variation in cosmic radiation

Cosmic radiation is attenuated by the thickness of the atmosphere, which shields our planet. On this basis, the dose rate from cosmic radiation increases with altitude. Figures 1 and 2 highlight this point.

Cosmic radiation also varies with latitude, but to a lesser extent. This variation is due to the fact that the atmosphere is thicker near to the equator (15 - 17 km) than at the poles (7 km).

Cosmogenic tritium

Tritium (^{3}H) is the radioactive isotope of hydrogen. Tritium is produced naturally when cosmic radiation interacts with nitrogen, oxygen and argon atoms in the upper atmosphere. Tritium, just like all hydrogen atoms, is a component of water molecules and organic matter. Tritium is known as HTO in the form of water (tritiated water) and as OBT (Organically-Bound Tritium) when part of organic matter (see focus article on pp. 29-31).

Tritium activity is often stated in Bq/L, for free river water, water vapour in the air, water extracted from organic matter by drying or water extracted from a sample by combustion (see focus article on tritium measurements in chapter 1). Natural tritium activity represents approximately 0.1 - 0.6 Bq/L, which corresponds to activity levels of approximately 0.001 - 0.006 Bq/m^3 in air and 0.1 - 0.6 Bq/kg fresh in flora and fauna.

FIGURE 1 / **MAP OF THE AIRBORNE DOSE RATE INDUCED BY COSMIC RADIATION (µSv/h)**

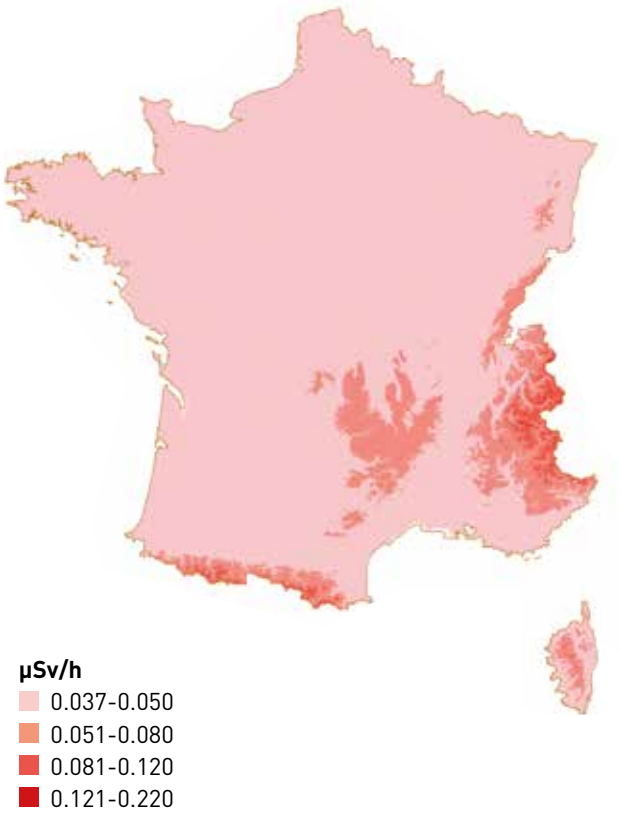
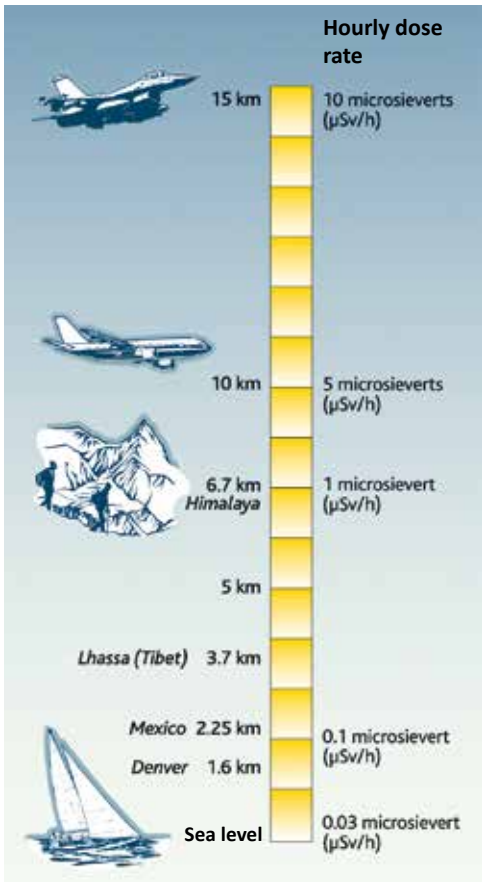


FIGURE 2 / **VARIATION IN DOSE RATE WITH ALTITUDE (µSv/h)**



Current tritium activity measured in the environment systematically exceeds these values. In fact, this natural tritium must be added to the residual tritium from fallout from the atmospheric testing of nuclear weapons in the northern hemisphere between 1945 and 1980, primarily between 1953 and 1963 (see chapter 2.2 on fallout from nuclear tests).

Cosmogenic carbon-14

Carbon-14 is produced naturally when cosmic radiation interacts with nitrogen atoms in the upper atmosphere. Just like stable carbon, carbon-14 is a component of organic matter. Carbon-14 is mainly present in the air as CO_2 and is incorporated into plants during photosynthesis, and subsequently transferred into the fauna eating the plants. The activity of this cosmogenic carbon-14 radionuclide is stated per stable carbon mass unit and known as "specific activity". This value was approximately 226 Bq/kg of stable carbon in air and all terrestrial environmental components prior to the start of nuclear testing (1945).

Large quantities of both tritium and carbon-14 were produced during the atmospheric testing of nuclear weapons in the northern hemisphere. Due to these tests, current environmental radioactivity is still slightly above this value (see chapter 2.2 on fallout from nuclear tests).

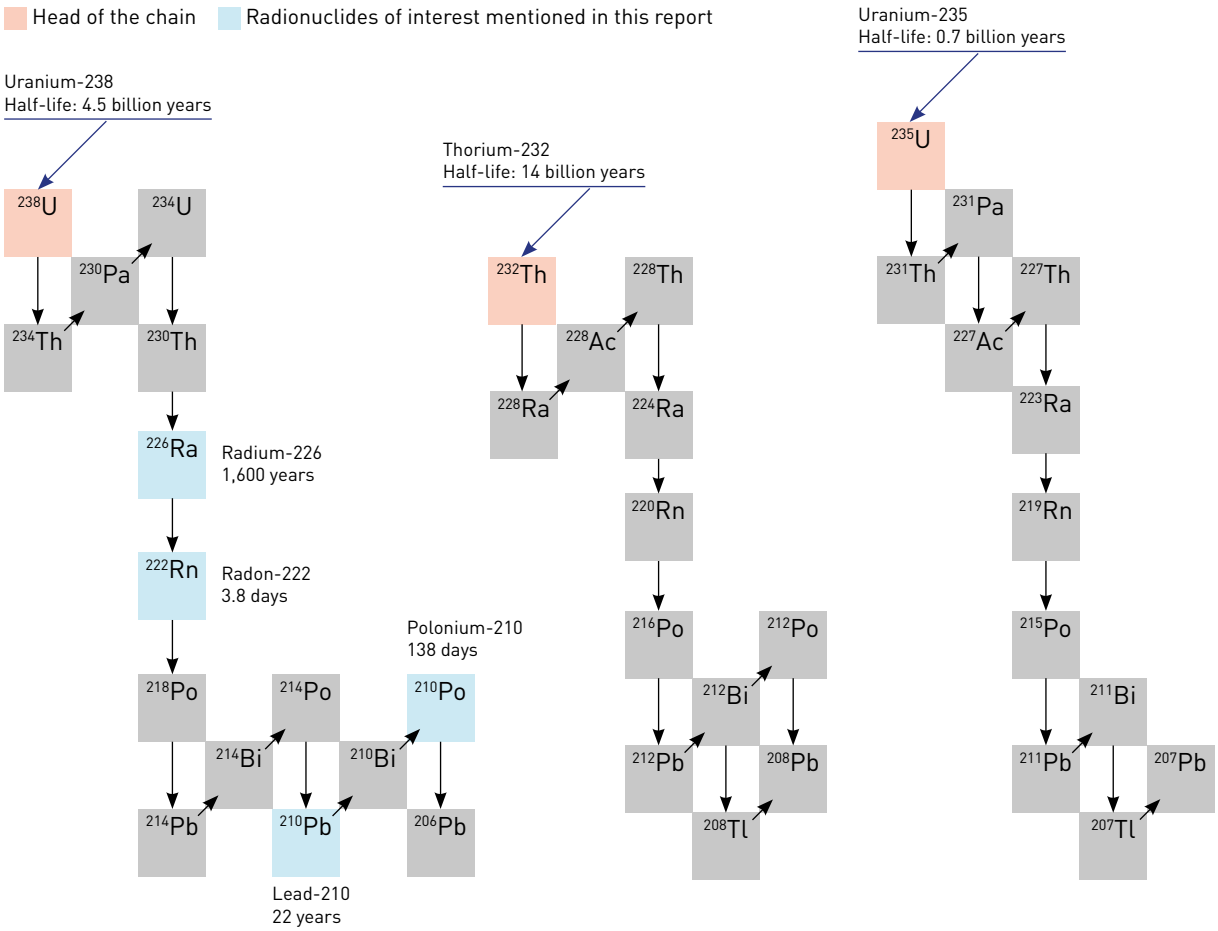
Telluric radionuclides in the environment

Telluric radionuclides have existed on Earth since it formed. The main telluric radionuclides are potassium-40 (^{40}K), and the decay chain products of uranium-238 (^{238}U), uranium-235 (^{235}U) and thorium-232 (^{232}Th). These four radionuclides are still present in the Earth's crust due to their very long half-lives (around several billion years). Uranium-238, thorium-232 and uranium-235 produce 36 radionuclides in their decay chain (see figure 3). On this basis, a total of around fourty telluric radionuclides are present in all environmental components: soil, air, water, flora and fauna (including people).

Le potassium-40

Potassium is widely available on Earth as part of many different minerals. Although potassium-40 only represents 0.0117% of the mass of potassium, it is the most frequently found radionuclide in the environment and its activity reaches several hundred Bq/kg in soils and continental and marine sediments (see figure 8). Potassium (including ^{40}K) is a key element for living organisms and is easily transferred to flora and fauna, which explains why its activity reaches hundreds of Bq/kg in food (see figure 9). Such an activity value is the highest of any natural or artificial radionuclides in the environment, excluding any local anthropic impacts, by far.

FIGURE 3 / **URANIUM-238, THORIUM-232 AND URANIUM-235 DECAY CHAINS**



Decay chain radionuclides for uranium-238, thorium-232 and uranium-235

In unaltered rocks, the activities of all uranium and thorium decay chain radionuclides are approximately the same as that of the head of the chain (^{238}U, ^{235}U or ^{232}Th): they are said to be at equilibrium. For example, radium-226 activity in a rock is equal to uranium-238 activity. This is not true for water or living organisms, which have different physical and chemical properties, leading to different reactions and transfers. Up to radium, telluric radionuclides are generally at equilibrium in soils, although minor unbalance can occur due to the presence of living organisms or soil leaching. No equilibrium is reached after radium isotopes. When radium decays a radioactive gas called radon (mainly ^{222}Rn) is produced. This radon is transferred from the soil to the atmosphere, breaking the equilibrium at the end of the decay chain. When radon decays, the daughter radionuclides fix to particles suspended in the air. These radionuclides include polonium-210 (^{210}Po) and lead-210 (^{210}Pb), which settle on the surface of the soil. This transfer slightly increases the activity of the surface soils in ^{210}Pb with respect to uranium-238 or radium-226.

In France, at any given location, uranium-238 and thorium-232 activities will be approximately the same in rocks and soils, however, uranium-235 activity will be 20 times less. A ratio of 20 to 1 between uranium-238 and uranium-235 activity reflects enrichment in uranium-235 (enriched uranium); a higher activity ratio would indicate depleted uranium. In addition, uranium-236 (another uranium isotope) can only be measured in the environment if the latter is affected by specific facilities. If this isotope is detected, an industrial source can be confirmed.

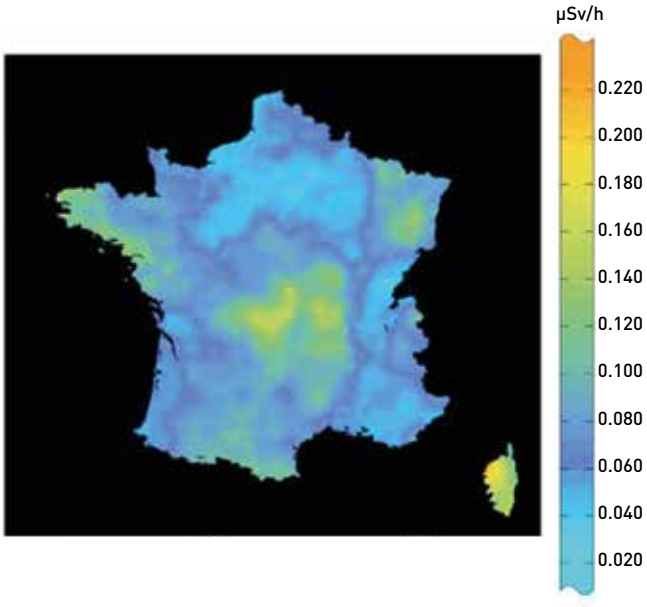
Variation in the uranium and thorium composition of soils and variation in dose rate attributable to telluric radiation

Uranium and thorium activities in the main terrestrial environment components: air, flora, fauna, surface water and sediments, and ground water, will depend on the activity of the underlying geological formations and soils.

IRSN has determined an average value of 40 Bq/kg dry for uranium-238 and thorium-232 in all regions, covering all types of soil and sites, however activity varies significantly from a few Bq/kg dry to a few hundred Bq/kg dry depending on the type of subsurface. In general, rocks in sedimentary basins (Paris basin, Aquitaine basin) and limestone formations contain less uranium than older rock formations (Armorican massif, Massif central, Vosges). These activities can reach a thousand Bq/kg dry in uraniferous soils. Variation in soil composition in terms of uranium and thorium daughters can be demonstrated based on variation in the radiation (airborne dose rate) they emit.

Figure 4 shows a map of variation in telluric gamma dose rates throughout mainland France. This map was prepared using measurements obtained by control dosimeters (i.e. dosimeters located in areas unaffected by any radiographic device) in 17,404 dentist and veterinary clinics spread throughout mainland France. The highest dose rates are primarily detected in the Massif central, the Armorican massif, Vosges and Corsica. These regions all consist of geological formations with relatively high uranium content (granitic formations). This map should be compared with figure 6, which also highlights these geological formations as the most likely potential source of radon emissions in the air.

FIGURE 4 / **MAP OF VARIATION IN TELLURIC GAMMA DOSE RATES USING DATA OBTAINED FROM CONTROL DOSIMETERS**



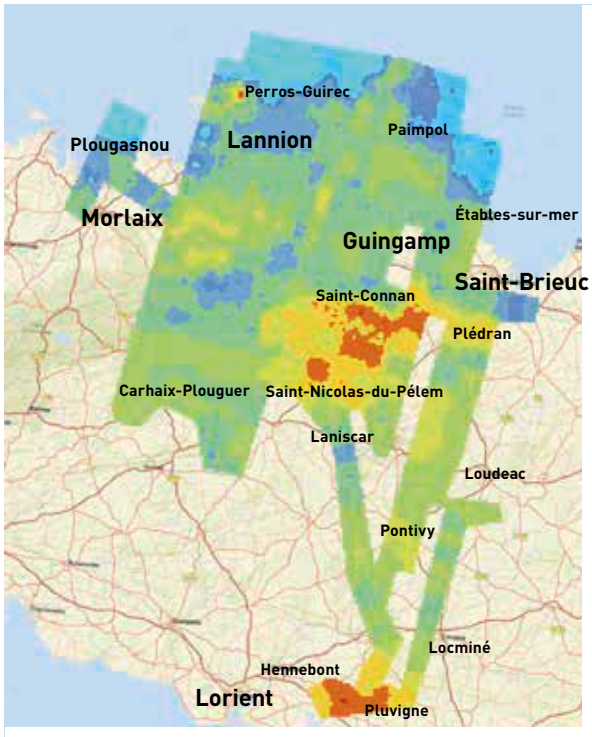
© IRSN

IRSN's Ulysse onboard gamma spectrometer; the sensors are installed in the pods on each side of the helicopter. This set-up was used, on a plane, to obtain the data shown in the map in figure 5A.

Variation in the uranium and thorium composition of soils and variation in the dose rate in the air attributable to the former are also clearly apparent at regional level On this basis, figure 5A shows variation in dose rate throughout north Brittany. This map was prepared directly using airborne gamma dose rate measurements. If we compare the uranium content of soils on a relative basis (see figure 5B), strong correlation appears: areas with high uranium content, shown in turquoise and dark blue, coincide with the highest dose rates (shown in yellow-orange/red).

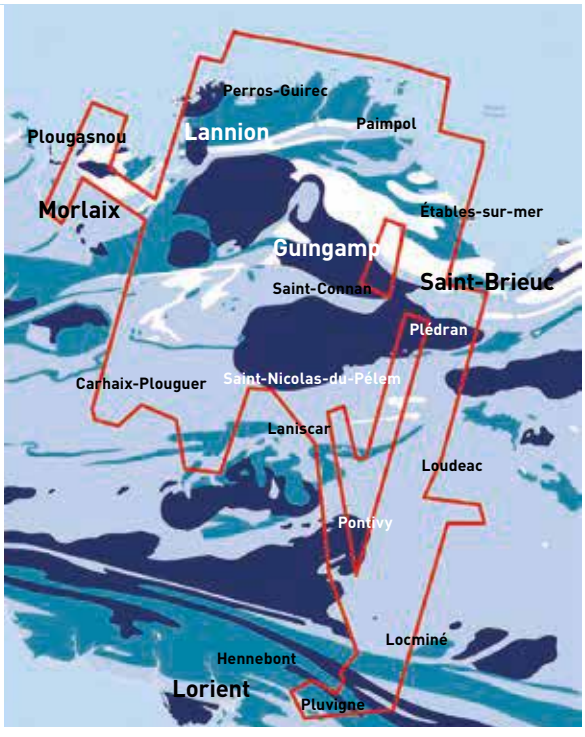
In addition, very local variations appear over distances of just a few kilometres. To the south of Guingamp or to the north of Lannion, the dose rate climbs from less than 0.050 to over 0.100 µSv/h. Such variations in dose rate caused by the uranium-thorium composition of soils can also be detected at micro-local level, where dose rates can double, or more, over just a few hundred metres.

FIGURE 5A / **MAP OF THE DOSE RATE 1 M ABOVE THE GROUND AS MEASURED WHILE FLYING OVER PART OF BRITTANY**



Map of equivalent gamma dose rates acquired in 2013 using IRSN's airborne radiological measuring system, ULYSSE, during a joint operation with the civil security teams.

FIGURE 5B / **MAP SHOWING THE AVERAGE URANIUM CONTENT OF GEOLOGICAL FORMATIONS IN NORTH BRITTANY**



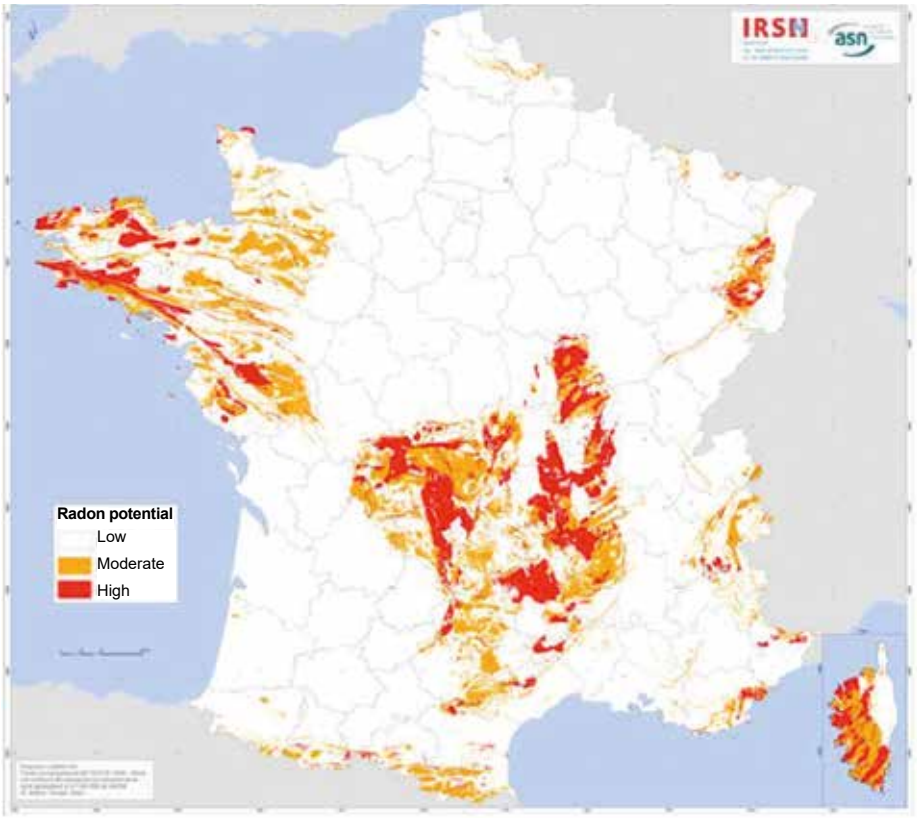
Map showing the mean uranium content of geological formations in north Brittany.

Variation in radon content in ambient air

Radon is a radioactive gas and is omnipresent on the surface of Earth, where it forms when natural radionuclides (uranium, thorium) in the rocks and soils decay. Three radon isotopes exist (^{219}Rn, ^{220}Rn and ^{222}Rn), however only radon-222 has a long enough half-life (3.8 days) for significant activity per volume to be detected in the environment. Radon-222 is part of the decay chain of uranium-238 and is the daughter product of radium-226 (see figure 3).

Variable quantities of radon are emitted from soils and rocks depending on the properties of the source material (geological properties, radium content, porosity, air permeability). Radon activity by volume in soil air is more significant in regions where the rocks have high uranium content, such as some types of granite and some metamorphic rocks (Armorican massif, Massif central, Vosges, Corsica, etc.), and even, on a more exceptional basis, in sedimentary formations (e.g. in the Lodève region) or in karst formations. Radon activity can therefore vary substantially throughout France. The same applies for dose rates, at regional and even local level. What's more, some geological structures (faults, underground caverns, thermal springs, etc.) can make it easier for the radon to transfer to the surface. A national map showing potential radon content (see figure 6) was prepared based on geological knowledge of France. This map can be used to target the areas where radon is the most likely to be produced and transferred to the surface and the atmosphere.

FIGURE 6 / **MAP SHOWING THE POTENTIAL RADON CONTENT OF GEOLOGICAL FORMATIONS WITH A SCALE OF 1: 1,000,000**



Radon activity by volume in soil air generally varies between 1,000 and several hundred thousand Bq/m^3 and varies substantially depend on the type of soil and underlying geological formations. Table 1 shows the ranges of radon activity by volume as measured in soil air.

The radon released to the atmosphere will also depend on weather conditions, in addition to the properties of the soils and rocks. Weather conditions (wind, rain, low temperatures, etc.) will affect variations in radon activity over time at any given location.

Activities per volume measured in the atmosphere are much lower than in the soil: airborne activity varies between a few Bq/m^3 and around a hundred Bq/m^3, with a mean value of a few tens of Bq/m^3. Many factors affect activity, including the geology of the location in question, the distance to the soil, topography and atmospheric conditions. For example, if we consider a distance covering a few hundred metres, activity may differ between the bottom of a narrow, but deep, valley, with limited air flow, where the radon can concentrate, and an intermediate position half way up a slope, or a well-ventilated summit where the radon will more rapidly disperse (see the Écarpière site described in chapter 4 for forming mining sites). Finally, daily fluctuations can occur at one single location, with high activity at ground level at sunrise and sunset, when air movements are reduced.

Figure 7 shows radon activity by volume in the atmosphere measured two metres above the ground along a road in the southern Vosges. These measurements were taken using a portable laboratory travelling very slowly by night. As is clear on the map, activity varied substantially over the length of the road covered. Activity varied due to the varying concentrations of uranium in the underlying rocks, with a transition from granitic rocks to the north (which are relatively rich in uranium) to volcano-sedimentary rocks to the south (which contain significantly less uranium).

FIGURE 7 / **RADON-222 ACTIVITY BY VOLUME MEASURED DURING ONE NIGHT (from 22:00 to midnight) USING A PORTABLE LABORATORY (measurements were taken 2 m above the ground)**

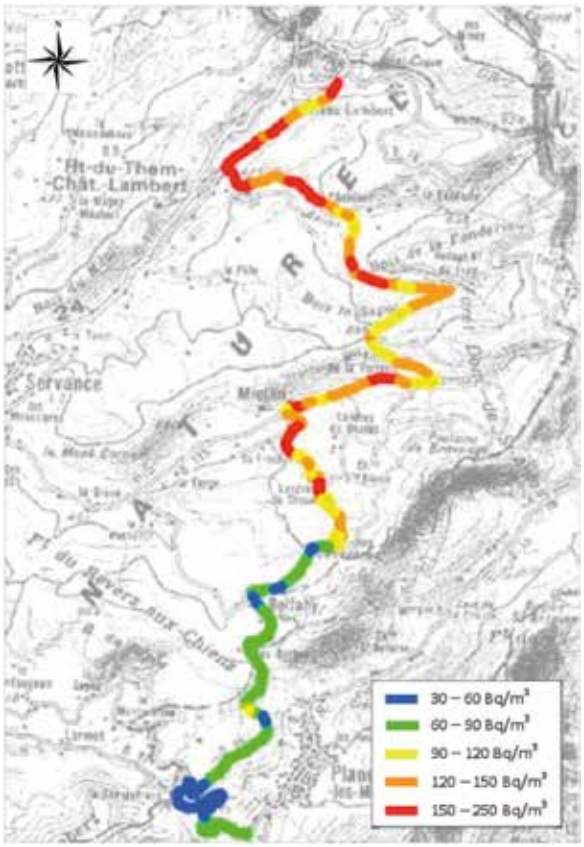


TABLE 1 / **VARIATION IN RADON ACTIVITY BY VOLUME IN SOIL AIR BASED ON GEOLOGICAL PROPERTIES, AS MEASURED IN SEVERAL REGIONS OF FRANCE**

Type of rocks	Range of radon activity by volume in soil air (Bq/m^3)	Mean radon activity by volume in soil air (Bq/m^3)
Granites, orthogneiss	10,000 – 500,000	100,000
Sedimentary and meta-sedimentary formations	1,000 – 150,000	40,000
Basic volcanic formations	1,000 – 90,000	20,000

Variation in the activity of telluric radionuclides in the environment

Radionuclides in the soil can be absorbed by plant roots. Airborne radionuclides, particularly polonium-210 and lead-210, radon daughter products, settle onto the plant leaves. These two radionuclides have the highest activities in food of all telluric radionuclides (see figure 9). In general, far higher levels of radium isotopes are absorbed by plant roots than uranium or thorium isotopes. This means that radium activity is higher in flora.

Activity is mainly transferred to livestock and related foodstuffs (milk, meat, eggs) *via* the food chain. On this basis, radium, polonium-210 and lead-210 levels in food of animal origin are also higher than uranium or thorium isotope content.

Natural radionuclides reach the seas and oceans *via* drainage systems from continental land areas and radon degassing. Telluric radionuclides behave differently in this environment due to their different chemical properties, therefore activity varies substantially between the different marine components. In water, uranium and radium are mainly dissolved, with activities of approximately 30 to 40 mBq/L for uranium-238 (as was the case for soils, ^{235}U activity is 20 times lower) and approximately 3 mBq/L for radium-226. On the other hand, thorium fixes to particles settling into sediment and activity for thorium-232 dissolved in the water is extremely low. Lead and polonium also have a strong tendency to fix to particles, however, due to surface enrichment from the atmosphere (radon decay), activity in surface seawater is approximately 0.3 - 5 mBq/L. The marine environment has one special characteristic: very high polonium-210 content in marine foodstuffs. This situation is caused by high assimilation by plankton. The marine organisms which depend the most directly on plankton also contain the highest levels of lead-210. This is particularly true for molluscs, shellfish and small fish (sardines, herrings, anchovies).

The levels of uranium and thorium decay chain daughter products in surface water and ground water vary substantially due to different rock and soil compositions, as well as the physical and chemical characteristics of the water, which can also vary. In rivers, uranium-238, uranium-234, radium-226 and radium-228 activities are mostly (over 95%) below 0.1 Bq/L, but can range from less than 0.001 Bq/L to exceptional figures such as 1 Bq/L. Higher values have been measured in surface water near to former mining sites (see chapter 4).

Lead-210 and polonium-210 activities are generally low and less than 0.01 Bq/L, however they can reach 0.6 and 0.1 Bq/L respectively in exceptional cases.

Comments on figures 8 to 13

Figures 8 to 13 show activities for the main radionuclides measured in France considered as background radiation in mainland France. These radionuclides are either natural or residual elements from old fallout (see chapter 2.2). The data used to compile these charts have been acquired by IRSN since 2009 in various contexts. Some series with specific sources have been added to ensure a comprehensive overview. Box plots are used to indicate the ranges of activity corresponding to 80% of the significant values measured (activity between the 10% and 90% percentiles is shown as a coloured box), mode values (50% percentile) shown as a line cutting the coloured boxes in half, and peak measurements (top lines). These statistics are representative of IRSN measurements, but only approximate the actual situation. More specifically, only significant measurements, i.e. those above the decision threshold (see chapter 8 of the appendices) are considered; the lowest levels of environmental activity cannot be measured and are not shown. No minimum values are shown for the box plots for this reason. In general, the more data are available, the more representative the statistics are. For information, the number of analyses and

the number of significant measurements used are indicated on the x-axis for each data series. The statistics shown may still be biased, even if the number is high, particularly for natural radionuclides. Natural radionuclide levels indeed vary substantially in France, between the sedimentary basins and the older massifs. However the older massifs contain higher levels of uranium and thorium daughter products, but are poorly represented in the samples collected and analysed by IRSN. To offset this bias, figure 11 can be used to compare activity at sites with a High Level of Natural Radioactivity (or HLNR), with activity throughout the rest of mainland France. In addition, a box plot format was selected to show as much information as possible, despite the fact that very little data is actually available, if the statistics provided would appear realistic. Finally, it is important to highlight that values above the peak values shown can still be measured.

FIGURE 8 / **ACTIVITIES OF THE MAIN RADIONUCLIDES IN SOILS AND SEDIMENTS IN FRANCE**

Although mean plutonium-239+240 content in soils and sediments, the result of nuclear testing fallout, would appear fairly homogeneous in France, the degree of variation detected in soils without crops reflects the variation in deposition shown on the map in figure 15: plutonium activity is higher in mountain areas due to higher mean annual precipitation. Soil caesium activity is generally consistent with the map showing the total deposition of fallout from nuclear testing and the Chernobyl accident (figure 18): activities are lower to the west (mean value of 7 Bq/kg dry) than the east (mean value of 11 Bq/kg dry), and are higher in areas with greater fallout (zones where mean residual radionuclides reach 26 Bq/kg dry; see focus article on p. 70). In addition, hot spots occur at altitude corresponding to small surface areas of less than 1 m² where snow concentrated in May 1986. These hot spots have much higher activity levels: around 10,000 Bq/kg dry. Soil caesium-137 activity is much higher than strontium-90 activity for two main reasons: on the one hand, fallout from the Chernobyl accident, particularly in east France, combined with fallout from nuclear testing, and on the other hand, strontium transfers more easily in soils, therefore a higher percentage of the activity initially deposited migrates to greater depths. In terms of the levels of natural telluric radionuclides, uranium and thorium decay chain daughter isotopes, soils and sedimentary basins are easily identifiable using the data (mean value of 26 Bq/kg dry), and can be differentiated from the soils of older massifs (mean value of 44 Bq/kg dry), and soils with a very high level of natural radioactivity (data for Haute-Vienne and Saône-et-Loire). Finally, potassium-40 activity is higher and homogeneous across soils and sediments, as expected. The number of measurements used (results above the decision threshold) and the number of analyses performed (e.g. 262/270) are shown for each soil or sediment category.

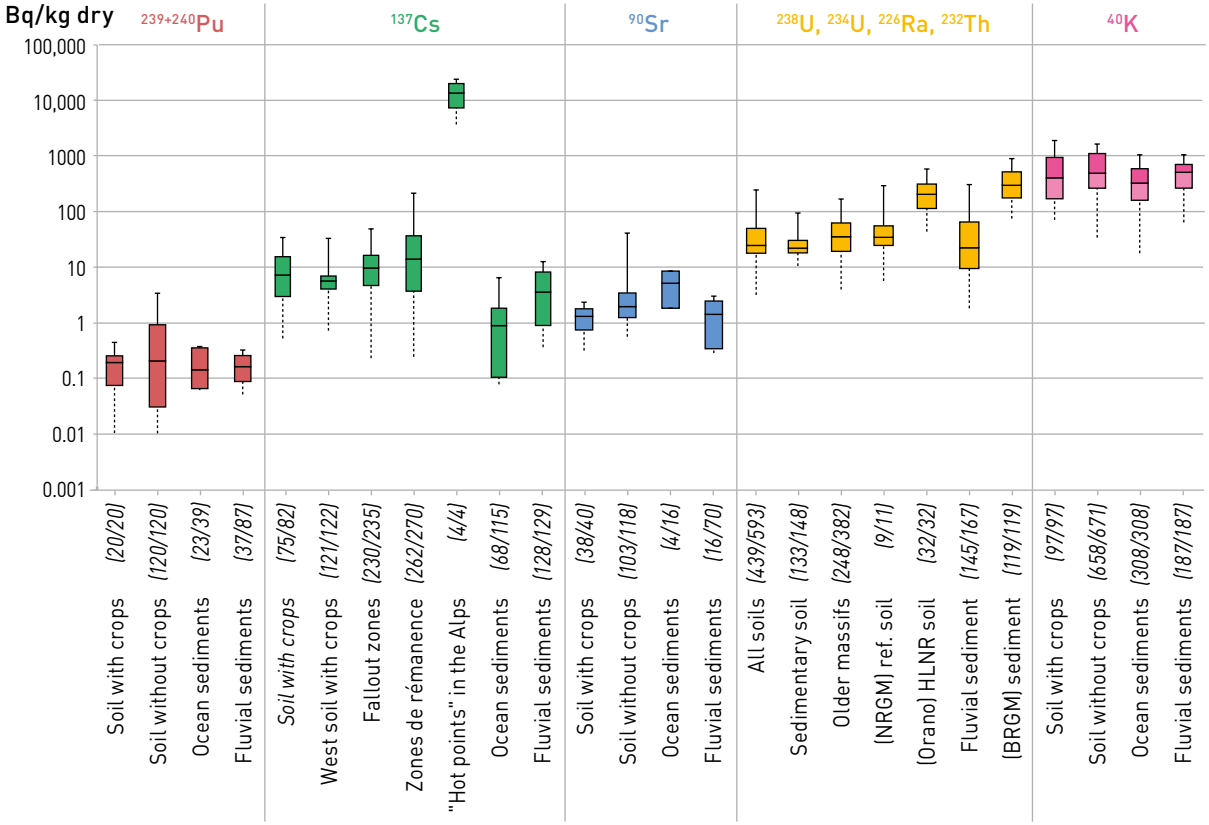


FIGURE 9 / **ACTIVITIES OF THE MAIN NATURAL RADIONUCLIDES IN FOOD PRODUCED IN FRANCE**

The activities of the main natural radionuclides in food produced can be broken down into 4 orders of magnitude. Terrestrial uranium activities are lower than radium activities due to less absorption by roots. These values are higher in the oceans as uranium is soluble in seawater. Terrestrial lead-210 and polonium-210 food activities are higher than radium activity as these two radionuclides are deposited onto plant leaves from the air after the emanation of radon. While these two radionuclides have similar levels of activity in the air and in terrestrial components, polonium-210 activity is considerably higher in the oceans. In fact, for reasons which are not entirely understood by scientists, polonium concentrates in plankton and therefore in all living organisms feeding off plankton: molluscs, shellfish, and to a lesser extent, small fish. As an essential nutrient, the potassium content and therefore the potassium-40 activity of the organic matter is the highest possible value. The number of measurements above the decision threshold and the number of analyses performed (e.g. 10/12) are shown for each food category.

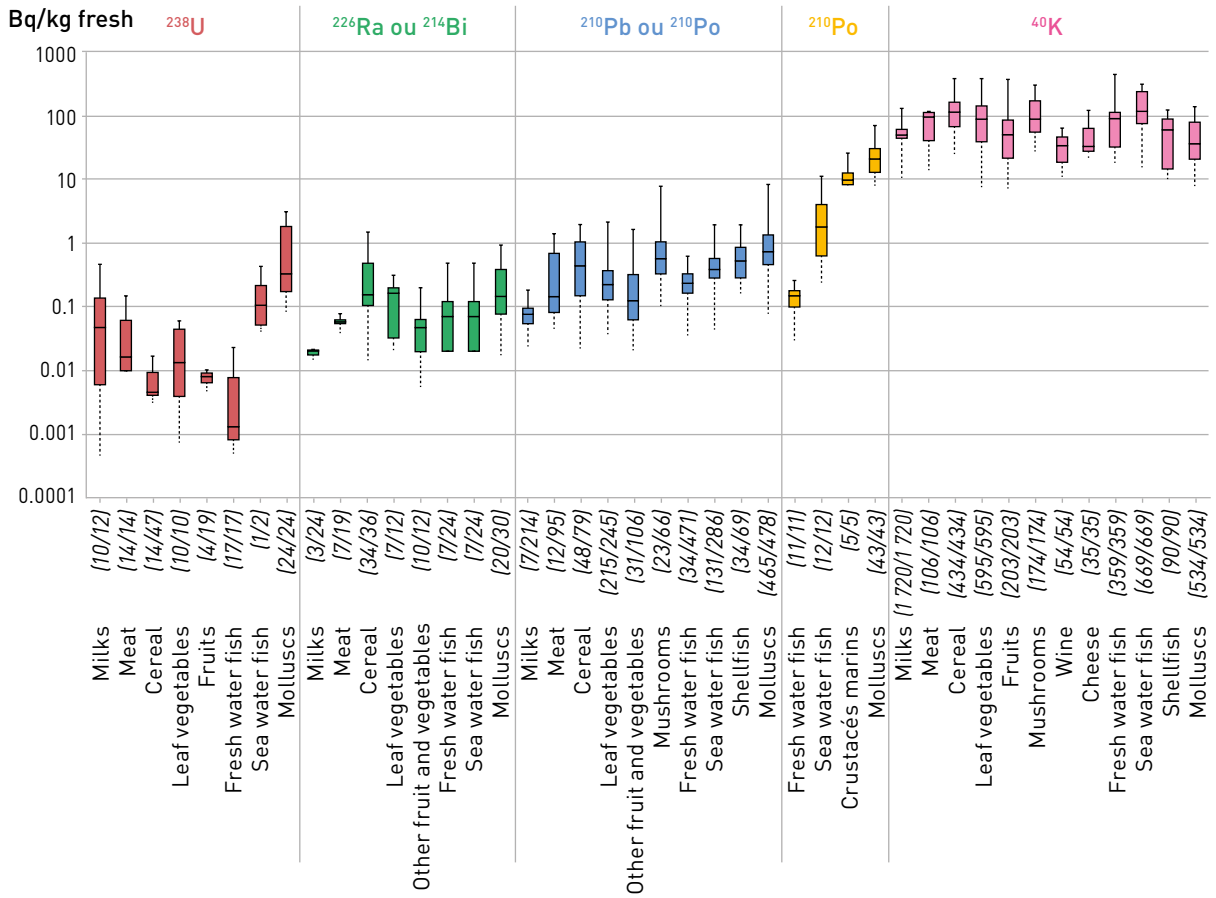


FIGURE 10 / **ACTIVITIES OF THE MAIN ARTIFICIAL RADIONUCLIDES IN FOOD PRODUCED IN FRANCE**

Figure 10 shows the activities of the main artificial radionuclides in food produced in France. These activities are primarily attributable to residual fallout from nuclear tests and the Chernobyl accident (for caesium-137).
Plutonium-239+240 activities are lower for three main reasons: (1) during fallout periods after nuclear testing, $^{239+240}$Pu deposits were approximately 100 times lower than caesium-137 or strontium-90 deposits;
(2) caesium-137 in fallout from the Chernobyl accident combined with the fallout from nuclear tests,
and (3) less plutonium will transfer to roots than caesium or strontium. Although caesium-137 activity in the soils hosting these radionuclides is much higher than strontium-90 activity (see figure 8), the levels of these two radionuclides are similar in food as strontium transfers to roots more easily. Wild food (mushrooms, berries and game) are a special case as residual fallout from the Chernobyl accident is much higher in forests (see focus article on areas with residual fallout p. 70). Terrestrial tritium activity is fairly constant in any type of food, at equilibrium is reached with the air, the host reservoir for this radionuclide. This activity is primarily attributable to residual fallout from nuclear tests, although current levels are approaching natural cosmic radioactivity. This natural cosmogenic radiation, which is approximately 10 times lower, can be detected in the oceans, which remain almost unaffected by fallout from nuclear testing due to the abundance of cosmogenic hydrogen. In the same way, carbon-14 occurs naturally, but is mainly residual fallout from nuclear weapons testing. The number of measurements used (above the decision threshold) and the number of analyses performed (e.g. 262/270) are shown for each food category.

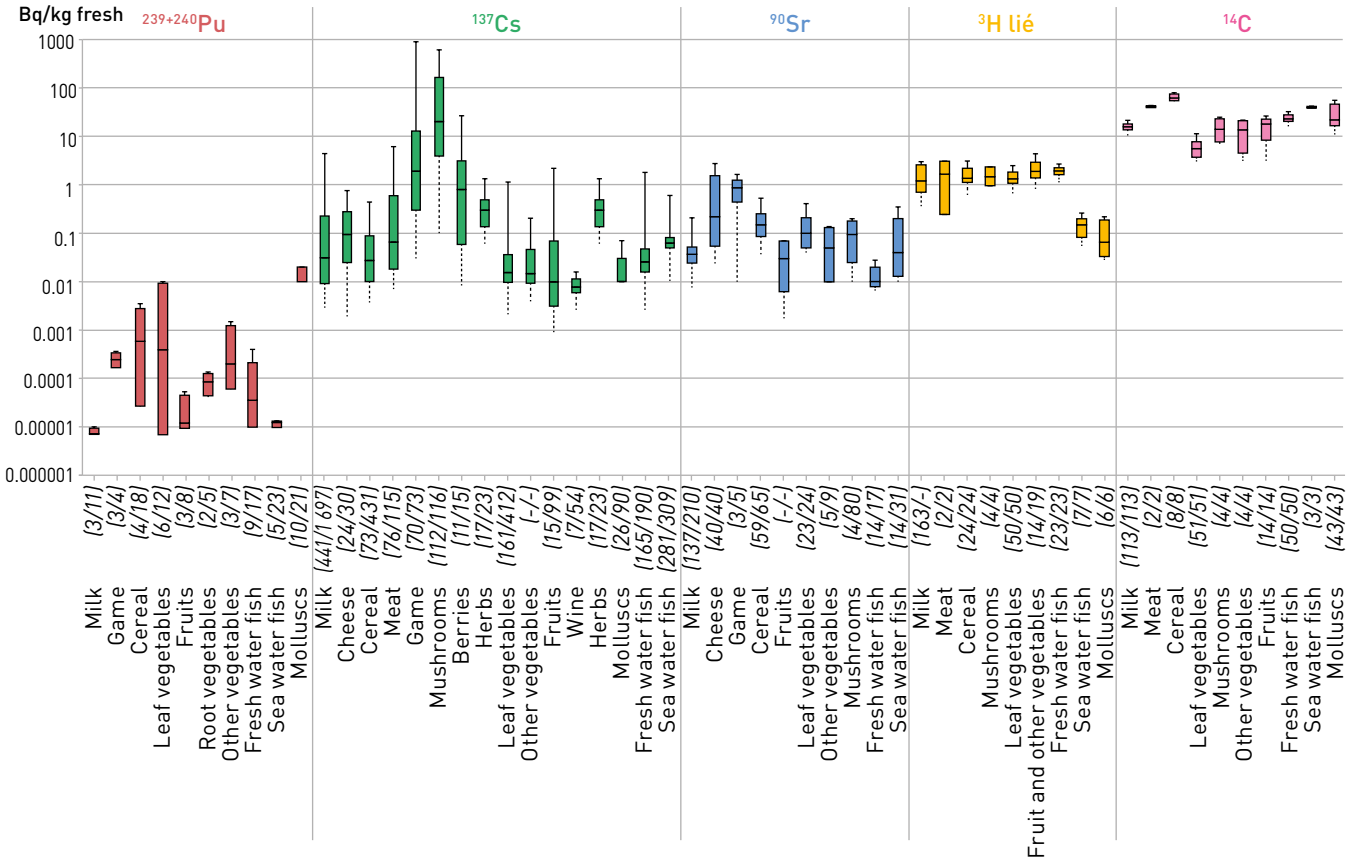


FIGURE 11 / **COMPARISON OF ACTIVITIES FOR SOME FOODSTUFFS PRODUCED IN ZONES WITH A HIGH LEVEL OF NATURAL RADIOACTIVITY (HLNR - mainly Haute-Vienne and Saône-et-Loire) WITH FOODSTUFFS MAINLY PRODUCED IN SEDIMENTARY AREAS (Paris basin, Aquitaine basin, river valleys, etc.)**

As mentioned previously, the data shown in figure 9 are generally representative of large scale alluvial plains and sedimentary basins, where uranium levels in soils are low to moderate. Figure 11 illustrates areas with a High Level of Natural Radioactivity (HLNR) which can be found in the Massif central, Amorican massif, Vosges or Corsica. This figure can be used to compare activity levels in the different HLNR areas (darker colours on the graphic) with the "reference" values indicated on figure 9 (paler colours on the graphic) for each food category. In HLNR areas, activity ranges for natural radionuclides are generally higher than, or much higher than, activity levels in the rest of France. Activities measured near to former mining sites, as described in chapter 4, must be compared with HLNR data. The number of measurements used (above the decision threshold) and the number of analyses performed (e.g. 262/270) are shown for each food category.

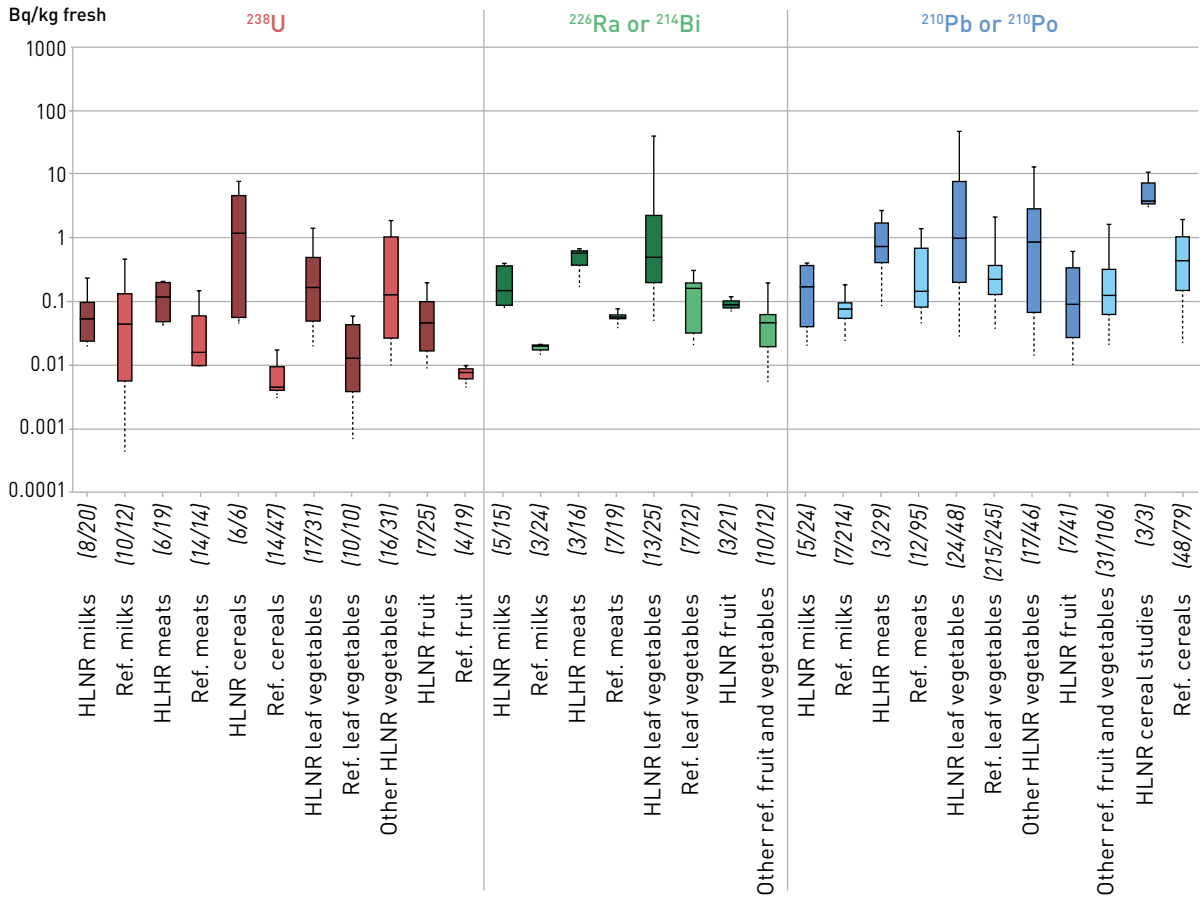
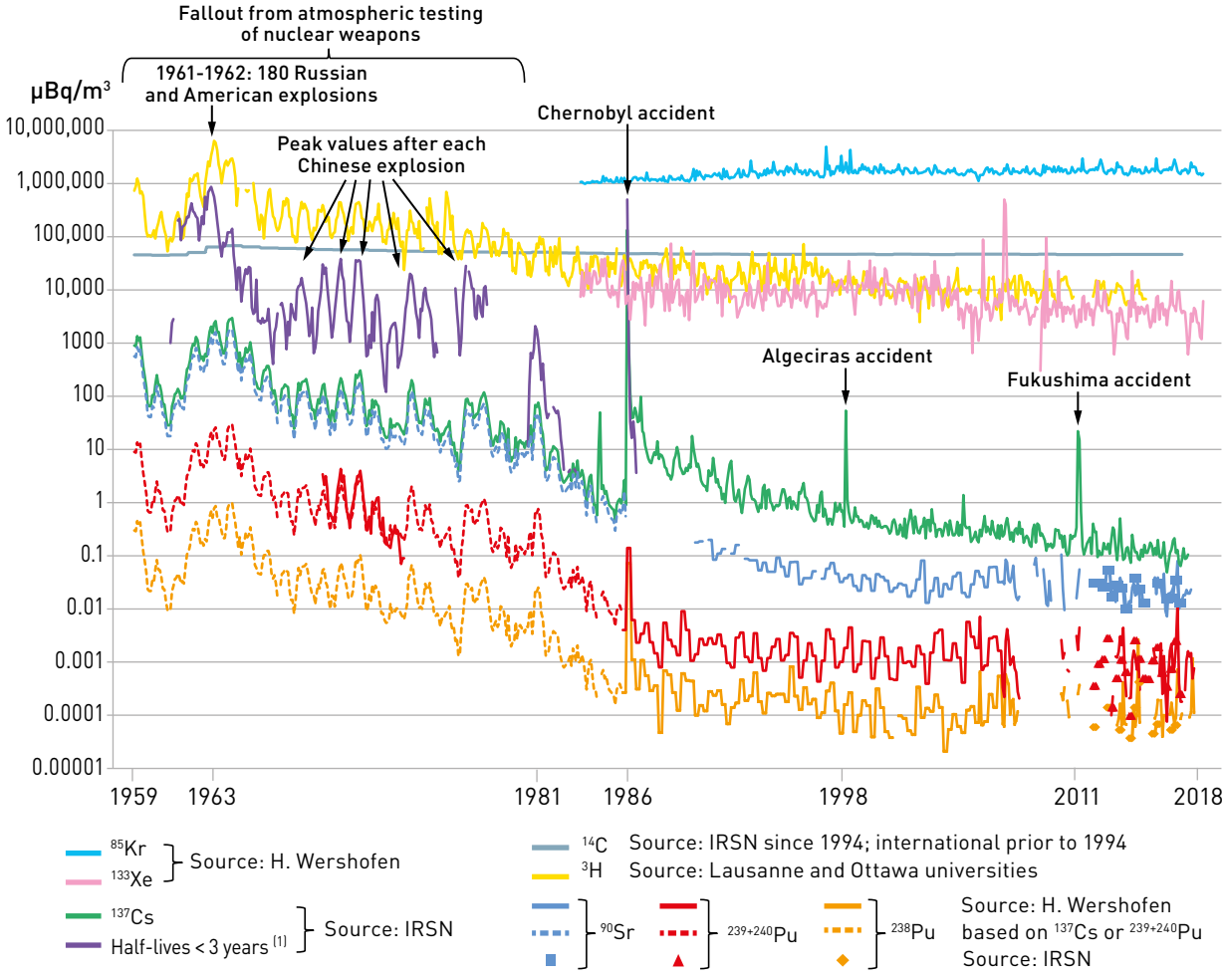


FIGURE 12 / **VARIATION IN THE ACTIVITY OF THE MAIN ARTIFICIAL RADIONUCLIDES MEASURED IN THE AIR IN FRANCE AND GERMANY OVER THE LAST 60 YEARS**

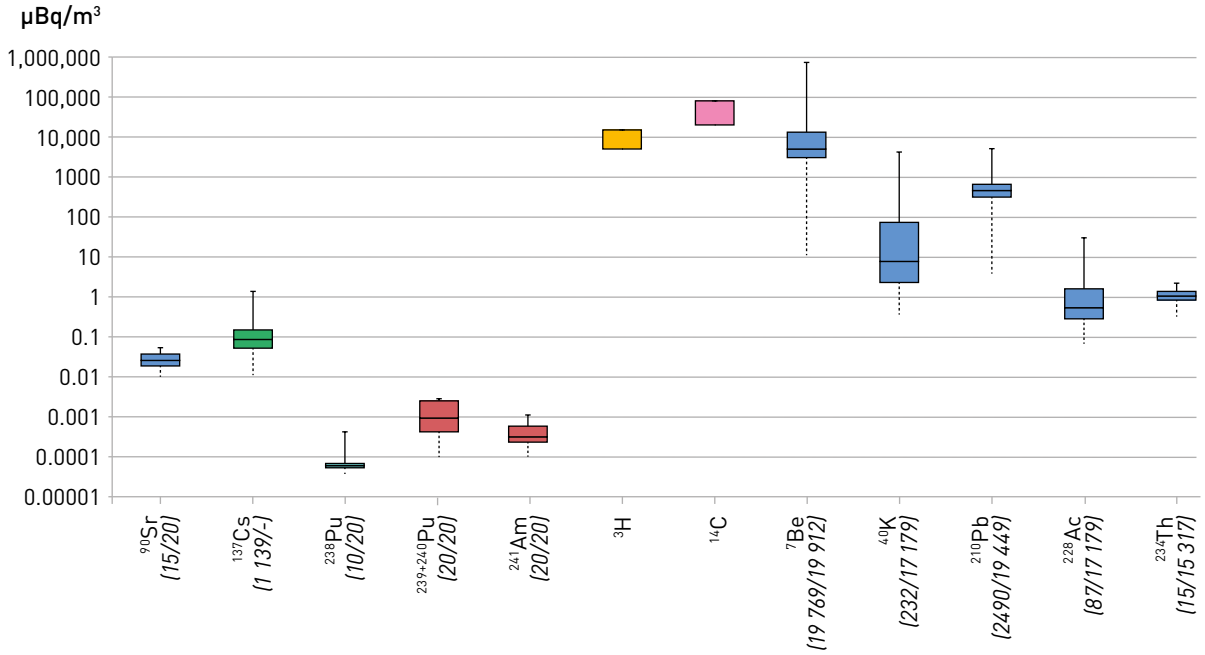
Figure 12 shows data acquired by IRSN in France and by Physikalisch-Technische Bundesanstalt (source: H. Verschofen) in Germany. These German data for background radiation in France are fully representative of radionuclides from nuclear test fallout; strontium-90 and plutonium data acquired by IRSN since 2012 particularly corroborate the German data. Krypton-85 activity measured in Germany can be considered as representative of background radiation in France, from four different sources: natural (very low), nuclear weapons tests, the Chernobyl and Fukushima accidents and all effluents discharged from fuel processing plants. In France, effluents discharged from the La Hague plant merge with this background radiation (see chapter 3.3 La Hague). Xenon-133 was released during nuclear weapons tests, and during the Chernobyl and Fukushima accidents, and is discharged by many nuclear facilities, particularly NPP. However, discharges by the radio-pharmaceutical industry are the main source of xenon-133. On this basis, IRE (Institut national des radioéléments - National institute of radioelements) based at Fleurus in Belgium is the main source of xenon-133 in the air in France and Germany. Mean monthly values are shown for all radionuclides, covering France as a whole. These mean values will smooth out any temporary high or low measurements. For example, on 1 May 1986 after the Chernobyl accident, caesium-137 activity in the air reached 7 Bq/m³ (7,000,000 µBq/m³) in Verdun. In the same way, caesium-137 activity measured at the La Seyne-sur-mer station after a source of caesium-137 was accidentally incinerated on 25 May 1998 at Algeciras in Spain, reached 2480 µBq/m³ early June. Finally, peak activity for radionuclides with a half-life less than 3 years (mainly ^{131}I and ^{134}Cs) temporarily reached almost 10,000 µBq/m³ (including 7,500 µBq/m³ of gaseous iodine-131 and 2,000 µBq/m³ of particulate iodine-131), and 250 µBq/m³ of caesium-137, between 25 March and 20 April 2011 after the Fukushima accident. Plutonium-238 activities are 30 times less than plutonium-239+240 activities. These radionuclides were released during nuclear weapons tests and when a satellite (SNAP 4) powered by this radionuclide was destroyed in the atmosphere in 1964. Finally, americium-241, a plutonium-241 daughter product released during nuclear testing, is not shown in this graphic. Airborne activity over the last two decades has reached approximately half that of plutonium-239+240 activity, as shown by figure 13.



1. Radionuclides with half-lives of less than 3 years: ^{131}I, ^{140}Ba, ^{141}Ce, ^{103}Ru, ^{89}Sr, ^{91}Y, ^{95}Zr, ^{144}Ce, ^{54}Mn, ^{106}Ru, ^{55}Fe, ^{125}Sb, ^{134}Cs...

FIGURE 13 / **MEAN ACTIVITIES FOR A FEW NATURAL AND ARTIFICIAL RADIONUCLIDES MEASURED IN THE AIR IN FRANCE SINCE 2009**

Figure 13 shows the mean activities for a few natural and artificial radionuclides measured by IRSN over the last decade. The number of measurements used (results above the decision threshold) and the number of analyses performed (e.g. 15/20) are shown for each radionuclide.



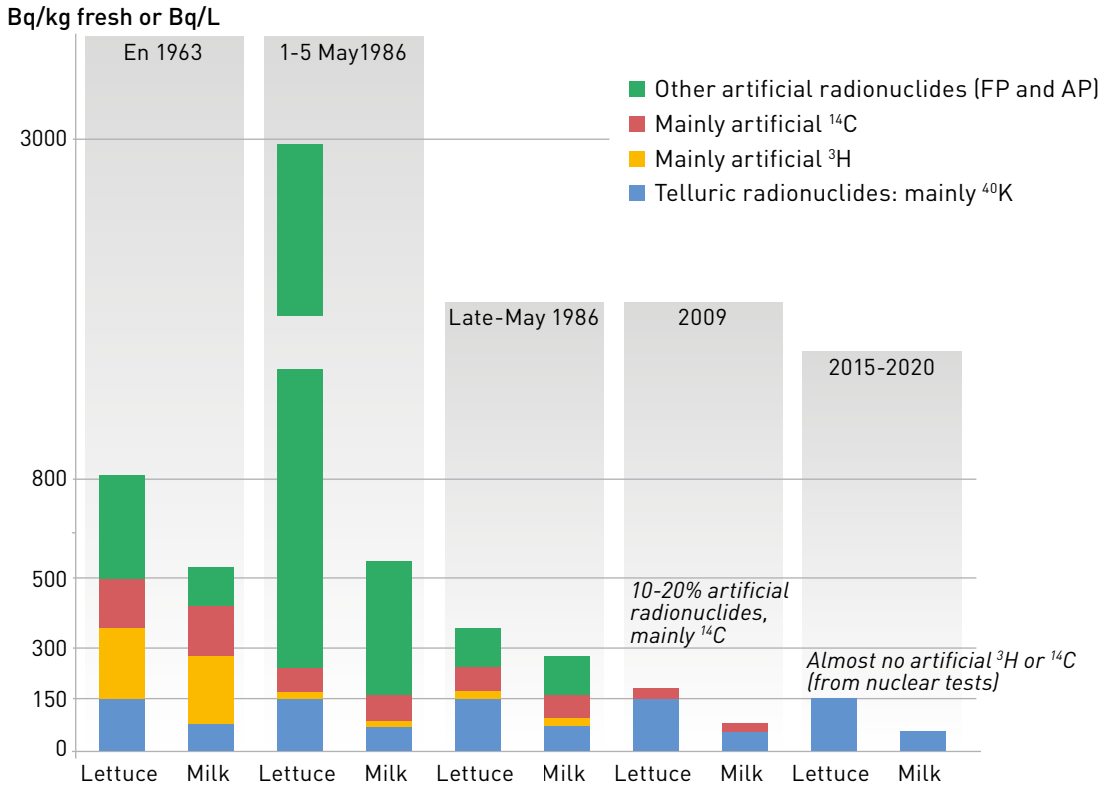
2.2. BACKGROUND RADIATION FROM OLD FALLOUT

Fallout from the atmospheric testing of nuclear weapons

Between 1945 and 1980, over 500 atmospheric tests were carried out for nuclear weapons by the United States, the USSR, Great Britain, China and France. Most radioactive fallout was generated in two specific periods: between 1951 and 1958 and between 1961 and 1962, before the Test Ban Treaty was signed in 1963. Many radionuclides were released into the atmosphere during these tests, and around twenty were regularly measured in the air in France (see figure 12), in rainwater and various foodstuffs. In 1963, when radioactive fallout peaked, the mean activity from artificial radionuclides reached 8 Bq/m^3 in air (including 6 Bq/m^3 for tritium), 650 Bq/kg fresh in lettuce (1/3 tritium and 1/5 carbon-14), and 450 Bq/L in milk (see figure 14). During the same year, people in France were subjected to an estimated average dose of 300 µSv, mainly by ingesting contaminated food. Most radionuclides with a short half-life (less than 3 years) released as part of this fallout, have disappeared. Today, only tritium, carbon-14, caesium-137 (^{137}Cs), strontium-90 (^{90}Sr), plutonium isotopes 238, 239, 240 and 241 (^{238}Pu, ^{239}Pu, ^{240}Pu et ^{241}Pu), and americium-241 (^{241}Am) from the decay of plutonium-241 remain.

With the exception of tritium and carbon-14, the soil is currently the main reservoir for all of these radionuclides, feeding the other environment components: air when raised into suspension, plants when absorbed *via* the roots or when particles in suspension settle onto the leaves, rivers from soil drainage and fauna *via* ingestion. Figure 15 shows the map of total plutonium-239+240, caesium-137 and

FIGURE 14 / **PEAK ACTIVITY MEASURED IN LETTUCES (Bq/kg fresh) AND MILK (Bq/L) IN FRANCE DUE TO FALLOUT FROM TESTING NUCLEAR WEAPONS (1963), AND FALLOUT FROM THE CHERNOBYL ACCIDENT (1 - 5 May 1986), LATE MAY 1986, IN 2009 AND EXPECTED IN THE COMING YEARS**



strontium-90 deposits in soils. In old fallout (from nuclear weapons and satellite destruction; see comments for figure 12), regardless of which environmental component is considered, plutonium-238 activity is 30 times less than plutonium-239+240 activity.

Tritium and carbon-14

Most tritium and carbon-14 can be found in the air. These two radionuclides are integrated in organic matter in flora *via* photosynthesis. They are then transferred to fauna when the flora is ingested.

Variation in carbon-14 composition since the 1950's due to fallout from nuclear tests can be measured in all environmental components in the form of the specific activity in Bq/kg of carbon. On land, the carbon-14 content of flora and fauna is in equilibrium with the air, which gives the same specific activity in both components. These specific activity is precisely determined and varies each year. Furthermore, this activity does not vary over terrestrial environmental components. Figure 16 shows variation in specific activity for the entire northern hemisphere since 1950.

This specific activity increased from cosmogenic levels (226 Bq/kg of C; see chapter 2.1 on cosmogenic radionuclides) to around 420 Bq/kg of C in 1963, when test fallout peaked, and when US-USSR atmospheric testing ceased. While the total activity of the atmospheric component has only decreased slightly since that time (insignificant radioactive decay and low absorption/fixation by organic matter), specific activity has dropped substantially due to the increase in CO_2 of fossil origin. In fact, the specific activity of this CO_2 is at cosmogenic levels, and dilutes the residual carbon-14 from nuclear testing. The current specific activity of 227 Bq/kg of C is close to cosmogenic levels. If specific activity differs by more than 3 Bq/kg of C, a local anthropic impact can be assumed: effluents discharged from a nuclear facility if the specific activity measured exceeds this value, industrial discharges from fossil CO_2 generation if the specific activity measured is less than this value. On this basis, specific activity can be used to detect very low local impacts which cannot be detected by measuring activity by mass (Bq/kg fresh).

The specific activity of carbon-14 in rivers and lakes is systematically less than that recorded for the other environmental components as the radionuclides are diluted by former carbonates to varying degrees. These carbonates are not affected by fallout from nuclear testing in the environment. The specific activity of carbon-14 in rivers currently varies between 200 and 220 Bq/kg of C depending on carbonate levels.

In the same way as carbon-14, residual tritium fallout from nuclear weapons testing is present in the atmosphere. Carbon-14 is also transferred to organic matter *via* plant photosynthesis, with an activity in Bq/L of water (see focus article in chapter 1) at equilibrium (with the same activity) with atmospheric water vapour. The activity of rivers also depends on the atmosphere, particularly due to precipitation. Rainwater activity can therefore be considered as a proxy for variation in background tritium in the atmosphere/terrestrial environment/continental aquatic environment. Figure 17 hows how tritium activity in rainwater in the northern hemisphere suddenly increased from 1950 from cosmogenic levels (0.1 to 0.6 Bq/L; see chapter 2.1) and peaked at approximately 600 Bq/L in 1963 at the high point for atmospheric fallout from nuclear weapons testing. This activity has since decreased, as the tritium is diluted in the oceans, a large hydrogen reservoir. In fact, thanks to the shear size of this reservoir, fallout from nuclear tests has had little impact on the tritium activity of sea water, which has remained at cosmogenic levels.

FIGURE 15 / **CAESIUM-137, STRONTIUM-90 AND PLUTONIUM-239+240 DEPOSITS AFTER THE ATMOSPHERIC NUCLEAR TESTING**

Deposition peaked after the fallout from the atmospheric testing of nuclear weapons (1945-1980) in Bq/m² during rain, therefore ground activity measurements reflect mean annual precipitation.

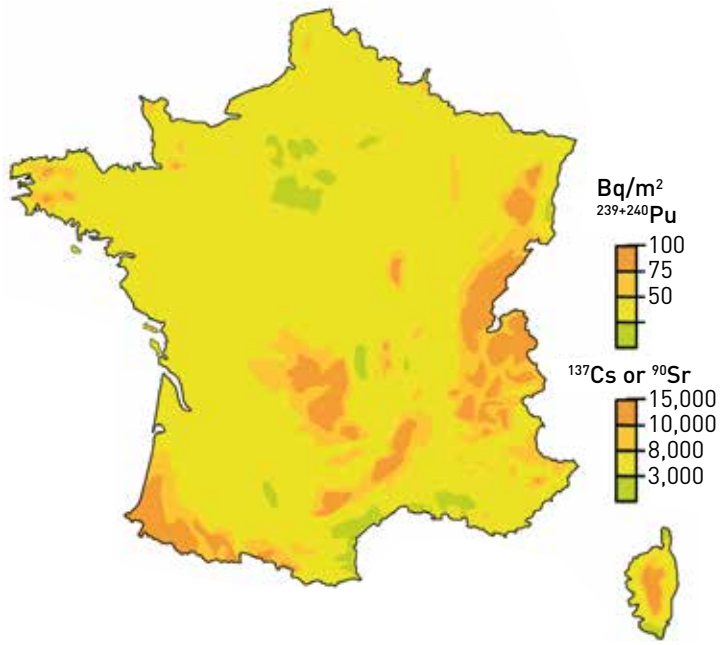


FIGURE 16 / **VARIATION IN THE SPECIFIC ACTIVITY OF CARBON-14 IN THE NORTHERN HEMISPHERE SINCE 1950 (Bq/kg of carbon)**

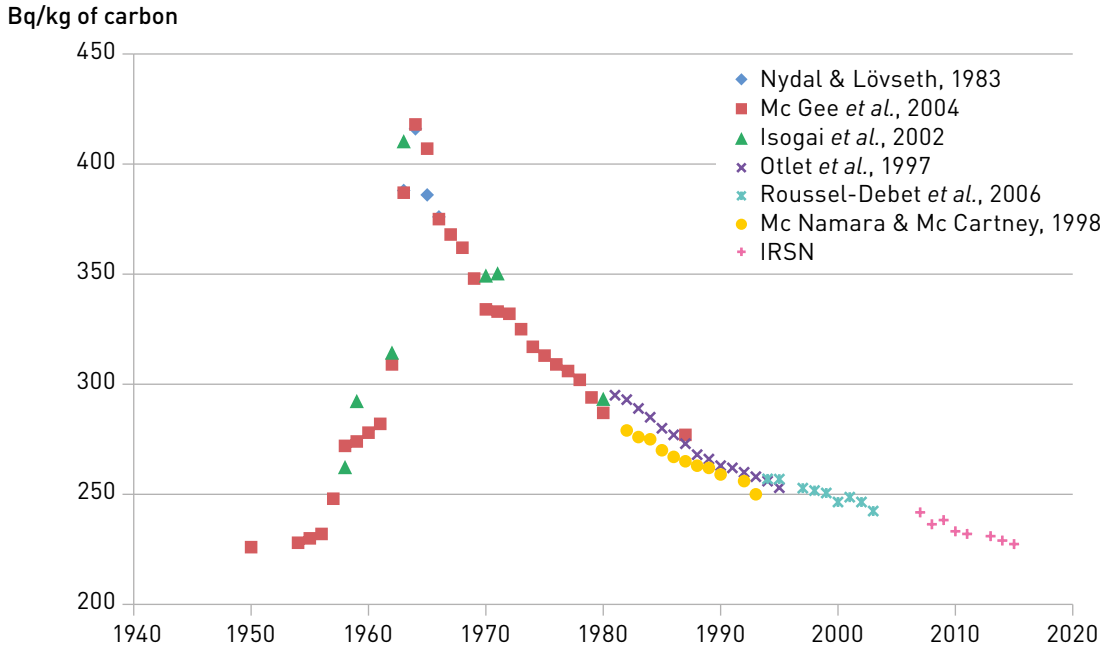
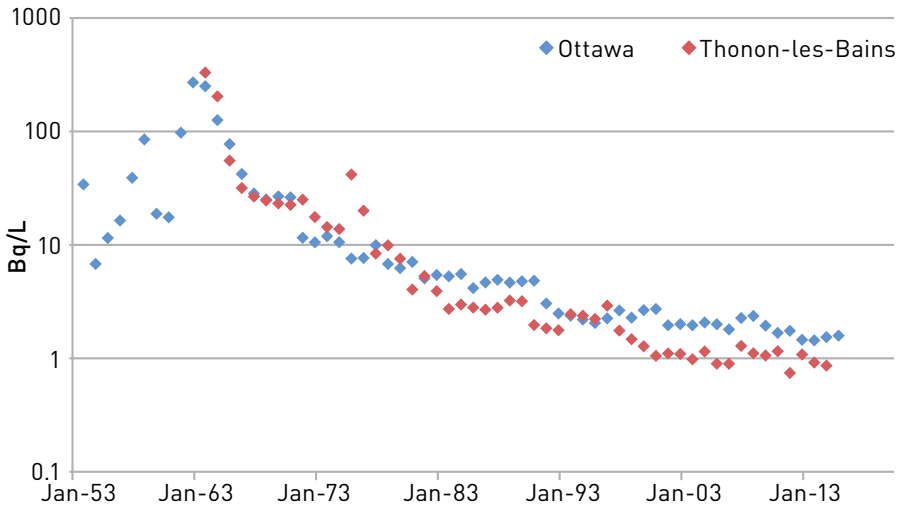


FIGURE 17 / **VARIATION IN TRITIUM ACTIVITY IN RAINWATER (Bq/L; source: IAEA)**

Matching data from Canada (Ottawa) and France (Thonon-les-Bains) demonstrate how homogeneous levels of atmospheric tritium from residual fallout after nuclear weapons testing are throughout the northern hemisphere.



Fallout from the Chernobyl accident

The air masses contaminated by the Chernobyl accident reached France early May 1986, mainly between 1 and 5 May 1986. Due to highly variable rain levels in east France during this period, radioactive deposits (particularly iodine-131 and caesium 134 and 137) were higher in this area compared with the rest of France, and varied substantially (see figure 18). Food contamination peaked immediately after fallout deposition and affected vegetables, mainly leaf vegetables and milk (see figure 13) as well as sheep and cattle at a later stage. Iodine-131 activity disappeared after 3 months due to radioactive decay and caesium activity was divided by 100 to 1,000 over the same period. As the accident occurred early in the growing season for most crops, cereal and fruit harvests were relatively unaffected. During 1986, the effective doses reaching adults in east France represented 0.75 mSv on average (May-December 1986). These doses later gradually decreased year by year (see figure 19). These effective doses were re-assessed in 2015 using measurements acquired in 2013-2014 as part of the radiological overview of residual artificial radioactivity (see p. 69 and the focus article on p. 70). Mean equivalent doses reaching the thyroids of children living in east France between May and July 1986 represented approximately 10 mSv. Most of these doses were received by eating contaminated food, particularly fresh vegetables and milk, during the first three months after the radioactive fallout.

Note: in east France, caesium-137 is mainly attributable to fallout from the Chernobyl accident, while in the western 2/3, a large percentage, potentially even most, of this radionuclide comes from atmospheric fallout from nuclear weapons testing.

Fallout from the Fukushima accident

Radionuclide levels in atmospheric fallout in mainland France from the Fukushima accident of 11 March 2011 in Japan, were very low and rapidly dispersed: traces of iodine-131, caesium 134 and 137 were detected from late-March to May 2011 in the air, rainwater and a few foodstuffs (leaf vegetables, milk, etc.) with activities 500 to over 1,000 times less than those measured in France early-May 1986 after the Chernobyl accident. These depositions were undetectable from mid-2011 (see IRSN report DEI 2011-01 "Analyse de l'impact de l'accident de Fukushima en France à partir des résultats de la surveillance renforcée de la radioactivité de l'environnement" (*Analysis of the impact of the Fukushima accident in France based on the results of the reinforced monitoring of environmental radioactivity* available from the IRSN website in French).

FIGURE 18 / **MAP OF CURRENT SURFACE CAESIUM-37 ACTIVITY IN SOILS IN FRANCE (Bq/m²) DUE TO RESIDUAL FALLOUT FROM NUCLEAR WEAPONS TESTING (see figure 14) AND THE CHERNOBYL ACCIDENT**

While most caesium-137 in the western 2/3 of France is substantially and mainly the product of nuclear testing, in east France, where it rained early May 1986, a very high percentage of caesium can be considered as fallout from the Chernobyl accident.

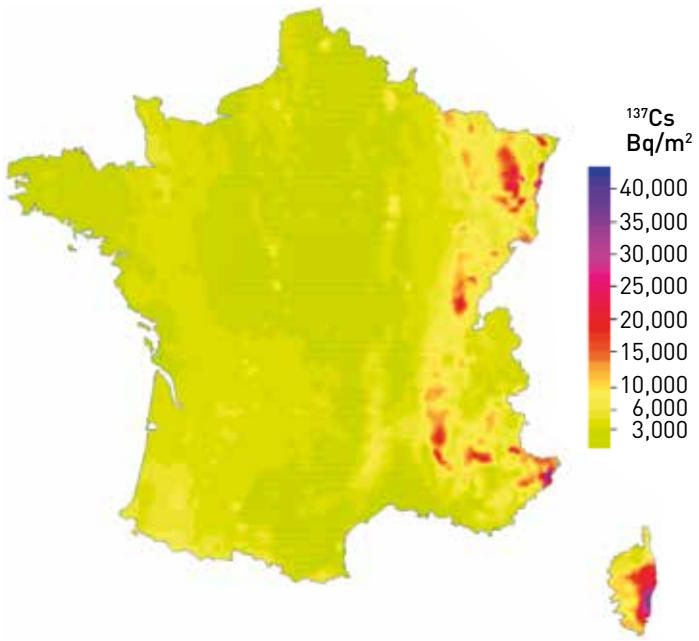
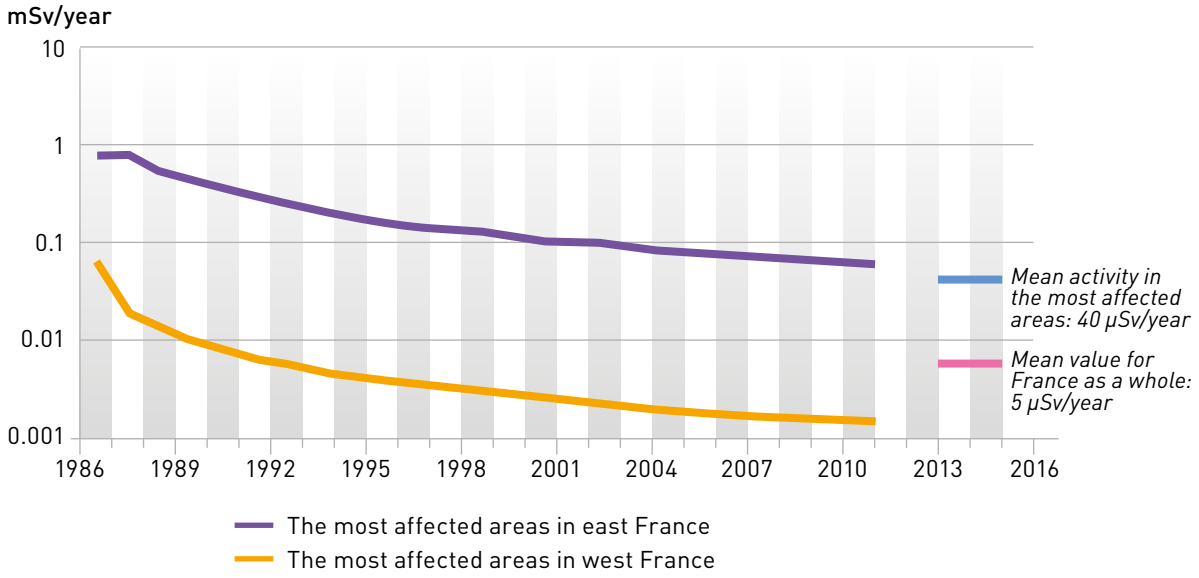


FIGURE 19 / **VARIATION IN THE TOTAL ANNUAL EFFECTIVE DOSE FOR ALL RADIONUCLIDES AND ALL MEANS OF TRANSMISSION IN FRANCE PER ADULT (mSv/year) ATTRIBUTABLE TO FALLOUT FROM THE CHERNOBYL ACCIDENT**



2.3. RANGE OF POPULATION EXPOSURE LEVELS DUE TO BACKGROUND RADIATION IN FRANCE

Most of the information provided below, on the effective doses received by people in France due to natural sources of radiation or residual old fallout, was obtained from IRSN report 2015-00004 "Exposition de la population française aux rayonnements ionisants" (*Exposure to ionising radiation for people in France*) available from the IRSN website in French.

Effective external doses due to cosmic and telluric radiation

If we consider the map of cosmic radiation in France (see figure 1, chapter 2.1), and that people spend most of their time indoors (22 h/day on average and 16 h/day for people who work outdoors), and that buildings reduce cosmic radiation by 20%, the mean effective dose reaching an adult due to cosmic radiation is estimated at 0.31 mSv/year. This figure is less than 0.36 mSv/year for 95% of individuals, but can reach 1.68 mSv/year for high-altitude areas. On this basis, exposure to cosmic radiation varies little for most people, with the exception of high-altitude areas and exposure during air travel. In fact, exposure levels are higher for people travelling by air. As most individuals do not travel frequently by air, this additional exposure is only 0.01 mSv/year on average for the entire French population, however, it reaches 0.55 mSv/year on average for frequent travellers, i.e. people flying between ten and thirty times annually (approx. 11% of passengers or 3% of the French population). Flight crews face the highest levels of ionising radiation, on average, with a mean effective dose per person of 1.9 mSv/year in 2013 (see IRSN/PRP-HOM report 2014-007 "Exposition professionnelle aux rayonnements ionisants en France : bilan 2013" - *Professional exposure to ionising radiation in France: 2013 overview*).

Levels of exposure to telluric radiation depends on the sub-surface and materials used. Construction materials are considered to add an extra 40% to the outdoor dose rate, for people indoors, to give worst-case figures. The measurement data used are obtained from control dosimeters installed in 17,404 dentist and veterinary clinics spread throughout France (see chapter 2.1). If cosmic radiation is deducted from these results, the mean effective dose for telluric radiation reaching an adult is equal to 0.62 mSv/year. Most people (90% of the population) are subjected to a dose of between 0.36 and 1.1 mSv/year. This dose can reach 2 mSv/year in some municipalities.

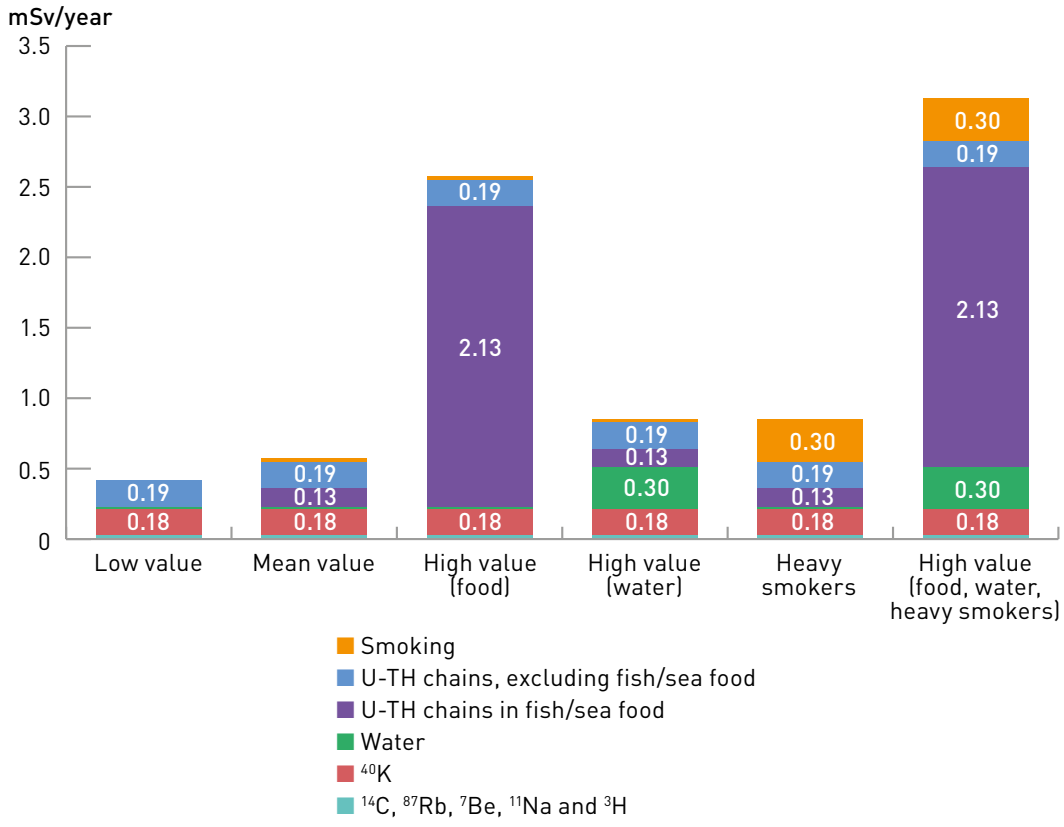
Effective doses received by ingesting natural radionuclides *via* food or smoking

The average effective dose of natural radionuclides (cosmogenic and telluric) absorbed by an adult due to eating food and smoking is estimated at 0.55 mSv/year. This dose varies due to individual consumer habits rather than geographic location, particularly for fish/seafood, ranging from 0.4 mSv/year for individuals who do not eat these foodstuffs to over 3.1 mSv/year for those consuming large amounts (see figure 20). Although potassium-40 is a significant percentage (30%) of this dose, this figure is fairly constant for all individuals and does not depend on food preferences, as the human body can regulate its potassium levels. Furthermore, the contribution of cosmogenic radionuclides is low (0.02 mSv/year, or less than 4%). The mean effective dose for the daughter products of the uranium and thorium decay chains in foodstuffs represents 0.32 mSv/year, which is around 60% of the total dose received by ingesting food. This figure varies substantially as it depends on the level of consumption of fish, and above all molluscs and shellfish, which contain high ^{210}Po levels. When compared with an individual who never eats molluscs or shellfish, regular consumption (once or twice weekly) will lead to an additional effective dose of 0.54 mSv/year, doubling the mean total dose attributable to eating food. In the same way, a heavy smoker can absorb an additional effective dose of approximately 0.3 mSv/year when compared with a no smoker, mainly due to the ^{210}Po level in tobacco.

Finally, drinks (tap and mineral water) contain a wide range of radionuclide levels. The dose reaching any individual will depend on their tap or selected mineral water. No national mean value can be provided. On this basis, the dose absorbed by adults drinking water will only exceed 100 µSv/year for less than 0.2% of the population, for those drinking tap water, or may be higher for people drinking one of the 4% of mineral water types with higher doses on a regular basis (2 L/day, or 730 L/year). The equivalent dose received by drinking water is probably between a few µSv/year and 100 µSv/year for the vast majority of adults.

FIGURE 20 / **SUMMARY OF DOSES (in mSv/year) ATTRIBUTABLE TO ADULTS INCORPORATING NATURAL RADIONUCLIDES**

The lower value is true for a non-smoker, who does not drink water with a high level of natural radionuclides and does not eat molluscs or shellfish; the high "food" value is true for someone who eats large quantities of sea food; the high "water" value is true for someone who drinks water with high levels of natural radionuclides.



Effective dose received by inhaling radon

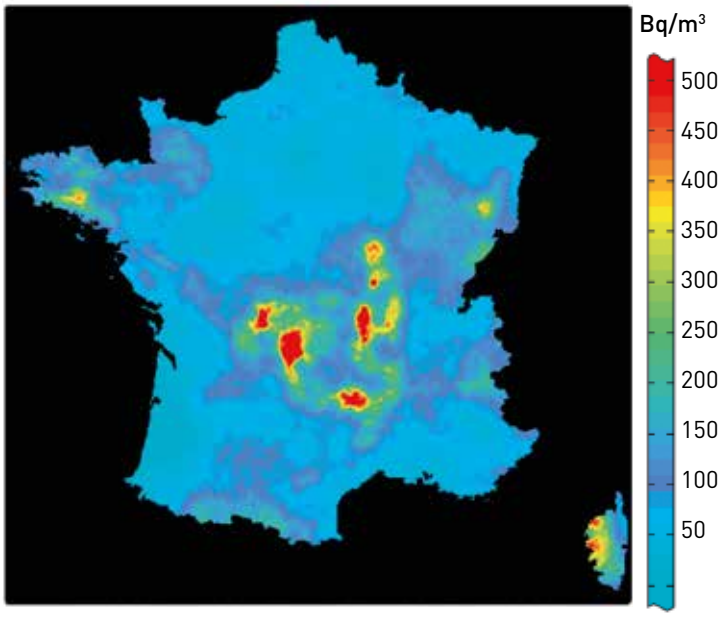
Radon daughters will fix to aerosols in the air and, when inhaled, will settle in and irradiate the respiratory tracts. Radon can accumulate in confined spaces such as buildings, however this phenomenon will vary depending on the location and type of soils and underlying rocks, the type of building, the construction method used for the building and the behaviour of building occupants.

The mean radon-222 concentration inside homes in mainland France, weighted by type of group and home, is equal to 60 Bq/m^3. The corresponding average dose is estimated at 1.43 mSv/year. The map showing potential radon activity by volume inside housing (see figure 11) highlights the significant variation between most of France, where activity is less than 150 Bq/m^3, and a few areas in the Massif central, Vosges, Armorican massif and west Corsica, where activities are over 400 Bq/m^3. On this basis, while 90% of the French population absorbs an effective dose of radon between 0.54 and 3.15 mSv/year, the mean dose in départements such as Lozère or Cantal reaches 5 - 6 mSv/year. Higher values can be reached in specific locations (20 mSv/year). It is also important to realise that, if houses are built on top of old mining remains, radon levels in the air can reach several thousand Bq/m^3 with the corresponding higher dose rates.

The radon dose conversion factor (used to determine the dose-to-activity ratio for radon inhaled) must be increased in the near future based on recent epidemiological studies and new dosimetric calculations, as recommended by the International Commission on Radiological Protection (ICRP). At the time of writing, this recommendation had not yet been incorporated into French regulations. The above radon doses could be doubled based on this recommendation.

FIGURE 21 / **POTENTIAL RADON ACTIVITY PER VOLUME INSIDE HOUSING BASED ON THE UNDERLYING ROCK TYPES (Bq/m^3)**

The highest concentrations exceed 400 Bq/m^3 and are recorded in the older massifs (Armorican, Central, Vosges and north-western Corsica), while the lowest values are recorded in sedimentary basins (Paris and Aquitaine), dropping below 100 Bq/m^3.



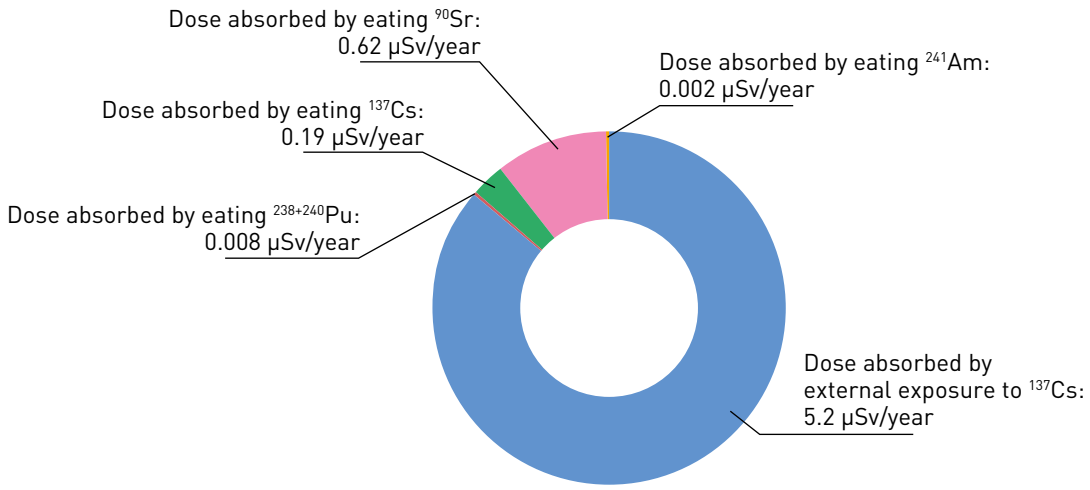
Effective doses due to residual radioactivity from old fallout comprising artificial radionuclides

Current exposure levels for people in France due to residual fallout from nuclear weapons testing and the Chernobyl accident were recently re-assessed on the basis of the measurement results obtained during the radiological overview completed by IRSN in 2013-2014 (see focus article on p. 70).

This dose is currently approximately 6 µSv/year for most adults. This dose is mainly (87%) attributable to exposure to the extreme radiation emitted by ^{137}Cs in soils (see figure 22). Only 13% of this dose is absorbed by eating food. Residual strontium-90 (^{90}Sr) from nuclear weapons testing is the main component of the dose absorbed by eating, ahead of caesium-137 from both sources and well ahead of plutonium and americium.

As explained in the focus article, the doses potentially received by people living in the French regions most affected by this fallout can be much higher, particularly for fans of mushrooms and game (see focus article on p. 72).

FIGURE 22 / **ESTIMATED EFFECTIVE DOSES ATTRIBUTABLE TO RESIDUAL FALLOUT FROM NUCLEAR TESTS AND THE CHERNOBYL ACCIDENT ABSORBED BY MOST FRENCH ADULTS (these data are valid for people who do not live in the areas most affected by the fallout)**



FOCUS ARTICLE

A RADIOLOGICAL OVERVIEW OF RESIDUAL ARTIFICIAL RADIOACTIVITY

This overview aims to update reports on artificial radionuclides still detected in the areas most affected by deposits from the atmospheric testing of nuclear weapons (between 1950 and 1980) and the Chernobyl accident (1986) and to assess the exposure of local inhabitants.

Research strategy

This study mainly focuses on mountain areas in east France, which were significantly affected by fallout from the Chernobyl accident (Vosges, Jura, South Alps and Corsica), and the Pyrenees, where radionuclide deposits from the atmospheric testing of nucear weapons are decisive.

Caesium-137 (^{137}Cs) released during Chernobyl fallout and atmospheric tests is omnipresent in the environment. Levels vary depending on the location, but quantities can generally be measured, meaning that this radionuclide can be used as the main indicator of levels of artificial radioactivity in the samples tested. Strontium-90 (^{90}Sr), and plutonium ($^{239+240}$Pu) and americium-241 (^{241}Am) isotopes were released as fallout from atmospheric tests.

Various samples (soils, grass, milk, cheese, berries, mushrooms and game) were taken in 2013 and 2014 from the area covered by the study. Caesium-137, strontium-90 and plutonium isotopes were measured in the samples. Samples of surface water, sediments, aquatic mosses and fish were taken from the aquatic environment: six Mercantour lakes and three coastal rivers in east Corsica (Fium Orbo, Tavignano and Golo). Measurements had been taken for these sites in the weeks immediately following the Chernobyl accident.

Main study results

According to the aquatic measurements, artificial radioactivity levels have not varied substantially since 1986 in the Mercantour lakes, with the exception of the mosses, where caesium-137 activity is decreasing thanks to an effective half-life of approximately 6 years. Artificial radionuclides are clearly persisting in these "contained" environments in water (^{137}Cs: 0.2 - 1.7 mBq/L), aquatic mosses (^{241}Am: 2.5 - 5 Bq/kg dry) and sediments (^{137}Cs and ^{241}Am exceed 1,000 and 1 Bq/kg dry, respectively). If we compare these values with an "open" environment, such as the rivers draining east Corsica, caesium-137 activity in fish and sediments (0.05-0.09 Bq/kg fresh and 4-14 Bq/kg dry, respectively) has dropped significantly since the initial measurements taken in 1986-1987 (1-100 Bq/kg fresh and 10-700 Bq/kg dry, respectively). The effective half-life of caesium-137 in the sediments of the Var river and its tributaries is similar to that recorded in other rivers in France, with no local anthropic impacts.

Three key points appear if we summarise the activities of artificial radionuclides in a terrestrial environment:

- caesium-137 activity is highest in the soils in massifs in east France (Vosges, Jura, South Alps and Corsica), reaching over 10,000 Bq/m^2 at some sampling points. These observations match the levels expected in these areas, where Chernobyl fallout combined with the activity from nuclear testing. Caesium-137 activity is lower in soils in the Pyrenees (^{137}Cs activity exceeds 3,000 Bq/m^2), and mainly the outcome of nuclear testing. These results corroborate the levels calculated from deposition models (see map in figure 18). Plutonium ($^{239+240}$Pu activity from nuclear weapons tests) activity in soils in hilly areas (100-200 Bq/m^2) matches the map shown in figure 15, i.e. two to four times higher than soils in low-lying flat areas (50-80 Bq/m^2). Thirty years after the Chernobyl accident, very high caesium-137 activity (over 10,000 Bq/kg at some specific locations) is still detected at the high-altitude flat "hot spots" in the Alps, which vary from surface areas of a few dm^2 to a few m^2. At these locations, caesium-137 concentrated in the snowbanks formed by the snow which precipitated as the air masses carrying fallout from the Chernobyl explosion travelled over the Alps (in May 1986);
- data also highlight vertical migration in soils and the transfer of fission products (^{137}Cs and ^{90}Sr) to plants in fields and forests. As expected, as strontium-90 transfers more easily than caesium-137, strontium-90 has achieved greater depths in soils and transferred more substantially to plants in low-lying flat areas. Details of migration and transfers depend on the physical and chemical properties of soils (particle size, pH, organic content and exchangeable cations) and anthropic factors such as land use and crops grown;
- food activity in the hilly areas studied is generally higher than in low-lying flat areas. To give one example, caesium-137 activity in the milk samples taken in residual fallout areas (mean value: 0.32 Bq/L) is ten to a hundred times higher than in milk samples taken in areas near to EDF nuclear power plants (between 0.004 and 0.03 Bq/L). These observations match soil activity measurements, which are one order of magnitude higher in hilly areas, on average, when compared with data for low-lying flat areas.
  One key difference arises between the level of activity measured in food from low-lying flat areas (average value for ^{137}Cs: 0.32 Bq/L in milk) and food from forests (berries, mushrooms and game), where caesium-137 activity varies more widely over approximately two orders of magnitude depending on the species and sampling area) and can exceed 100 Bq/kg fresh (for mushrooms and wild boar meat).

The effective doses absorbed by adults living in the areas most affected by artificial radioactivity were estimated based on caesium-137 activities measured in food and *in situ* measurements of the airborne dose rate (see table A).

TABLE A / **DOSES IN AND OUT OF THE AREAS MOST AFFECTED BY ARTIFICIAL RADIOACTIVITY (in µSv/an)**

	External exposure	Internal exposure (ingestion)
Outside of the most affected areas	5 µSv/year	1 µSv/year
Inside the most affected areas	Up to 40 µSv/year	From a few dozen to a few hundred µSv/year for living organisms eating mushrooms and game

The external dose reached after exposure to caesium-137 (40 µSv/year) fallout was calculated using airborne dose rate measurements (2 - 7 nSv/h)[1]. The highest dose rate values (100 nSv/h) are measured at Mercantour "hot spots" (with a surface area varying between a few dm² and one m², and where caesium-137 activity reaches a few tens of thousands of Bq/kg). If one individual remained in contact with these soils for several hours (bivouac camping or afternoon nap, lying down), the effective external dose would reach a few tens of µSv/h. Eating food from areas with a high level of residual artificial radioactivity would lead to the ingestion of 1 µSv/year. However, eating food from forest areas (mushroom and game), with a caesium-137 activity of several hundred Bq/kg fresh, could lead to a dose representing a few tens to a few hundreds of µSv/year, depending on the quantities eaten.

For more info.: http://www.irsn.fr/FR/expertise/rapports_expertise/surveillance-environnement/Documents/IRSN_Constat-Remanence-France_201604.pdf

1. Subjects are assumed to spend 8 hours a day outdoors and to benefit from a protection factor of 0.4 when indoors.

Report on effective doses received due to background radiation in France

The mean exposure of people in France to background radiation, as defined above, and excluding medical exposure, is estimated at 2.9 mSv/year. This dose varies based on the geographic location (radon accumulated in the air, telluric radiation) and lifestyle (shellfish eaten, smoking, air travel).

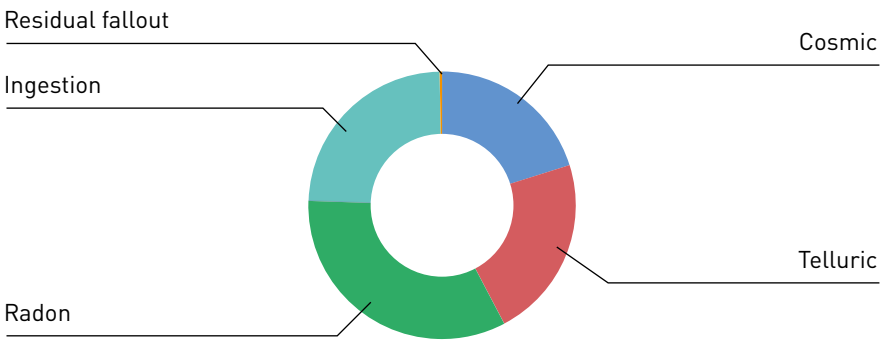
Figure 23 shows doses for two very different scenarios: the first covers an individual with the lowest exposure levels in France, and the second an individual with high levels of exposure due to their home address and lifestyle (high radon exposure, ingestion of natural radionuclides, air travel, smoking).

As mentioned previously (see the paragraph on radon exposure), it is important to consider that the radon contribution could shortly double due to the ICRP's recommendation on how to assess the impact of this radionuclide. In this case, radon exposure would become clearly decisive for the French population. Exposure incurred due to medical operations must also be added to this background radiation (see IRSN report 2015-00004 "Exposure of French citizens to ionising radiation").

FIGURE 23 / **EFFECTIVE DOSES ATTRIBUTABLE TO NATURAL RADIATION FOR 2 DIFFERENT EXPOSURE SCENARIOS (mSv/year)**
Taken from IRSN report 2015-00004 "Exposure of French citizens to ionising radiation"

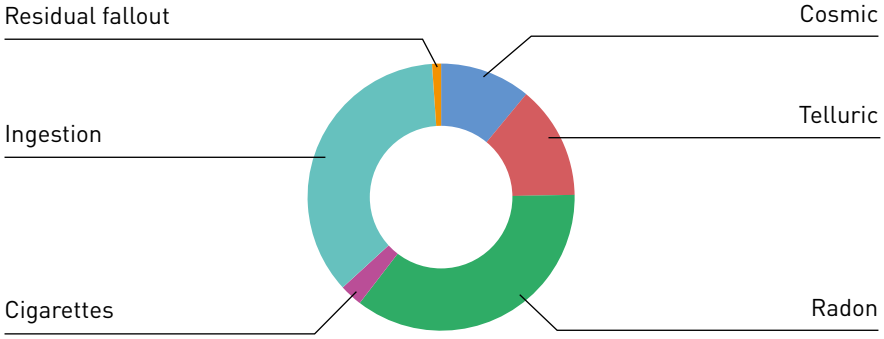
SCENARIO 1 : 1.6 mSv/year

Data for a non-smoking adult living in an area with low radon levels and a low level of telluric radiation, little affected by residual fallout, eating food with low levels of natural radionuclides.

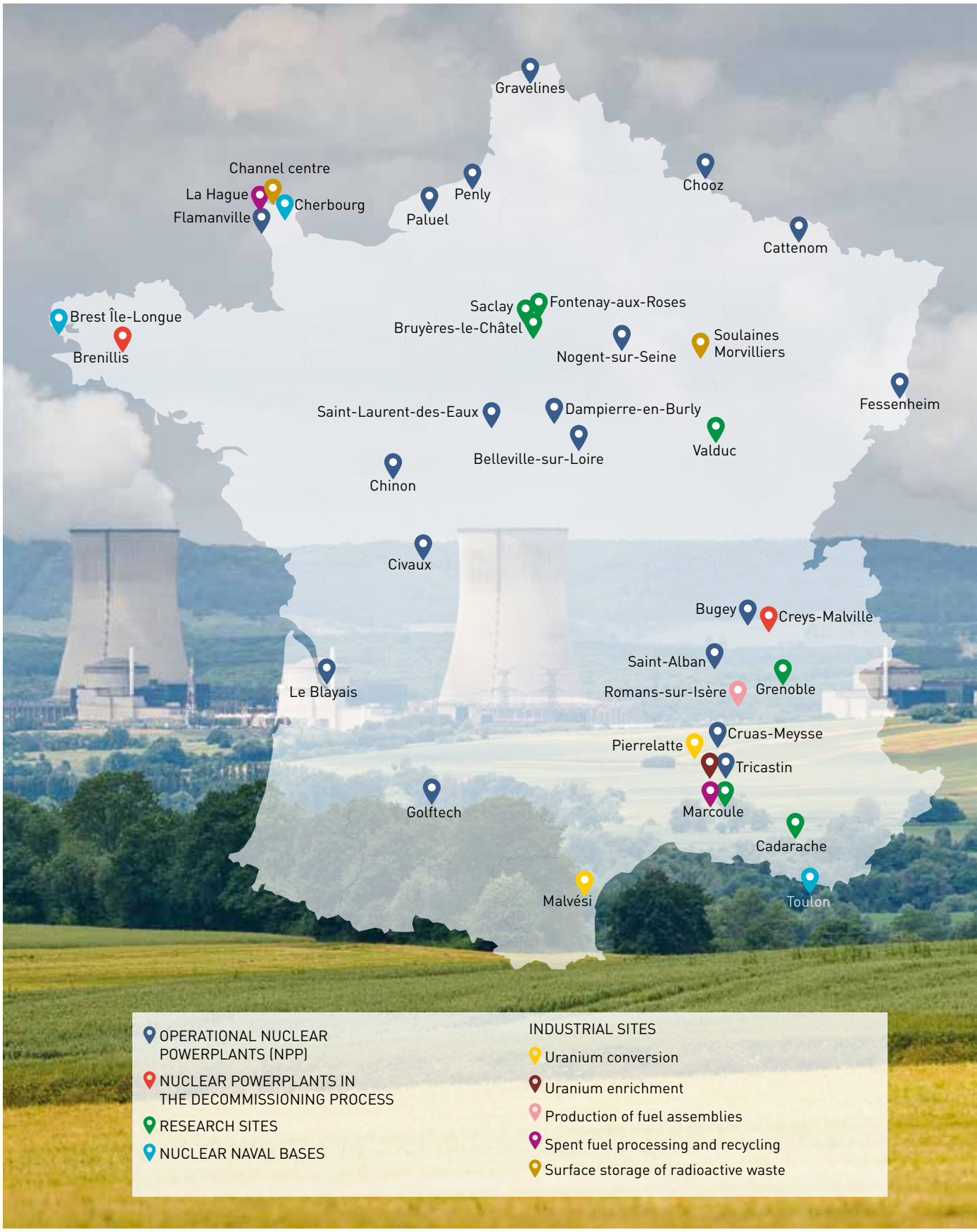


SCENARIO 2 : 8.6 mSv/year

Data for an adult who smokes and travels by air frequently, living in an area with high radon levels and a high level of telluric radiation, substantially affected by residual fallout, eating large amounts of food with high levels of natural radionuclides.



Cattenom NPP



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03

DATA FOR THE DIFFERENT NUCLEAR SITES IN FRANCE

03
DATA FOR THE DIFFERENT NUCLEAR SITES IN FRANCE

3.1. OPERATIONAL NUCLEAR POWERPLANTS (NPP)

EDF SA is currently operating 19 nuclear powerplants in France Each NPP includes 2 to 6 reactors, representing a total of 58 operational reactors: 34 reactors with a unit power of 900 MWe, 20 reactors at 1,300 MWe and 4 reactors at 1,450 MWe.

FIGURE 1 / **LOCATION OF OPERATIONAL EDF NUCLEAR POWERPLANTS, THOSE IN THE DECOMMISSIONING OR CONSTRUCTION PROCESS, NUMBER AND POWER OF OPERATIONAL REACTORS**

- 900 MWe reactor
- 1,300 MWe reactor
- 1,450 MWe reactor
- 1,600 MWe reactor (construction in progress)
- Reactors in the decommissioning process (UNGG, PWR, FNR)

Discharged radioactive effluents

Radioactive effluents are produced when operating an NPP. Specific authorisation must be obtained for each powerplant, defining the conditions for discharging these effluents into the environment. These effluents are discharged into the atmosphere, rivers or at sea after radioactivity levels have been checked/monitored. As per regulations, each NPP has obtained specific authorisation defining the volumes of radioactive substances which can be discharged into the air or adjacent rivers or at sea and the applicable conditions, among other provisions.

Discharge conditions must guarantee that public exposure remains below 1 mSv/year in accordance with article R.1333-8 of the French Public Health Code in all normal operating conditions and ranges, including worst-case operating conditions.

However, actual discharges by operators remain below, frequently significantly below, the maximum authorised discharge levels based on optimisation and limitation policies. Tables 1 and 2 show the ranges (minimum and maximum levels) for atmospheric and liquid discharges per site based on the number of reactors at the NPP and their ratings, over the period covered by this radiological report focusing on the environment.

If we consider the levels of activity discharged, ignoring noble gases (xenon, argon and, above all, krypton, which are only found in the air and are not transferred to other environmental components as they are chemically inert), tritium and carbon-14 represent the highest concentrations of radionuclides in the effluents discharged, whether atmospheric or liquid (see tables 1 and 2).

TABLE 1 / **RANGES OF ANNUAL ATMOSPHERIC EFFLUENTS DISCHARGED PER YEAR (min. and max.) (GBq/year) FOR THE PERIOD 2014-2016 DEPENDING ON THE POWER OF THE REACTORS INSTALLED AT EACH SITE**

NPP	Noble gas	^{3}H	^{14}C	Iodines	FP/AP*
Gravelines	3950-6320	2760-3380	830-1130	0.113-0.152	0.013-0.021
Cattenom, Paluel	510-850	1480-3320	640-910	0.034-0.048	0.007-0.011
Bugey, Cruas, Chinon, Dampierre Tricastin, Blayais	430-7250	620-1740	410-680	0.014-0.196	0.002-0.017
Civaux, Chooz	360-1370	620-1880	280-670	0.015-0.146	0.001-0.005
Belleville, Flamanville, Golfech, Nogent, Penly, St-Laurent	350-3260	880-2290	280-670	0.009-0.075	0.001-0.009
Fessenheim, St-Alban	120-4710	630-910	200-350	0.008-0.035	0.001-0.002

* FP/AP: fission products / activation products: cobalt-60, cobalt-58, argent-110m, caesium-137, etc. (see glossary in chapter 8).

TABLE 2 / **RANGES OF ANNUAL LIQUIDS DISCHARGED PER YEAR (min. and max.) (GBq/year) FOR THE PERIOD 2014-2016 DEPENDING ON THE POWER OF THE REACTORS INSTALLED AT EACH SITE**

NPP	^{3}H	^{14}C	Iodines	FP/AP*
Gravelines	59,000-77,500	51.3-67.3	0.03-0.05	2.06-3.02
Cattenom, Paluel	52,800-122,000	30.0-68.2	0.01-0.02	0.64-2.10
Bugey, Cruas, Chinon, Dampierre Tricastin, Blayais	28,500-56,800	17.3-62.7	0.01-0.04	0.33-2.90
Civaux, Chooz	36,600-69,800	35.0-44.9	0.005-0.01	0.21-1.08
Belleville, Flamanville, Golfech, Nogent, Penly, St-Laurent	38,800-72,500	15.2-44.4	0.004-0.02	0.17-0.70
Fessenheim, St-Alban	16,900-30,100	9.0-22.8	0.004-0.01	0.33-0.61

* FP/AP: fission products / activation products: cobalt-60, cobalt-58, argent-110m, caesium-137, etc. (see glossary in chapter 8).

Monitoring plans for the immediate environment of an NPP

EDF monitors discharges at source (before, during and after discharge into the receiving environment) and radioactivity in the immediate environment of the sites for all operational NPP. Only environmental monitoring provisions are described in this document. EDF produces approximately 50,000 measuring results for all NPP each year.

In general, regulatory requirements relating to environmental monitoring are defined in ASN (French nuclear safety authority) decision no. 2013-DC-0360 dated 16 July 2013 on controlling disturbances and the effects of basic nuclear facilities on health and the environment, amended by ASN decision no. 2016-DC-0569 dated 29 September 2016, and by ASN decision no. 2017-DC-0588 dated 6 April 2017, on water consumption and sampling provisions, effluent discharges and environmental monitoring for pressurised water reactors at nuclear powerplants. On this basis, these requirements are listed in the specific decisions for each NPP.

TABLE 3-A / **EXAMPLE OF A STANDARD MONITORING PLAN DRAFTED BY EDF (regulatory monitoring) AND BY IRSN**

Environment monitored or type of testing	EDF	IRSN
Soil air	• 4 daily measuring and sampling points for gross β activity with a filter • γ spectrometry if values > 2 mBq/m³ and total for monthly filters • 1 weekly tritium (^{3}H) measurement under the prevailing winds	• 1 continuous aerosol sampling station with a flow of 80 m³/h with weekly γ spectrometry
Ambient γ radiation	• 10 sensors around the edge of the site • 4 sensors at a distance of 1 km and 4 at a distance of 5 km	• Up to 16 Téléray sensors within a radius of 10 to 30 km around the site
Rain	• 1 bimonthly gross β and tritium measurement	• 1 monthly tritium measurement
Terrestrial plants	• 1 grass sampling point and monthly γ spectrometry, HTO and OBT measurements Quarterly ^{14}C and total C measurements • Annual focus on agricultural output including γ spectrometry and ^{14}C, HTO and OBT measurements	• 1 leaf vegetable sampling run for ^{3}H, ^{14}C and γ spectrometry analyses • 1 annual cereal sampling run for ^{14}C and γ spectrometry analyses
Milk	• 2 sampling points for monthly γ spectrometry, HTO, OBT and ^{40}K measurements and annual ^{14}C measurements	• 1 6-monthly milk sampling run for ^{3}H and γ spectrometry analyses
Soils	• 1 annual sampling run for γ spectrometry analysis	
The receiving environment for liquid effluents discharged	• 1 gross β measurement for suspended solids and 1 ^{3}H measurement mid-discharge for NPPs located on rivers or after dilution in cooling water, or bimonthly seawater measurements for coastal NPPs*	• 1 monthly γ spectrometry measurement on suspended solids (plus annual α, U, Sr, gross α and gross β analyses for each drainage area) • 1 ^{3}H measurement in water mid-discharge for NPPs located on rivers or after dilution in cooling water for coastal NPPs
Aquatic flora	• 2 aquatic plant sampling runs (upstream and downstream of NPPs located on rivers) • 1 annual sampling run for γ spectrometry and ^{3}H (HTO) analyses	
Aquatic fauna	• 2 fish sampling runs (upstream and downstream of NPPs located on rivers) • 1 annual sampling run for γ spectrometry, ^{14}C and ^{3}H (HTO) analyses	• 1 fish sampling run for annual γ spectrometry, ^{14}C and ^{3}H (OBT) analyses
Ground water	• Monthly gross β and ^{3}H analyses and samples	

* These samples and analyses are intended to ensure that discharges meet requirements rather than monitor the environment; this is particularly true for coastal NPPs, where samples are taken in the discharge channel, and not in the actual environment, as is the case for NPPs on rivers.

IRSN also monitors nuclear facilities in general, and EDF NPP in particular, as part of its assignments (see table 3-A, column 2). Approximately 30,000 analysis results are produced on an annual basis in this respect. Most of these results relate to air and water, i.e. the receiving environment for the effluents discharged.

EDF has organised annual monitoring based on radioecological expertise at its NPP for over 25 years now, to complement the above monitoring provisions. This radioecological monitoring is also complemented with ten-year radioecological reports carried out by IRSN and SUBATECH.

Table 3-B shows a typical example of samples and analyses in this context. Thanks to the use of more advanced metrological techniques, to match the targets assigned to expertise-based monitoring, complementing routine monitoring, combined with the appropriate biological indicators, radionuclides (natural and artificial) in aquatic and terrestrial components, such as tritium and carbon-14, can be identified.

Other radionuclides can be characterised on an ad hoc basis, however it is important to take note that the contents of terrestrial food are too low to be measured, even using the most effective available devices, with the exception of residual caesium-137 from fallout from the Chernobyl accident and/or the atmospheric testing of nuclear weapons (see chapter 2).

TABLE 3-B / **EXAMPLE OF A STANDARD SAMPLING AND ANALYSIS PLAN DRAFTED BY IRSN AND SUBATECH AS PART OF ANNUAL RADIOECOLOGICAL MONITORING ON BEHALF OF EDF IN ADDITION TO THE REGULATORY MONITORING DESCRIBED IN TABLE 3-A**

Environment	Matrices	Analyses				
		Spectrometry γ	Tritium		Carbon-14	Iodine 131
			free	bound		
Terrestrial	Mosses and/or lichens	2				2
	Low-lying grasslands	1				
	Goat's or cow's milk	1		1		
	Drinking water supply		1			
Aquatic continental	Sediments	2				
	Mosses and aquatic plants	3	2	2	2	2
Oceans	Algae		3	3	3	3
	Molluscs				2	

The impact of NPP on their immediate environment and associated public exposure

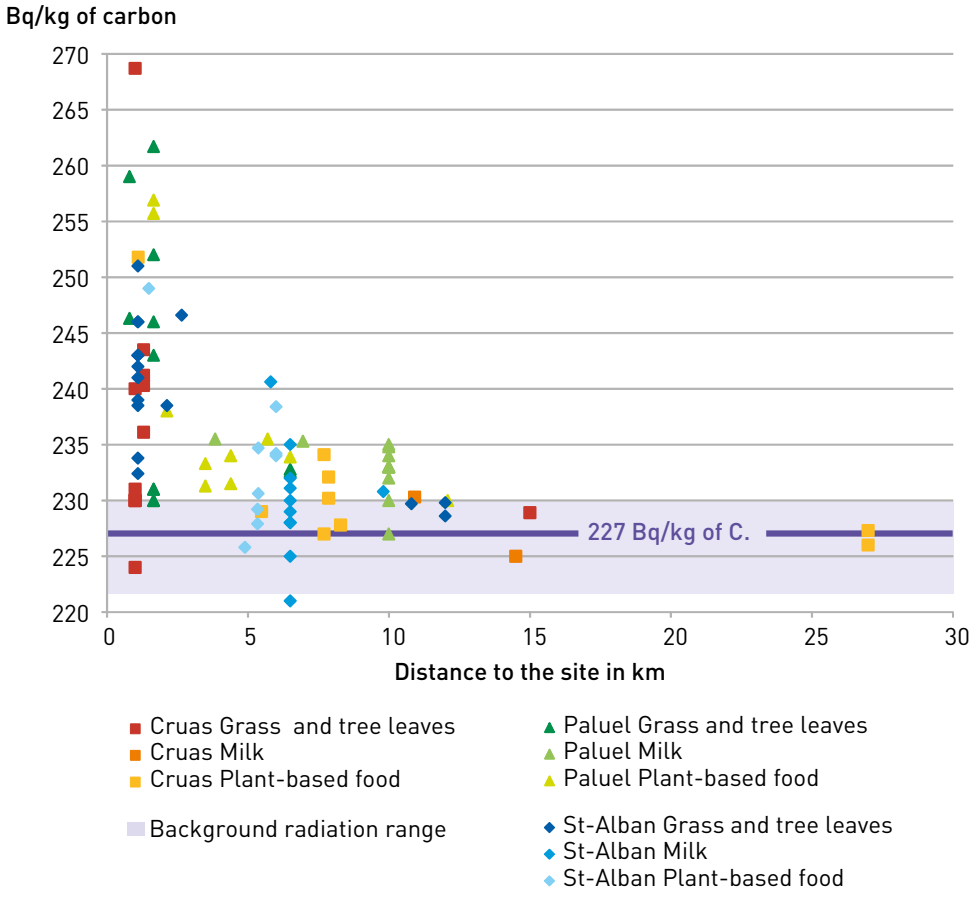
It is easiest to characterise the impact of NPP in the environment for carbon-14 and tritium radionuclides due to their relative high activities discharged and their extent to which they easily transfer in the environment. Despite their low radiotoxicity, these two radionuclides are the main contributors to the potential exposure of residents living near to these facilities.

The impact of effluents discharged into the atmosphere: carbon-14

Levels of carbon-14 in the immediate environment around NPP due to atmospheric discharges are low, however they can be detected thanks to advanced analytical techniques. Carbon-14 content was quantified during a series of measurements taken by IRSN at Cruas from May 2015 to May 2016 (see focus article, pp. 84-85). According to these measurements, ^{14}C activity in the air can reach levels up to twice ambient background radiation for this radionuclide at the south site fence, less than 1 km from the stack on the leeward side. However, including for an individual living at this precise location all year round, the dose inhaled due to this added atmospheric carbon-14 activity is insignificant: approx. 0.001 µSv/year.

As explained in the focus article, only one third of EDF discharges take the form of CO_2 likely to be absorbed by plants during photosynthesis. The ^{14}C activity added from atmospheric discharges from NPP into the terrestrial environment is too low to be quantified by measuring activity by mass. This activity can only be measured using the specific activity of ^{14}C expressed as Bq/kg of carbon.

FIGURE 2 / **VARIATION IN THE SPECIFIC ACTIVITY OF ^{14}C (Bq/kg of carbon) MEASURED IN 2014-2016 IN VARIOUS TERRESTRIAL ENVIRONMENTAL COMPONENTS NEAR TO THE SAINT-ALBAN, CRUAS AND PALUEL NPPS, BASED ON DISTANCE FROM SITE DISCHARGE POINTS**



This indicator is highly sensitive and can be used to identify weak local effects (see chapter 1, focus article p. 32 and chapter 2). This indicator is measured around NPP as part of environmental monitoring by IRSN and as part of the radioecological monitoring of sites by IRSN and SUBATECH at the request of EDF.

Figure 2 shows variation in the specific activity of ^{14}C measured in the various terrestrial components near to the Cruas, Saint-Alban and Paluel NPPs, based on distance from the site. At a distance of between 1 and 2 km, the activity added from discharges reaches a mean value of + 8%, and can occasionally reach + 15 to + 20% of background radiation (BR = 227 Bq/kg of C over the 2014-2016 period; see chapter 2), which matches the airborne results described previously (BR + 36% at a distance of less than 1 km). Activity also varies the most within a short distance from the site: 224 - 268 Bq/kg of C. Specific activity then decreases with distance until it reaches background radiation levels at 10 - 15 km. In general, this decrease is easiest to detect from the measurements taken for all types of plants. Milk analysis results reflect the source of the feed supplied to the animals and their drinking water. However, the activities measured in milk are still consistent with plant analysis results.

The mean specific activity added within a radius of 5 km around an NPP, determined based on 348 measurement results acquired during the 2014-2016 period at 19 EDF sites, is equal to + 11 Bq/kg of C (or BR + 5%). The highest activity levels measured around the Tricastin site were not used to calculate this mean value to avoid bias due to discharges from other facilities, in addition to the NPP. It is also important to take note that this mean specific activity added to the environment is conservative due to the larger amount of data obtained in the immediate vicinity of the sites (< 2 km).

The activity by mass of carbon-14 added to fresh food due to effluents discharged from NPP can be deducted from the total specific activity added to the environment. On this basis, the mean specific activity added represents + 11 Bq/kg of C, which corresponds to a mean activity by mass added of + 0.3 Bq/kg fresh for a lettuce, + 0.7 Bq/kg fresh in fruit or cow's milk, + 2 Bq/kg fresh in beef and up to + 4 Bq/kg fresh in cereals.

The extra activity added within a radius of 10 km, determined using 206 measurement results, will also be lower: +7 Bq/kg of C, or BR +3%.

Local residents are mainly exposed to atmospheric ^{14}C discharges via the potential consumption of food grown locally due to the physical properties of this radionuclide. If we consider the food intake and percentage of food grown locally as per the figures in chapter 8, doses attributable to ^{14}C absorbed by eating food grown within a radius of 5 km around an NPP are estimated at 0.075 µSv/year, compared with 0.05 µSv/year when grown within a radius of 10 km around an NPP. These estimates are similar to the figures calculated by EDF based on discharges from 2016. For information, a figure of 0.026 µSv/year was calculated for Cruas and 0.023 µSv/year for Gravelines. These estimates corroborate the figure of 0.1 µSv/year indicated in the previous Radiological report (2011-2014), which had been established on the basis of a more general approach using measurements taken between 1994 and 2004 and assuming that all food eaten was grown near to the sites.

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Saint-Laurent-des-Eaux NPP

The impact of effluents discharged into the atmosphere: tritium

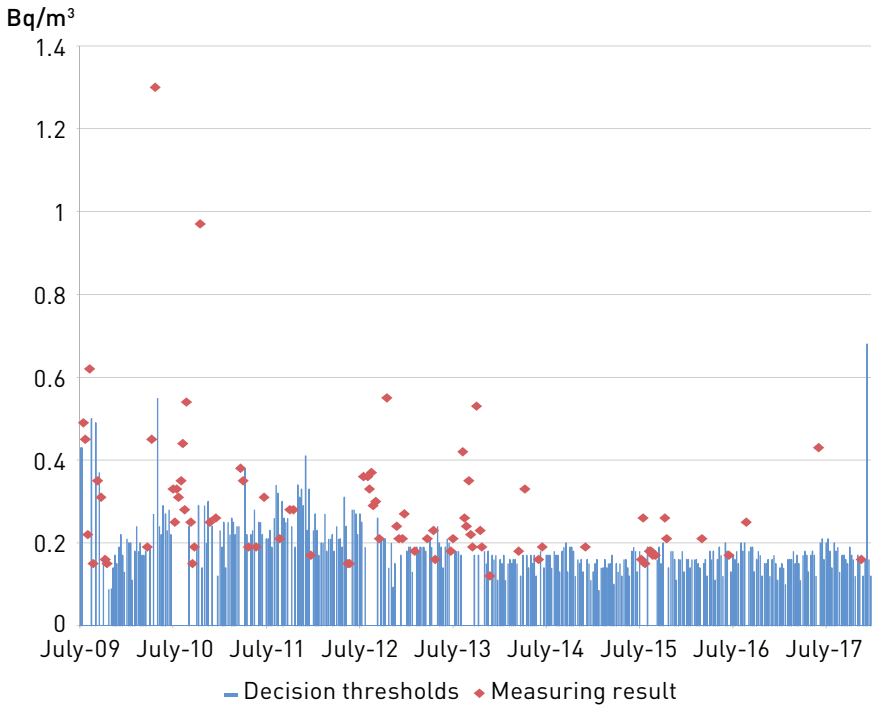
Tritium in atmospheric water vapour (HTO in the air) is analysed on a weekly basis in the immediate vicinity of each of the 19 NPPS as part of regulatory monitoring. For 99% of the 2,694 samples taken over the 2015-2017 period, activity levels are too low to be measured with the test methods used for routine monitoring, however it would appear that activity is less than 0.25 Bq/m^3. This value should be compared with the regulatory limit of 50 Bq/m^3. Over this 2015-2017 period, activity measurements peaked at 0.43 Bq/m^3 during the 1st week of June 2017, near to Tricastin. In general, all of the data acquired since 2011 imply that tritium activity in the air reaches its highest value near to the Tricastin site (figure 3). There are two reasons for this distribution:

- other industries also discharge tritium at the Tricastin nuclear site;
- the site is near to the Marcoule centre, which had some of the highest discharge levels in France until recently.

Tritium content in the air due to an NPP could only be quantified during a series of expertise-based measurements taken by IRSN at the Cruas site between May 2015 and May 2016 (see focus article).

According to the results, activity by volume at a distance of less than 1 km on the leeward side of the discharge point are generally between 0.03 and 0.1 Bq/m^3, with a mean value of 0.07 Bq/m^3. These activity measurements match the values obtained by EDF and are indeed often too low to be quantified during routine monitoring. However, this value, measured in the immediate vicinity of the NPP, is 7 times higher than background radiation for this radionuclide. According to the study carried out at Cruas, the tritium in the water vapour (HTO), measured as part of routine monitoring by EDF, represented 86% of the tritium released. The dosimetric impact and activities of the other forms of tritiated hydrogen (HT) and tritiated methane (CH_3T) in the air were considerably less. Despite this, for an individual living at this precise location all year round, the dose inhaled or absorbed transcutaneously due to this added atmospheric tritium activity represents approximately 0.007 µSv/year.

FIGURE 3 / **TRITIUM ACTIVITY IN ATMOSPHERIC WATER VAPOUR NEAR TO THE TRICASTIN SITE (Bq/m^3) MEASURED AS PART OF REGULATORY MONITORING SINCE 2009**



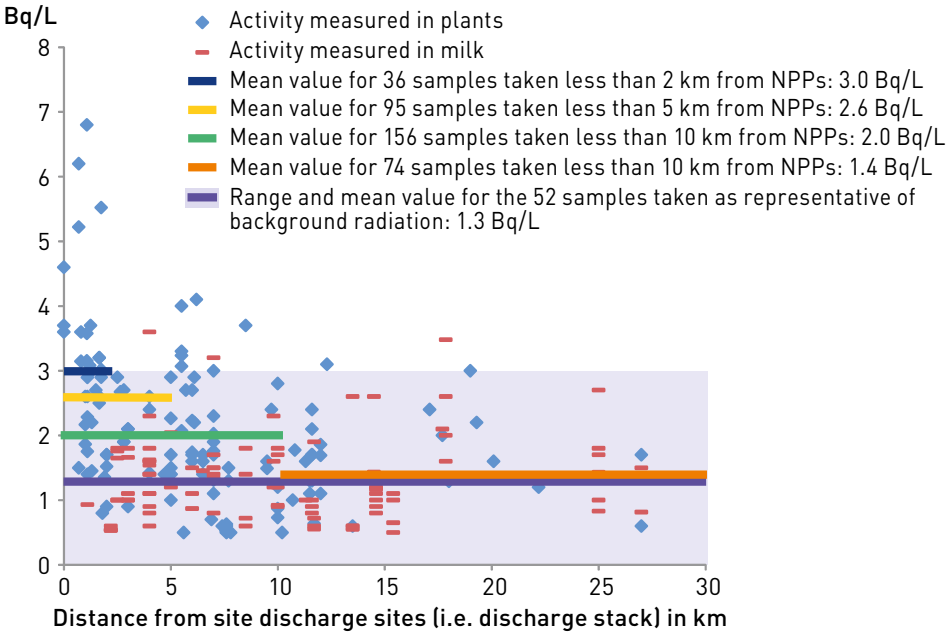
This estimate corroborates the value calculated by EDF on the basis of effluents discharged in 2016, of 0.0024 µSv/year, although the figure is slightly higher as the station is located less than 1 km from the discharge point while EDF's estimate refers to the control group (see chapter) located in the municipality of Savasse 3.5 km from the site.

Tritium in water vapour is transferred to plants during photosynthesis. The activity added to the air, in this form, from NPP discharges, will then lead to a local increase in activity in plants and in the rest of the downstream food chain. This increase can also be detected by measuring organically-bound tritium (OBT) activity in all biological environmental components. This OBT activity is measured in various plant samples, particularly leaf vegetables, and in milk samples taken near to NPPs as part of the radioecological monitoring of sites by IRSN and SUBATECH at the request of EDF.

The mean organically-bound tritium (OBT) activity for the samples taken less than 5 km from the discharge points, determined over the 2014-2016 period using 95 sample results for the immediate environment of the 19 NPP, is equal to 2.6 Bq/L. This value is within the current background radiation range, which fluctuates from less than 1 to 3 Bq/L. However, this value can be differentiated from mean background radiation, estimated as 1.3 Bq/L. As shown in figure 4, beyond a distance of 10 km, tritium activity determined using 74 measurements, drops to the range of background radiation with a mean value of 1.4 Bq/L if effluents are discharged in the vicinity, versus 1.3 Bq/L with no additional discharges. As is the case with ^{14}C, the decrease in activity with distance cannot be identified based on activity measured in milk, which reflects the source of the feed supplied to the animals and their drinking water.

In the same way as carbon-14, local residents are mainly exposed to atmospheric tritium discharges via the potential consumption of food grown locally. If we consider the food intake and percentage of food grown locally as per the figures in appendix 8 to chapter 8, the dose of tritium absorbed by eating food grown within a radius of 5 km around an NPP is estimated at 0.003 µSv/year.

FIGURE 4 / **VARIATION IN TRITIUM ACTIVITY IN ORGANIC MATTER (Bq/L of combustion water) MEASURED IN 2014-2016 IN VARIOUS TERRESTRIAL ENVIRONMENTAL COMPONENTS NEAR TO THE 19 NPPS, BASED ON DISTANCE FROM SITE DISCHARGE POINTS**



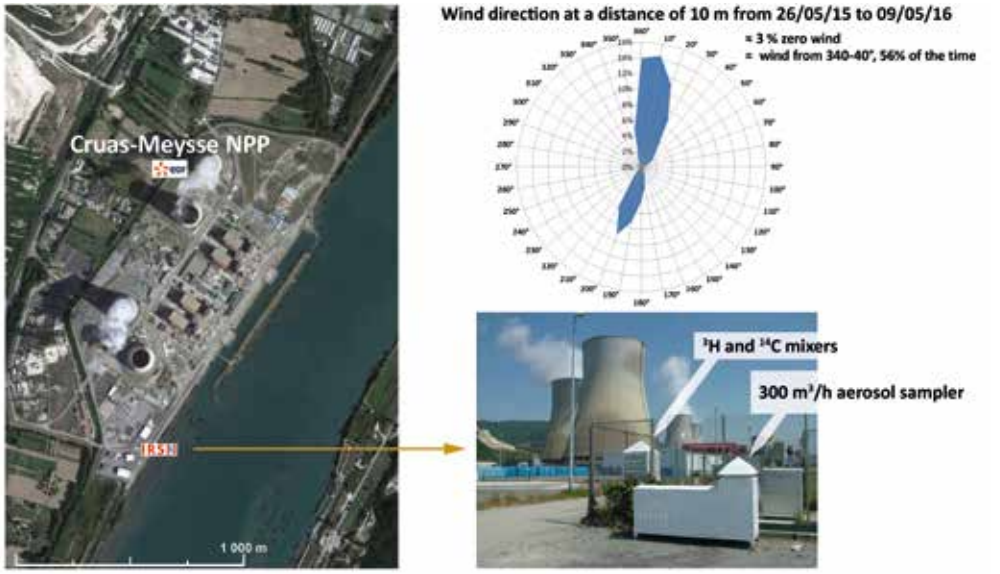
FOCUS ARTICLE

STUDY OF ATMOSPHERIC RADIOACTIVITY LEVELS FOR CARBON-14 AND TRITIUM NEAR TO THE CRUAS-MEYSSE NPP

Although NPP mainly discharge tritium and carbon-14, advanced metrological techniques are required to quantity their activity in the air. These techniques cannot be used for routine monitoring. IRSN installed two sampling devices designed for atmospheric carbon-14 and tritium between May 2015 and May 2016 as part of an atmospheric characterisation programme organised to the south of the Cruas-Meysse site and at the same time as analyses on aerosols (see focus article below).

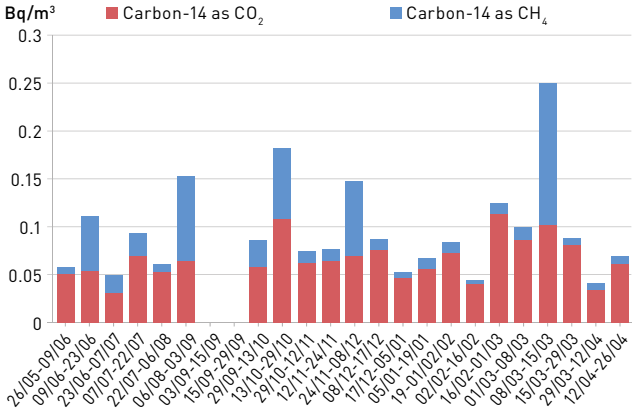
Two bubbler type samplers (SDEC) were used for the purposes of liquid scintillation analyses for tritium (MARC 7000) and carbon-14 (HAG 7000). These bubblers were installed in the immediate vicinity of the site, less than 1 km from the discharge points (as per figure A). Bimonthly samples were taken. By combining these devices with advanced metrological techniques, the different chemical forms of these radionuclides in the ambient air can be studied: mainly CO_2 and CH_4 for carbon-14, HTO (tritiated water vapour) and HT (tritiated hydrogen) for tritium.

FIGURE A / **LOCATION OF THE ^{3}H AND ^{14}C BUBBLERS SOUTH OF THE CRUAS-MEYSSE NPP**



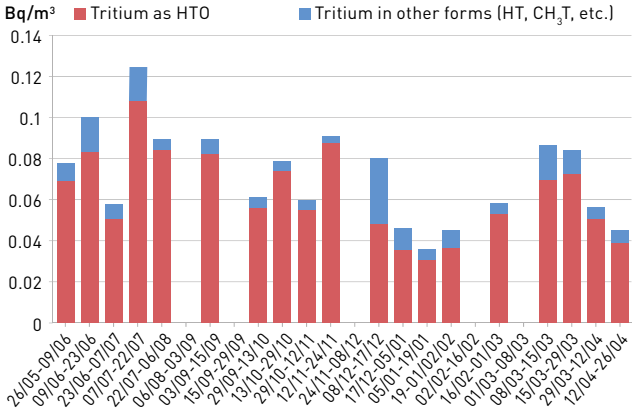
Carbon-14 activities measured during this study represented between 0.042±0.018 Bq/m^3 and 0.25±0.023 Bq/m^3 (figure B) with a mean value of 0.095 Bq/m^3, which is approximately double background radiation levels for this radionuclide (0.047 Bq/m^3 with zero discharges). These results corroborate the total activity measurements by added volume calculated by the operator. The ^{14}C in the samples is mainly found as dioxide ($^{14}C0_2$=67.4% of total atmospheric carbon-14 on average). However, only 27% of this $^{14}C0_2$ is attributable to NPP discharges, the rest is all natural. This percentage of $^{14}C0_2$ added by NPPs can be assimilated by plants during photosynthesis, which explains the low levels detected in plants in the immediate vicinity of EDF NPPs. However, the main radionuclide in site discharges is CH_4 (64% of all carbon-4 discharged), which represents almost all of this form measured in the air as the percentage of $^{14}CH_4$ attributable to ambient background radiation is very low (approx. 0.0002 Bq/m^3 vs. 0.031 Bq/m^3 of $^{14}CH_4$ actually measured).

FIGURE B / $^{14}CO_2$ AND $^{14}CH_4$ ACTIVITY MEASURED IN THE AIR TO THE SOUTH OF THE CRUAS-MEYSSE NPP BETWEEN MAY 2015 AND MAY 2016



Tritium activities measured during this study represented between 0.036±0.004 and 0.124±0.007 Bq/m³ (figure C). Facility discharges multiply background radiation with no additional inputs, which is around 0.01 Bq/m³, by approximately 7. These tritium activity measurements, mainly referring to HTO water vapour (≈ 86%) and attributable to NPP discharges, corroborate the measurements taken in the different terrestrial components.
The other forms of ambient tritium measured (HT and CH_3T) represent very small amounts and fail to or barely contaminate the environment as they are not assimilated during photosynthesis by plants.

FIGURE C / HTO AND HT-CH_3T ACTIVITY MEASURED IN THE AIR TO THE SOUTH OF THE CRUAS-MEYSSE NPP BETWEEN MAY 2015 AND MAY 2016



Precise tritium and carbon-14 levels were measured
in the ambient air in the immediate vicinity of an NPP directly due to atmospheric discharges from the facility. These levels are indeed lower than those measured during routine monitoring and well below the decision thresholds defined in regulations and applicable to the operator. These results also confirmed the dominance of HTO for tritium and CH_4 for carbon-14 in NPP discharges.

The impact of effluents containing other radionuclides discharged into the atmosphere

The activities of the other radionuclides in the effluents discharged represent approximately 10,000 - 100,000 times less than tritium and carbon-14 activities. These radionuclides mainly include the radioactive isotopes of iodine, caesium-134 and 137, cobalt-58 and 60 and silver-110m. The activities of these radionuclides in the air or the terrestrial environment are far too low to be measurable as part of routine monitoring by EDF or IRSN. However, thanks to recent metrological developments, IRSN has been able to perform expertise-based measurements of these radionuclides in atmospheric aerosols (see focus article) near to some NPPs. The results of measurement runs at the Cruas site from May 2015 to May 2016, and data currently being obtained (since May 2017) at the Gravelines NPP, confirm the figures acquired at the Tricastin site in the 2012-2013 period. Activities range from under 0.1 µBq/m^3 to over 1 µBq/m^3 for the four radionuclides measured on a regular basis (^{58}Co, ^{60}Co, ^{110m}Ag and ^{137}Cs). Although the effluents discharged by the other facilities at the Tricastin site only represent about a tenth of the NPP discharges, they contribute to the activities measured and cannot therefore be attributed to the NPP alone. On the other hand, the location of the station set up at Cruas is optimal in terms of the prevailing local weather conditions, implying that the activity levels measured at this site are representative of the highest activities likely to be reached due to effluents discharged from an operational NPP. Despite higher discharge levels from the Gravelines site, activity measurements are lower than at Cruas due to more consistent wind characteristics.

Local populations are exposed to the radionuclides characterised via inhaling, as well as external exposure due to the radiation emitted by some radionuclides in the air. A person living at the precise location of the sampling stations would absorb a dose well below 0.001 µSv/year, almost exclusively by inhaling. External exposure would only represent a few percent. This dose is insignificant and corroborates the figure calculated by EDF based on discharges from 2016.

Once the radioactive aerosols have been released into the air, they fall back to ground level and can be absorbed by plants. However, plant activity levels are too low to be measured, even using the most advanced techniques available. However, activity in food grown locally can be assessed using airborne activity measurements. In this way, if we consider the foodstuffs with the highest sensitivity to atmospheric fallout, such as leaf vegetables (lettuce, spinach, etc.), activities remain below 1 mBq/kg fresh for all of the above radionuclides; these levels are well below the detection limits for the most effective metrological techniques (approx. 3 - 10 mBq/kg fresh for ^{60}Co, ^{58}Co and ^{110m}Ag). Added ^{137}Cs activity cannot be differentiated from residual fallout (see chapter), de facto demonstrating the low impact of NPP on ambient levels for this radionuclide.

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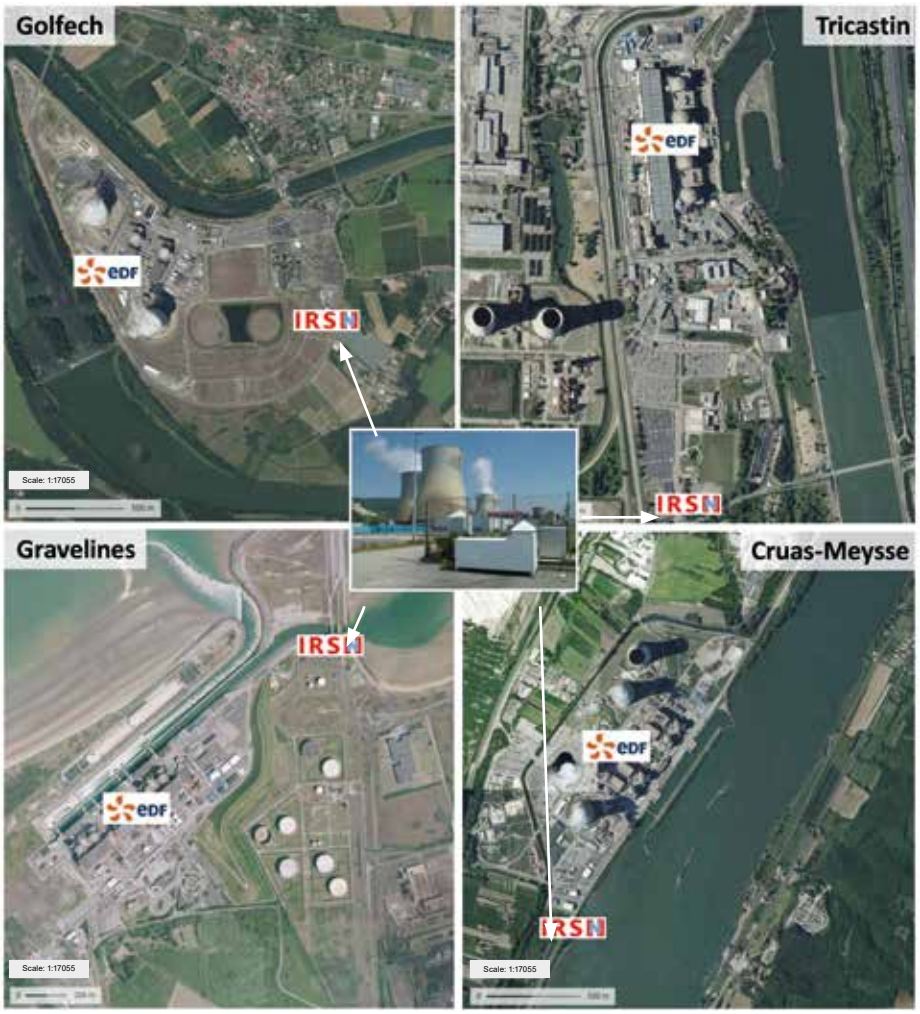
Fishing on the Garonne river downstream from the Golftech NPP

FOCUS ARTICLE

STUDY OF THE RADIOACTIVITY LEVELS OF ATMOSPHERIC AEROSOLS NEAR TO EDF NPPS

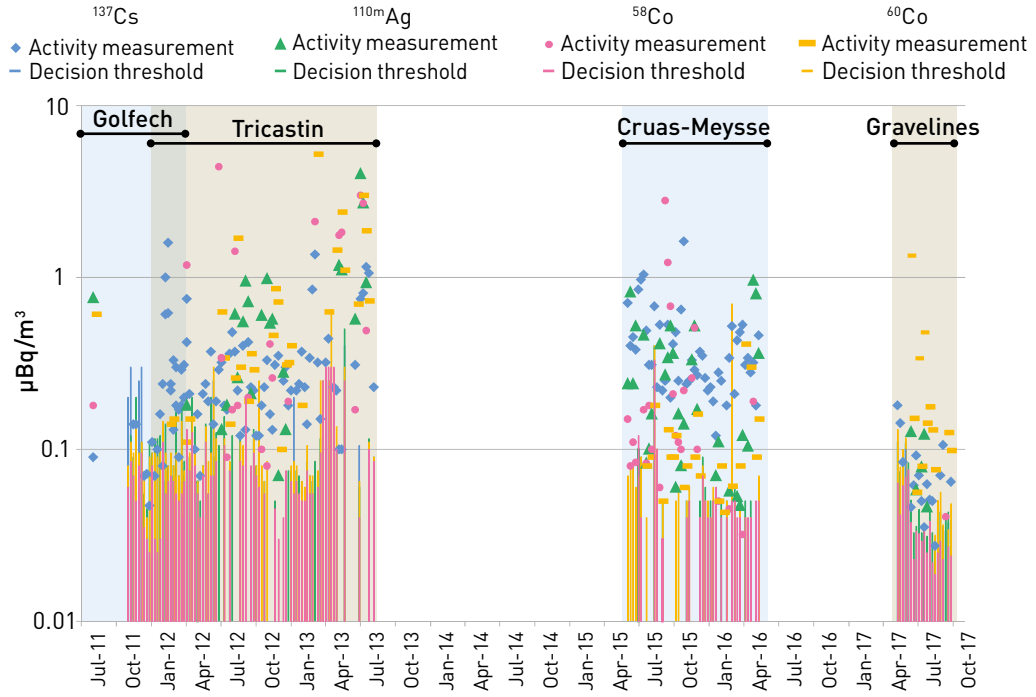
In addition to regular monitoring, IRSN measures the activity of atmospheric aerosols near to nuclear powerplants as part of specific studies organised in coordination with EDF. Four campaigns have been carried out since 2011, near to the Golfech (July 2011 - April 2012), Cruas-Meysse (May 2015 - May 2016), Gravelines (since May 2017, see figure A), and Tricastin NPPs. This latter site is home to other nuclear facilities, in addition to the NPP (January 2012 - August 2013). An atmospheric aerosol sampler with a high flow rate (300 m^3/h) was installed for each of these studies. The sampler operates 24/7 and complements EDF's systems installed in the immediate vicinity of sites as per regulations.
Thanks to the performance levels of the sampling system and the associated laboratory metrology techniques, very low levels of radioactivity can be measured: approx. 0.01 $\mu Bq/m^3$, which meets the targets of the set study.

FIGURE A / **LOCATION OF IRSN AEROSOL COLLECTION STATIONS NEAR TO 4 EDF NPPS (source: airborne images from the geoportail)**



In addition to natural radionuclides (^{7}Be, ^{40}K, ^{22}Na, ^{210}Pb, etc.) with similar activity levels to those measured in areas unaffected by the atmospheric discharges of the facilities, thanks to the data obtained in these measuring runs and the performance levels of the (sampling and metrology) systems used, the activities of the radionuclides in NPP atmospheric discharges can be quantified (figure B).

FIGURE B/ **ACTIVITIES OF THE MAIN ARTIFICIAL RADIONUCLIDES MEASURED BY IRSN DURING THE 4 MEASURING CAMPAIGNS ORGANISED NEAR TO EDF NPPS**



Residual caesium-137 from fallout (from the atmospheric testing of nuclear weapons and the Chernobyl accident) is routinely measured by IRSN at 10 samplers with high flow rates (700 m^3/h) located outside of areas affected by atmospheric discharges from nuclear facilities.
This radionuclide can also be detected in atmospheric discharges from NPPs and was the most frequent artificial radionuclide measured during these studies (76 - 100% of filters). These activity levels vary between 0.03 and 1.62 µBq/m^3, with the highest measurements recorded for the sampler filters in the Rhône valley, the area the most affected by fallout from the Chernobyl accident. ^{137}Cs activity levels fluctuate to match fluctuating ^{40}K and dust levels, mainly due to natural phenomena (mineral dust on the ground raised into the air, pollen, forest fires, etc.), but do however remain well above background radiation levels in areas unaffected by discharges.
^{110m}Ag, ^{60}Co and ^{58}Co are the other main radionuclides measured. These radionuclides, which are typically found in atmospheric discharges by NPP, along with iodines, are the most frequently detected fission and activation products in NPP discharges (after tritium and carbon-14), despite filters. The activity levels measured during these studies, for these three radionuclides, vary between 0.03 and 5.2 µBq/m^3 (table A) and corroborate the activity levels calculated by the operator based on dispersal.

TABLE A / **ACTIVITIES OF THE MAIN ARTIFICIAL RADIONUCLIDES MEASURED BY IRSN DURING THE 4 RADIOACTIVITY STUDIES FOCUSING ON ATMOSPHERIC AEROSOLS NEAR TO EDF NPPS**

Activity in µBq/m³	^{137}Cs	^{110m}Ag	^{58}Co	^{60}Co
Cruas-Meysse NPP	**0.12 – 1.62**	**0.047 – 0.96**	**0.03 – 2.8**	**0.04 – 0.41**
Number of filters (out of 49)	49	30	24	22
Frequency of detection	100%	61%	49%	45%
Tricastin site	**0.07 – 1.59**	**0.07 – 4**	**0.08 – 4.4**	**0.1 – 5.2**
Number of filters (out of 75)	69	22	19	30
Frequency of detection	92%	29%	25%	40%
Golfech NPP	**0.05 – 0.6**	**0.76**	**0.18 – 1.2**	**0.61**
Number of filters (out of 24)	20	1	2	1
Frequency of detection	83%	4%	8%	4%
Gravelines NPP	**0.03 – 0.18**	**0.05 – 0.13**	**0.04**	**0.06 – 1.34**
Number of filters (out of 21)	16	5	1	12
Frequency of detection	76%	24%	5%	57%

The activities measured near to the Golfech (2 x 1 300 MWe reactors) and Gravelines (6 x 900 MWe reactors) NPPs for the 4 target radionuclides, were measured the least frequently and gave the lowest peak values. On the other hand, the activities measured near to the two NPPs in the Rhône valley (4 x 900 MWe reactors) were measured the most frequently and gave the highest peak values. Given that all samplers were installed at point AS1 at each NPP, at the distance required by regulations from the discharge point(s), based on the prevailing winds, it would appear that activity measurements depend on the radionuclides discharged, but also on the location of the equipment and its exposure to discharges, which fluctuates based on local wind conditions. If we consider the Cruas-Meysse site (or the Tricastin site), wind direction is very regular and generally comes from the north, with little variation. On this basis, the sampler is mainly affected by discharges from the facility. If we compare with the Gravelines site (or the Golfech site), wind is far more variable, and the percentage of discharged effluents reaching the sampler will fluctuate substantially.

Other radionuclides have also been measured near to the Tricastin site (^{54}Mn, ^{95}Zr, ^{95}Nb, ^{124}Sb, ^{51}Cr and ^{57}Co), however far less frequently (for 1 to 12% of filters) (table B). These radionuclides were measured during both maintenance operations (with the reactor shut down) and during production phases, although levels appear higher when the reactor is shut down. Effluents discharged from other facilities at the site probably increased the activity measured for these radionuclides to above the detection threshold. Note: ^{95}Zr and ^{95}Nb activities were also measured at a filter at the Gravelines station, giving results of 0.6 and 1 µBq/m³ respectively.

TABLE B / **OTHER ARTIFICIAL RADIONUCLIDES MEASURED DURING IRSN STUDIES AT POINT AS1 AT THE TRICASTIN SITE**

Activity in µBq/m³	^{54}Mn	^{95}Zr	^{95}Nb	^{124}Sb	^{51}Cr	^{57}Co
Tricastin site (January 2012 to August 2013)	**0.08 – 0.9**	**0.28 – 1.47**	**0.39 – 3.0**	**0.24 – 0.4**	**2.5 – 3.4**	**0.06**
Number of filters (out of 75)	9	4	4	2	2	1
Frequency of detection	12%	5%	5%	3%	3%	1%

The impact of carbon-14 in liquid effluents discharged

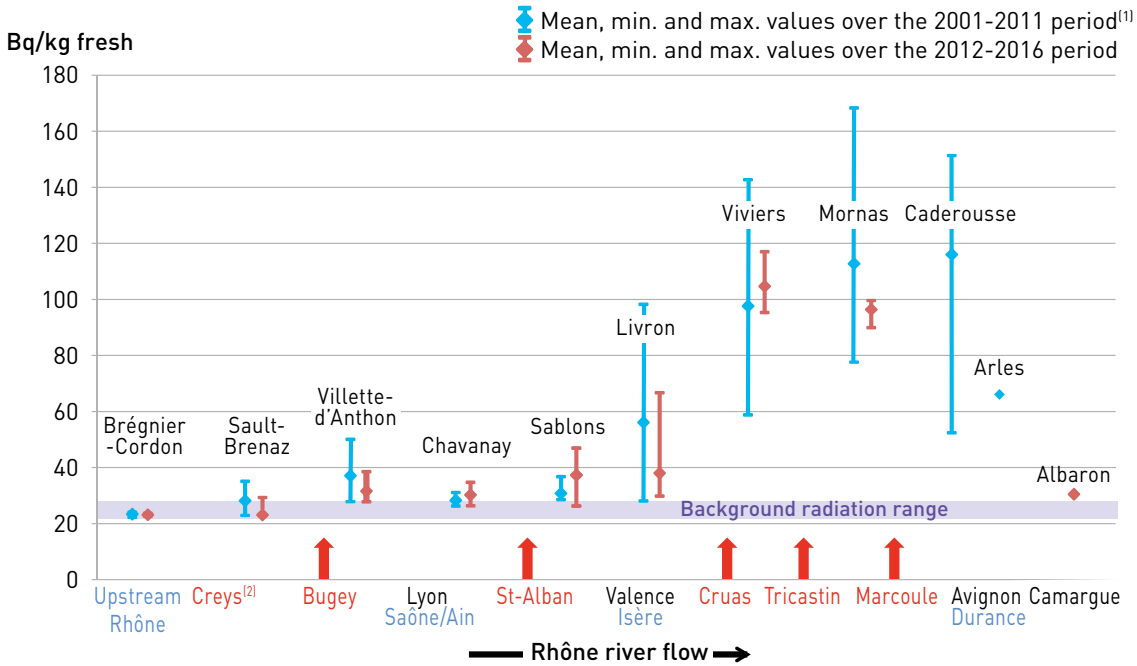
Carbon-14 activity in fish upstream and downstream of all NPPs is analysed on an annual basis, by IRSN as part of its monitoring programme, and by IRSN and SUBATECH at the request of EDF as part of annual radioecological monitoring.

The monitoring results obtained as part of the two programmes demonstrate that carbon-14 activity in fish in French rivers, where NPPs discharge carbon-14 in liquid effluents, leads to an increase in the activity by mass of fish in the rivers in question, however this increase varies substantially.

On this basis, ^{14}C activity in fish fluctuates over the entire length of the Rhône river depending on effluents discharged from the nuclear facilities installed on this river, particularly NPPs on the Rhône river, and due to varying levels of dilution by river flow, particularly when tributaries join the main river. Figure 5 shows this variation in activity over the length of the Rhône river and highlights how activity is stable over time, by comparing 2 periods: 2001-2011 and 2012-2016.

Upstream from the Bugey site, at Brégnier-Cordon or Sault-Brenaz, activity measurements from 2016 are in the background radiation range for ^{14}C in French freshwater fish: 22 - 29 Bq/kg with a mean value of 24 Bq/kg fresh (see chapter 2). Mean activity in fish captured downstream from the Bugey NPP represented 33 Bq/kg fresh over the 2012-2016 period, which is a + 9 Bq/kg increase over mean Background Radiation (BR). Assuming an annual fish consumption of 1.3 kg, which corresponds to the catch of an amateur fisherman, the dose corresponding to this added activity would be equal to 0.007 µSv/year. This figure would reach 0.03 µSv/year for people eating such fish more regularly (5.3 kg/year). ^{14}C activity at Chavanay, upstream from Saint-Alban, is similar to the level of background radiation due to dilution, particularly as the Ain and Saône rivers join the main river. Mean ^{14}C activity in fish increases due to discharges from the Saint-Alban, Cruas and Tricastin NPPs, ranging up to 105 Bq/kg fresh (BR + 81 Bq/kg fresh) after Cruas over the 2012-2016 period, and 113 Bq/kg fresh (BR + 89 Bq/kg fresh) at Mornas downstream of Tricastin over the 2001-2011 period. These activity increases correspond to doses of approximately 0.06 to 0.07 µSv/year for occasional consumers[1]

FIGURE 5 / **VARIATION IN CARBON-14 ACTIVITY IN FISH (Bq/kg fresh), OVER THE FULL LENGTH OF THE RHÔNE RIVER, ON THE BASIS OF MEASUREMENTS TAKEN OVER THE 2001-2011 PERIOD (shown in blue) AND OVER THE 2012-2016 PERIOD (shown in red)**



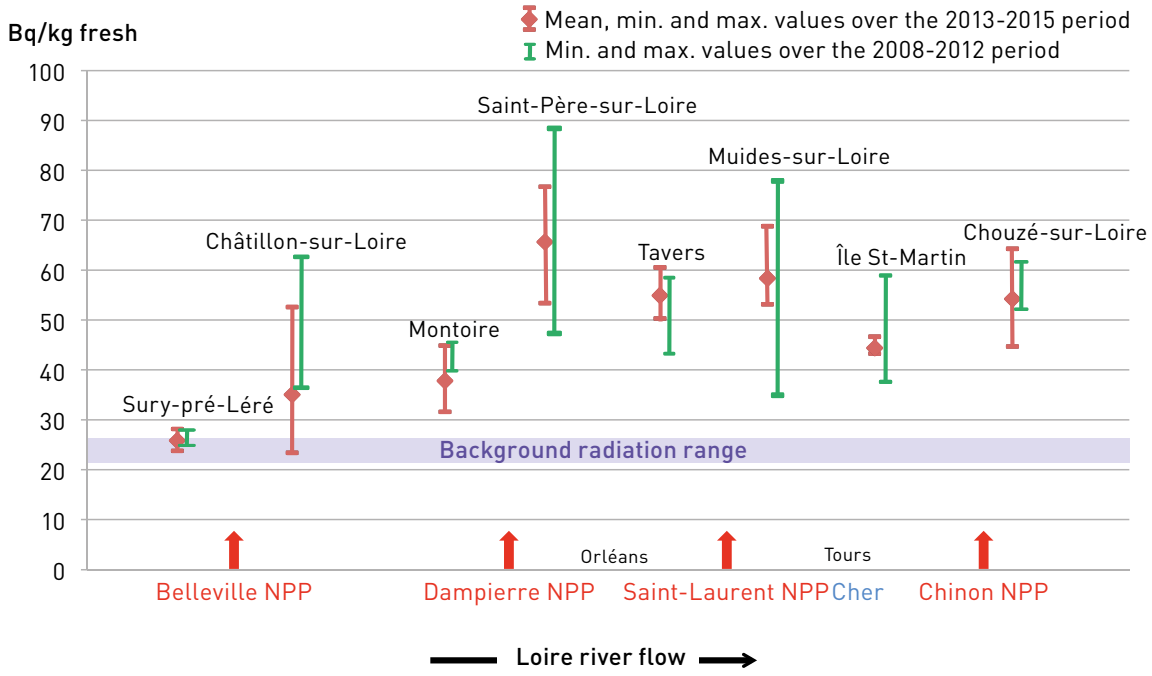
1. Prior to 2009, data only existed for some years (ten-year reports and specific studies)
2. The location of this site is indicated for information only; carbon-14 discharges are not authorised here.

(1.3 kg/year) and 0.2 - 0.3 µSv/year for regular consumers (5.3 kg/year). ^{14}C activity in fish will reach the level of background radiation with distance and when diluted in Durance river water, particularly for the Camargue, where the impact of discharges from the nuclear facilities on the Rhône approximates background radiation: 30 Bq/kg fresh (BR +6 Bq/kg fresh).

^{14}C measurements in fish captured in the Loire river vary in a similar manner for the 2008-2012 and 2013-2015 periods (see figure 6). At Sury-Pré-Léré, upstream from the Belleville NPP, where a mean activity of 26 Bq/kg fresh was recorded over the 2013-2015 period, ^{14}C activity in fish remains at background radiation levels.

The liquid effluents discharged from the Belleville, Dampierre and Saint-Laurent NPPs increase this activity, which reaches approximately 60 Bq/kg fresh between Saint-Père-sur-Loire and Muides-sur-Loire. This activity adds +35 Bq/kg to background radiation levels, which would give the following doses: 0.03 µSv/year for occasional fish consumers (1.3 kg/year) and 0.1 µSv/year for regular fish consumers (5.3 kg/year). ^{14}C fish activity is diluted by the Cher river (among other less significant inputs), falling to 44 Bq/kg fresh (or BR +20 Bq/kg) at Saint-Martin island, before increasing again due to the liquid effluents discharged at Chinon to 54 Bq/kg fresh (BR +30 Bq/kg fresh) near to Chouzé-sur-Loire.

FIGURE 6 / **VARIATION IN CARBON-14 ACTIVITY IN FISH (Bq/kg fresh), OVER THE FULL LENGTH OF THE LOIRE RIVER, ON THE BASIS OF MEASUREMENTS TAKEN OVER THE 2008-2012 PERIOD (shown in green) AND OVER THE 2013-2015 PERIOD (shown in red)**



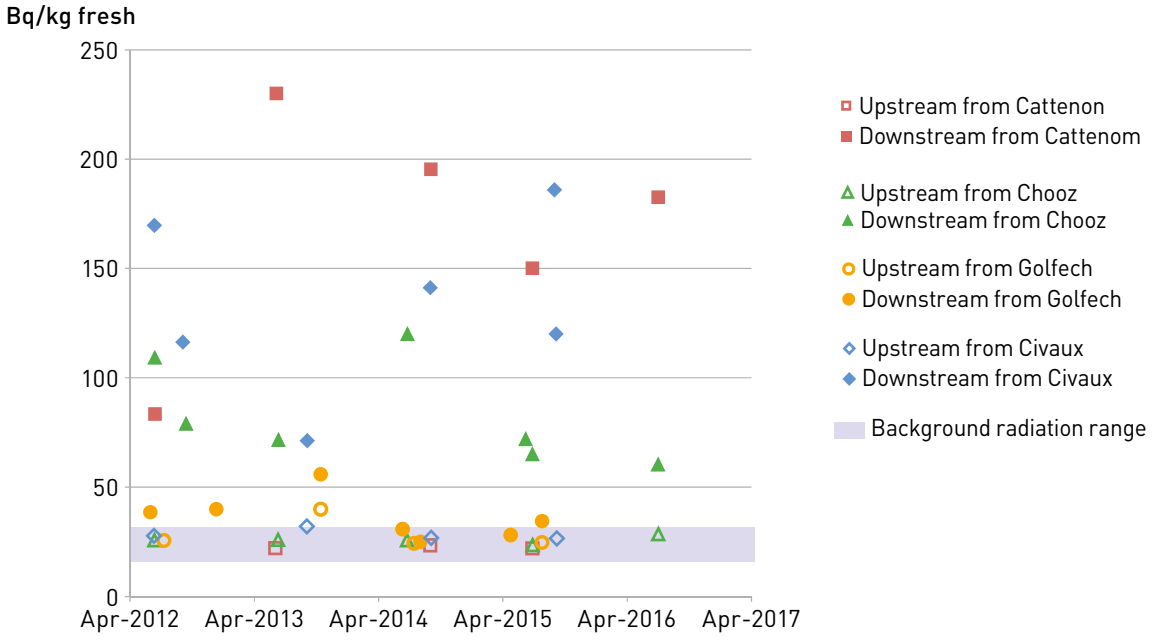
1. Note: fishing is partially prohibited in various sections of the Rhône river due to chemical pollution unrelated to NPPs.

Figure 7 compares ^{14}C activities in fish upstream and downstream from a few NPP since 2012. This figure shows how the flow rate of the receiving rivers affects fish activity by diluting/dispersing the liquid effluents discharged by NPP. Fish were captured downstream from discharge points. With the exception of the samples taken for Golfech in 2013, all of the activities in fish samples taken upstream of NPP are within the background radiation range. This exception does highlight how fish can travel both upstream and downstream from discharge points. Activity measurements downstream of sites vary substantially and depend directly on river flow rates. The Garonne river flows fast enough to maintain activity levels downstream from Golfech at similar levels to (or lower than) those detected for the Loire river in an earlier study. On the other hand, ^{14}C activity levels in fish captured in the Moselle and Vienne rivers downstream from the Cattenom and Civaux sites are higher than those measured at downstream locations on the Rhône, where discharges from various sources aggregate: 168 Bq/kg fresh on average downstream from the Cattenom NPP (BR + 144 Bq/kg fresh) and 137 Bq/kg fresh downstream from the Civaux NPP (BR + 113 Bq/kg fresh).

However, despite these activity levels, which are higher than those mentioned above, the doses absorbed by eating these fish remain extremely low: 0.1 µSv/year for occasional consumers and 0.4 µSv/year for regular consumers. For information, the dose absorbed when eating fish captured downstream from the Cattenom NPP, as calculated by EDF based on discharges from 2016, is equal to 0.2 µSv/year.

In general, the mean dose absorbed by eating fish contaminated by the liquid effluents discharged from NPPs containing ^{14}C, covering all sites, for the regular consumption of 5.3 kg of fish per year, was estimated at 0.12 µSv/year in the previous radiological report (2011-2014). This figure was confirmed for the 2014-2016 period, estimated at 0.15 µSv/year, which is extremely similar to the previous value. The ^{14}C contribution discharged by NPPs to the dose absorbed after eating one kg of fish still only represents 1% of the total dose of 12 µSv/year due to the natural radioactivity of fish (see page 70 of the radiological report for the 2011-2014 period).

FIGURE 7 / **SPECIFIC ACTIVITY FOR ^{14}C (Bq/kg of carbon) MEASURED SINCE 2012 IN FISH CAPTURED UPSTREAM AND DOWNSTREAM OF THE CATTENOM, CHOOZ, GOLFECH AND CIVAUX NPP**



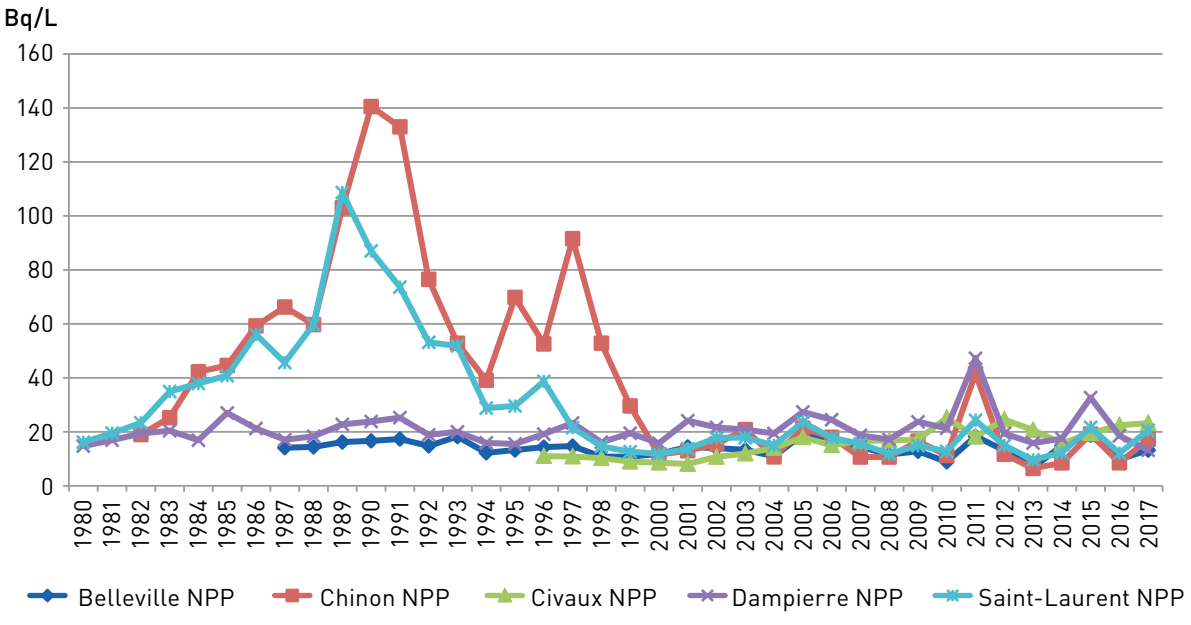
The impact of liquid discharges containing tritium

Most of the tritium detected in river water downstream from NPPs was added by the liquid effluents discharged from the facilities. Residual fallout from the atmospheric testing of nuclear weapons combined with natural cosmogenic tritium (see chapter 2) gives a total "background radiation" of approximately 1 - 3 Bq/L. The activities measured for samples collected using a permanent IRSN sampling system [2] are due to the effluents discharged from each site, the river flow rate and therefore its ability to disperse the effluents, and, for sites located downstream from other sites, combined effluents (figures 8, 9, 10 and 11 show variation over the years and table 4 shows mean values for the last 3 years).

On this basis, the lowest mean annual activities are measured in the Alsace canal and in the Rhône river, despite the number of facilities discharging this radionuclide into these rivers: 3 Bq/L in the Alsace canal downstream from Fessenheim, 6 Bq/L downstream from St-Alban and up to 11 Bq/L downstream from Bugey (near to the Bugey NPP, the main Rhône tributaries have not yet joined the main river and flow rate is a mere 450 - 600 m^3/s). Activity levels in the Loire river are fairly homogeneous and range from 14 Bq/L downstream from Belleville to 21 Bq/L downstream from Dampierre. The highest mean activities were measured at locations with the weakest flow rates: from 22 Bq/L on the Vienne river downstream from Civaux to 35 Bq/L on the Seine river downstream from Nogent. These figures are below regulatory limits and approximately 300 to 3 000 times less than the WHO's guide value for tritium in drinking water (10,000 Bq/L).

FIGURE 8 / **MEAN ANNUAL TRITIUM ACTIVITY FOR LOIRE RIVER WATER DOWNSTREAM FROM THE BELLEVILLE, DAMPIERRE, CHINON, SAINT-LAURENT AND CIVAUX NPPS (Bq/L)**

According to recurrent mean annual tritium activity measurements, as taken by IRSN from the Loire river water since the 1980's, liquid tritium discharged from EDF NPPs has remained stable since the first decade of the 21st century. Higher activity levels were also recorded downstream from the Chinon site up to 2000. After 2000, mean annual activity varied less from year to year. This may be partially due to the fact that the NPPs now coordinate their discharges prior to actual release: the Saint-Laurent-des-Eaux NPP coordinates discharges from all NPPs releasing effluents into this river. No two NPPs may discharge effluents simultaneously, unless an exemption is granted. Tritium activity increased in the river due to severe weather conditions in May-June 2011, with insufficient rain levels. Activity beat the 1996 record for the first time. Tritium activity measured in Loire river water downstream from the Dampierre site was also slightly higher than usual between July and December 2015.



2. Sequential samples are taken to obtain permanent measurements; on this basis, the activity measured is representative of mean monthly activity levels (see chapter 1, p. 17).

FIGURE 9 / **MEAN ANNUAL TRITIUM ACTIVITY FOR MEUSE, MOSELLE AND SEINE RIVER WATER AND WATER IN THE ALSACE CANAL DOWNSTREAM FROM THE CHOOZ, CATTENOM, FESSENHEIM AND NOGENT NPPS (Bq/L)**

Tritium activity in the Meuse river dropped substantially in the early 1990's, from 40 Bq/L to 10 Bq/L per year on average, with the final shutdown of the Chooz-A NPP in 1991. Since the mid-1990s, mean annual tritium activity levels in the Meuse river have increased slightly, but constantly, to the current value of approx. 30 Bq/L. Mean monthly activity in the Moselle river downstream from the Cattenom NPP has progressively increased, from the 1985 level of 15 Bq/L to the current level of approx. 30 - 40 Bq/L. Mean annual tritium activity downstream from the Fessenheim NPP has steadily decreased since 1976. Mean annual activity measurements for the Seine river since 2014 have represented between 27 and 48 Bq/L.

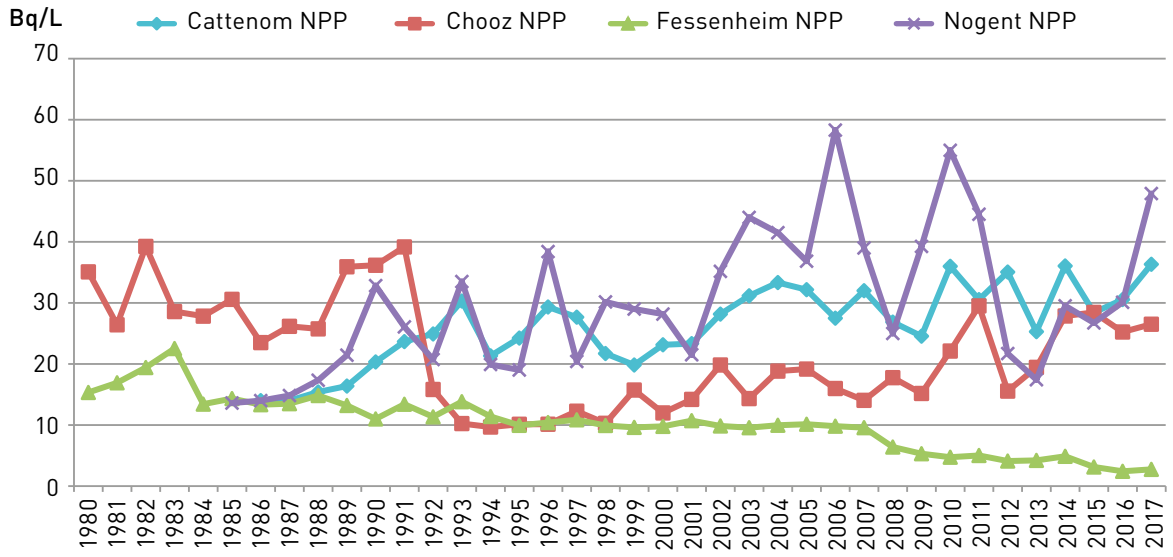


FIGURE 10 / **MEAN ANNUAL TRITIUM ACTIVITY FOR GARONNE RIVER WATER DOWNSTREAM FROM THE GOLFECH NPP AND GIRONDE RIVER WATER DOWNSTREAM FORM THE BLAYAIS NPP (Bq/L)**

The location of the IRSN water sampling system fitted downstream from the Blayais NPP was modified in 2007. The system was initially installed at Laspeyres, and was moved nearer to the NPP discharge point, which explains why activity measurements are higher, since the effluents are less diluted. Since 2007, samples have been taken directly at the NPP discharge point, leading to tritium activity measurements of 5 - 40 Bq/L. After the effluents have been diluted/dispersed in the estuary, no activity can generally be detected at Vitrezay or Pauillac. In addition, activity has constantly decreased and has been divided by 3 since 1981. Tritium activity measured in Garonne river water downstream from the Golfech NPP has also progressively decreased since the late 1980's. Mean annual activity measurements since 2014 have represented between 5 and 10 Bq/L.

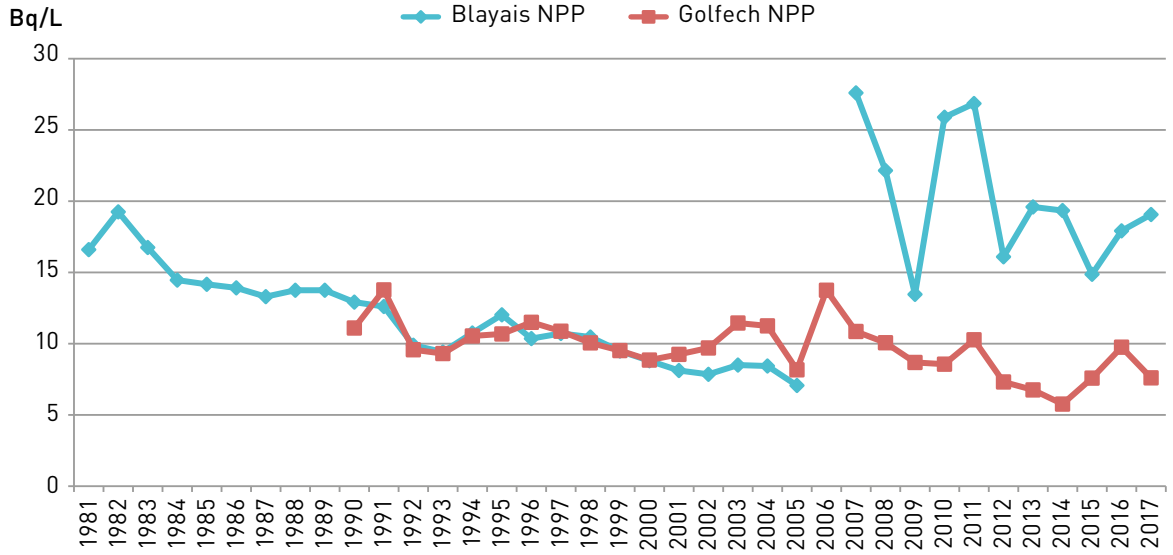
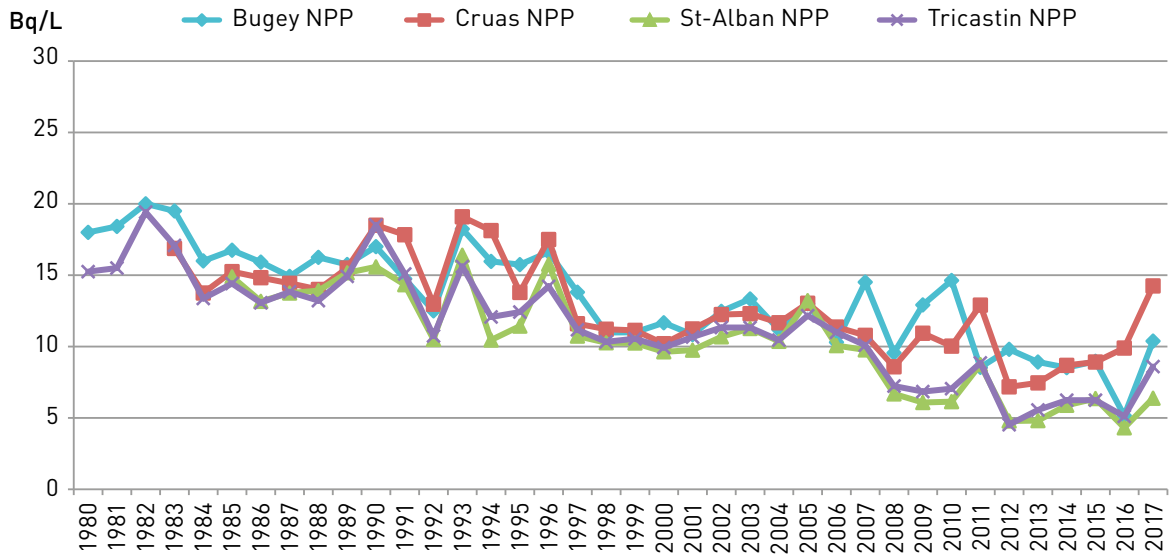


FIGURE 11 / **MEAN ANNUAL TRITIUM ACTIVITY FOR RHÔNE WATER DOWNSTREAM FROM THE BUGEY, SAINT-ALBAN, CRUAS AND TRICASTIN NPPS (Bq/L)**

Tritium activity in Rhône river water downstream of NPPs has been divided by 3 to 4 since the early 1980's.
As activity measurements were increasingly below 10 Bq/L, in 2008-2010, IRSN decided to improve its metrological performance to allow lower activity levels to be measured, down to a decision threshold of 1 Bq/L.
IRSN aims to quantify water activity well below regulatory limits.
Monthly activities measured downstream from the Cruas and Bugey NPPs in 2017 represented between 18 and 34.9 Bq/L, demonstrating increases in mean annual activity levels.



Tritium activities above background radiation levels are regularly detected in some drinking water samples taken from rivers: 12 Bq/L at Beaumont-en-Véron nnear to Chinon in 2014, 8 and 19 Bq/L in 2014 and 14 Bq/L in 2015 at Petit-Puy also near to Chinon, 24 Bq/L in 2014 at Blois due to the St-Laurent NPP, 6.3 and 12 Bq/L at the Mornas pump station near to the Tricastin site, 8.2 Bq/L at Chavanoz near to Bugey in 2017, etc. Unlike most radionuclides discharged in a liquid effluent, tritium is not "stopped" by drinking water treatment systems. On this basis, the activity levels measured in drinking water can match those recorded in river water samples.

The tritium dose absorbed if a person drinks 2 L of water per day over one year would reach approximately 0.04 µSv/year downstream from Fessenheim, 0.4 µSv/year downstream from Cattenom and 0.5 µSv/year downstream from Nogent, based on activity measurements. The highest of these doses are lower than those calculated by EDF using activity measurements for the effluents discharged: from 0.05 to 4.8 µSv/year for Fessenheim and Cattenom respectively.

Note: the highest tritium activities in river water samples as measured by EDG are recorded in the French Metrology network database. These analyses were carried out on samples taken during active discharge, as per regulations (see sampling mid-discharge in table 3-A) in order to ensure that the liquid effluents are discharged in compliance with the applicable requirements. It would therefore appear entirely natural for activity measurements to be up to 6 times higher, on average, than those measured by IRSN in the form of continuous sampling throughout the year (see page 80 of the radiological report for the 2011-2014 period).

70% of the results of analyses performed by EDF on ground water, as part of routine monitoring programmes, were below the decision threshold. However, due to malfunctions or incidents, ground water samples taken on EDF sites can contain tritium on a temporary basis (see page 78 of the radiological report for the 2011-2014 period). In particular, several incidents with significant environmental effects were detected by IRSN[3] for all NPPs between late-2014 and

3. FT/AV/PSN report-2018-00036: EDF-PWR, analysis of feedback; trends based on EDF declarations of incidents with significant environmental effects for the years 2015 and 2016.

late-2016, including one event when a pipe carrying tritiated effluents started leaking at the the Bugey site towards the end of 2014. The tritium contaminated the ground water near to the site due to this incident. According to the results of analyses carried out on water samples taken at piezometers N0 SEZ006 PZ and N0 SEZ013 PZ (figure 12) and the results acquired as part of reinforced monitoring (figure 13), tritium activity remained above background levels until 2017 at some locations. The results of analyses carried out on samples taken at other piezometers during this period remained within the usual range, demonstrating the highly local effects of the contamination caused by this incident.

FIGURE 12 / **TRITIUM ACTIVITY IN GROUND WATER (Bq/L) AT THE BUGEY SITE NEAR TO PIEZOMETERS N0 SEZ006 PZ AND N0 SEZ013 PZ AFTER THE INCIDENT WITH SIGNIFICANT ENVIRONMENTAL EFFECTS IN DECEMBER 2014**

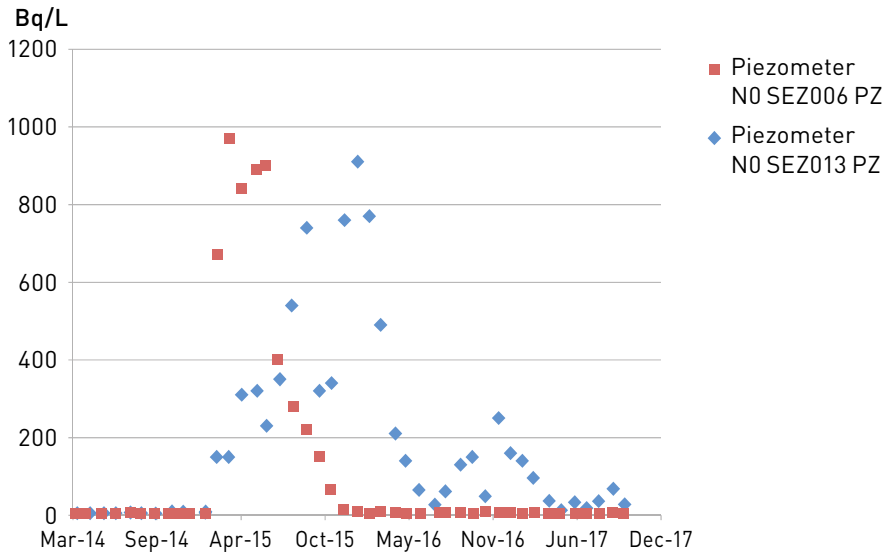
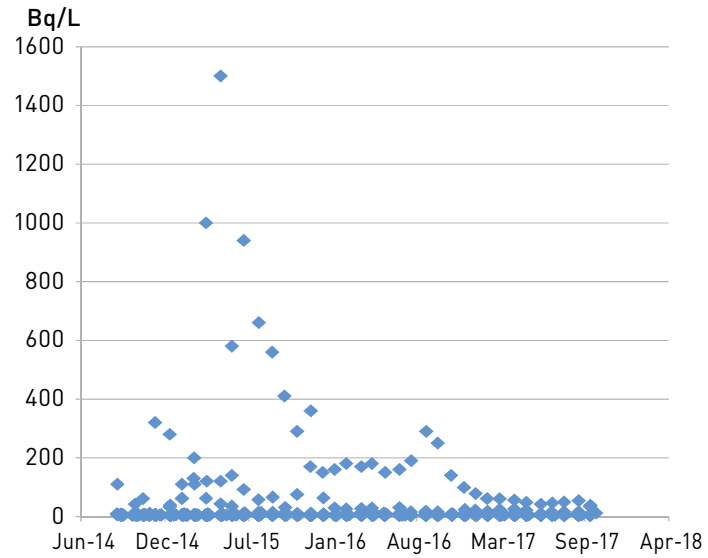
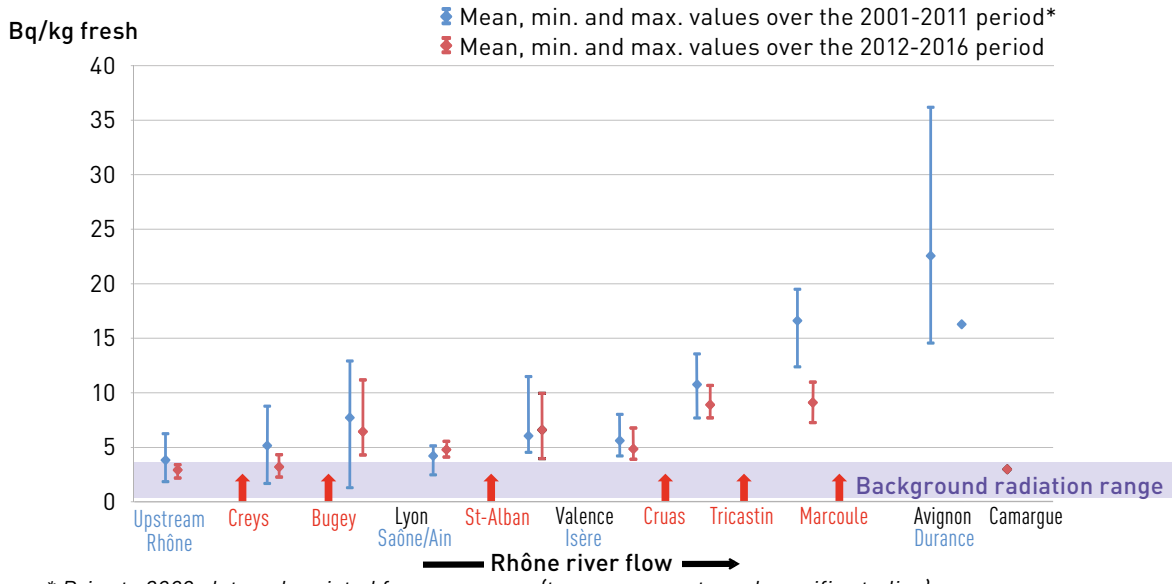


FIGURE 13 / **TRITIUM ACTIVITY IN GROUND WATER (Bq/L) AT THE BUGEY SITE MEASURED AS PART OF REINFORCED MONITORING BY EDF LAUNCHED AFTER THE INCIDENT WITH SIGNIFICANT ENVIRONMENTAL EFFECTS IN DECEMBER 2014**



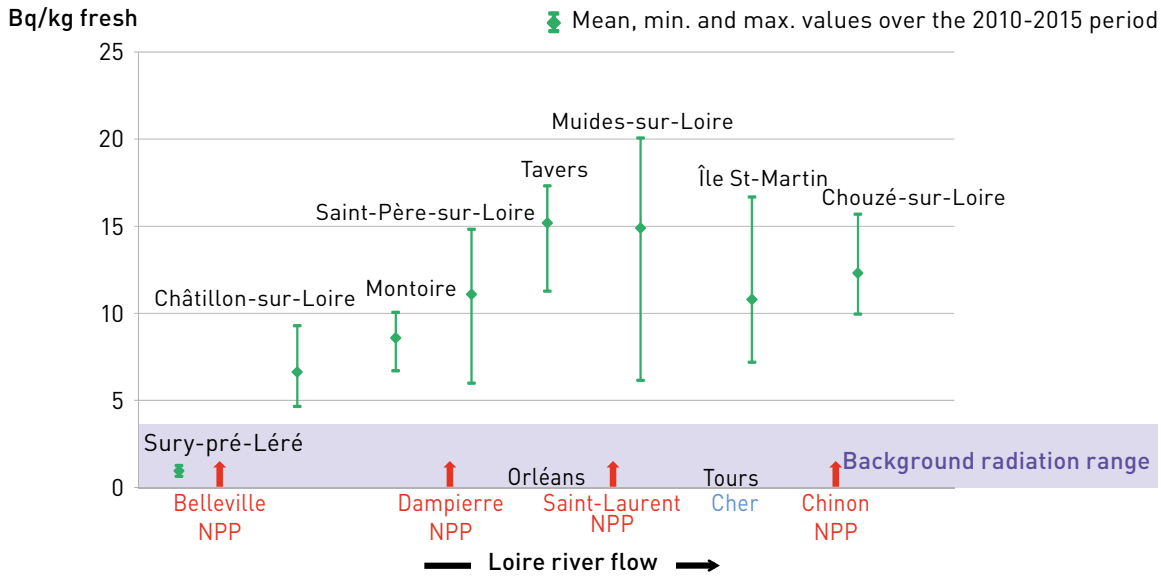
Tritium activity in fish captured in rivers containing effluents discharged from NPPs is measured as part of regulatory monitoring. Figures 14 and 15 show that variation in tritium activity in fish over the lengths of the Rhône and Loire rivers is very similar to the variation in carbon-14 described previously (figures 5 & 6): activity increases downstream from each NPP and decreases after each major tributary (Saône, Ain, Isère and Durance for the Rhône rivera and Cher for the Loire river) joins the main river due to the higher flow rate promoting the dispersal of the activity

FIGURE 14 / **VARIATION IN TRITIUM ACTIVITY IN FISH (Bq/kg fresh), OVER THE FULL LENGTH OF THE RHÔNE RIVER, ON THE BASIS OF MEASUREMENTS TAKEN OVER THE 2001-2011 PERIOD (shown in blue) AND OVER THE 2012-2016 PERIOD (shown in red)**



** Prior to 2009, data only existed for some years (ten-year reports and specific studies)*

FIGURE 15 / **VARIATION IN TRITIUM ACTIVITY IN FISH (Bq/kg fresh), OVER THE FULL LENGTH OF THE LOIRE RIVER, ON THE BASIS OF MEASUREMENTS TAKEN OVER THE 2010-2015 PERIOD**



added. If we compare activity measurements over the 2001-2011 and 2012-2016 periods along the full length of the Rhône, the effects of these NPPs would appear stable over time.

Figure 16 shows how the Moselle river is less effective at dispersing the effluents discharged from the Cattenom NPP, as was the case for carbon-14 (figure 7), with similar, or higher, activity levels measured downstream from this site, when compared with the activity of the Rhône river downstream from all NPP.

In general, tritium activity in fish correlates with water activity as measuring in the samples taken using sampling systems. According to table 4, the fish/water activity ratio is systematically equal to approximately 1.

The tritium dose absorbed after eating fish is insignificant compared with the equivalent carbon-14 dose: approximately 1,000 times less.

Tritium and carbon-14 are discharged in liquid effluents from the Flamanville, Paluel, Penly and Gravelines NPPs on the Channel. Based on the activities of these radionuclides as measured during IRSN campaigns and the radioecological monitoring programme run by EDF, the impact of liquid discharges from NPPs cannot be differentiated from that of the discharges from the Orano facility in La Hague, which are over 150 times higher, including at local level.

FIGURE 16 / **TRITIUM ACTIVITY IN FISH CAPTURED DOWNSTREAM FROM THE CATTENOM, CHOOZ, CIVAUX AND GOLFECH NPPS (Bq/kg fresh)**

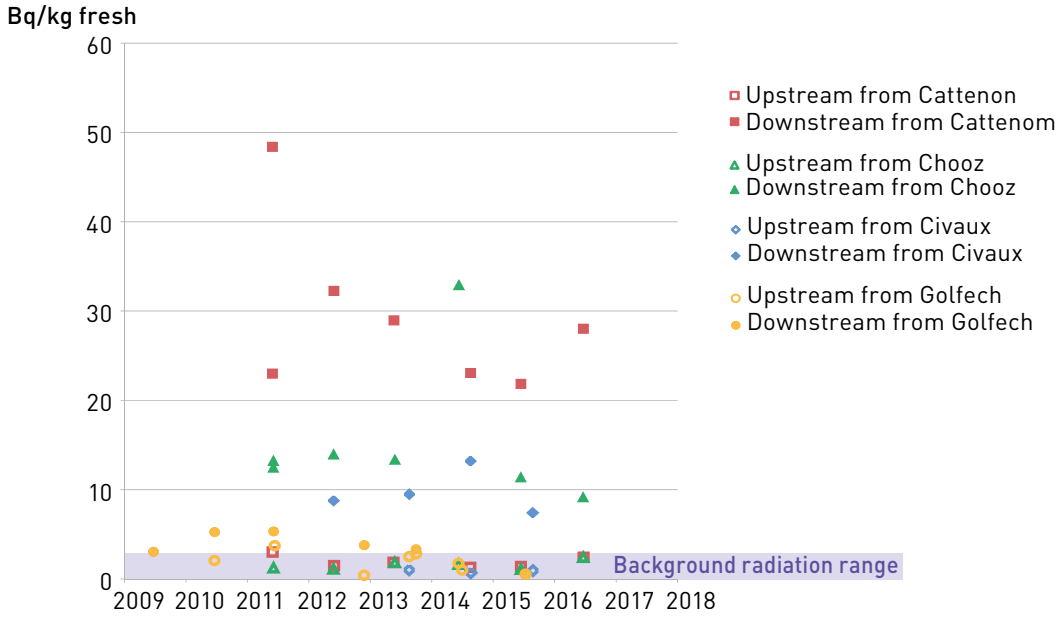


TABLE 4 / **MEAN TRITIUM ACTIVITY IN WATER SAMPLES COLLECTED USING SAMPLING SYSTEMS (Bq/L) AND FISH CAPTURED DOWNSTREAM OF THE NPP (Bq/kg fresh)**

NPP	Bel.	Civ.	Cho.	Cat.	Nog.	Gol.	Bug.	Tri.	Cru.	St-Al.	Chi.	St-La.	Dam.
Water	13.9	21.7	26.7	31.8	34.9	8.3	8.2	6.6	11.0	5.7	15.0	18.1	21.5
Fish	13.6	22.1	22.9	32.5	33.0	7.7	10.2	9.1	9.0	6.6	12.3	14.9	11.0
Fish/water	1.0	1.0	0.9	1.0	0.9	0.9	1.2	1.4	0.8	1.2	0.8	0.8	0.5

The impact of liquid discharges containing other radionuclides

Gamma-emitting radionuclides in river water are analysed on a monthly basis by IRSN *via* settling sludge samples obtained from the water collected using the 24 water sampling systems installed on the main rivers hosting the effluents discharged from the nuclear facilities. Sludge activity levels are representative of those of the particles suspended in the water, particularly for radionuclides which are mainly carried in rivers as particles (other radionuclides such as antimony-124 and 125 are dissolved). The main gamma-emitting radionuclides in the liquid effluents discharged by NPP were all detected at least once over the 2014-2017 period. As expected, cobalt-60 is discharged the most, and is the most frequently detected radionuclide (43% of analyses) in sludge from IRSN water sampling systems, with the highest activity levels (up to 46 Bq/kg dry). Silver-110m ranks second after cobalt-60 (18% of total radionuclides detected with a peak activity of 7.7 Bq/kg dry), followed by cobalt-58 (9.5% of total radionuclides detected with a peak activity of 13 Bq/kg dry), as was the case for discharges. Manganese-54, and caesium-134 are discharged far less frequently in NPP effluents, and are only rarely detected (1.7% and 0.69% of analyses respectively, with peak activities of 2.8 and 0.8 Bq/kg dry). Caesium-137 is frequently detected due to its presence in background radiation from residual fallout from nuclear tests and the Chernobyl accident. High activity levels comprising iodine-131 (up to 68 Bq/kg dry) are mainly recorded downstream of large hospitals using nuclear-based medical systems due to their discharges. Iodine-131 activity is also frequently higher upstream of NPP than downstream. Finally, ruthenium-106 was detected in settling sludge from the water sampling system twice, in November 2013 and December 2015, for the Flamanville NPP discharge zone. This radionuclide is not discharged by the NPP, it was probably released at La Hague, and transited via the seawater used to disperse the NPP's effluents.

Gamma-emitting radionuclides have also been detected in some biological indicators (aquatic plants), although very rarely in sediments, and never in fish, in recent years. These radionuclides can only be detected using the most advanced technologies available, implemented as part of the studies conducted by IRSN and SUBATECH at the request of EDF. ^{60}Co and ^{58}Co are regularly detected, while ^{54}Mn and ^{110m}Ag are occasionally detected, and ^{134}Cs has not been detected in the last three years. Figures 17 and 18 show ^{60}Co and ^{58}Co activity levels measured in aquatic plants sampled at various locations on the Rhône river, downstream from the Nogent, Chooz and Cattenom NPPs, since 2008. According to these figures, since the substantial decrease in discharge levels during the 1980-1990 period, when a minima was reached, activities have remained stable. The highest activity levels in the Rhône river are measured downstream from the Bugey NPP due to the low flow rate for the Rhône, which decreases the dispersal of the radionuclides (compare the flow rate of 450 - 600 m^3/s at Bugey with the 1,040 m^3/s recorded after the confluence with the Saône and Ain tributaries and 1,410 m^3/s at Valence after the Isère river joins the main flow). According to the results of sampling runs downstream from the Saint-Alban (Bugey discharges) and Tricastin (Cruas discharges) sites, the impact of effluents discharged from NPPs can be detected over several tens of kilometres. ^{110m}Ag activity measurements are also higher and more frequently detected downstream from the Bugey NPP (figure 19). Iodine-131 can be measured in aquatic components, however not systematically and levels vary substantially. As is the case for settling sludge, this radionuclide is mainly added by hospitals, where it is used for therapeutic purposes and diagnostics and later discharged.

FIGURE 17 / **COBALT-58 AND 60 ACTIVITY IN AQUATIC PLANTS (mosses and phanerogams) COLLECTED AT VARIOUS POINTS ON THE RHÔNE RIVER (Bq/kg fresh)**

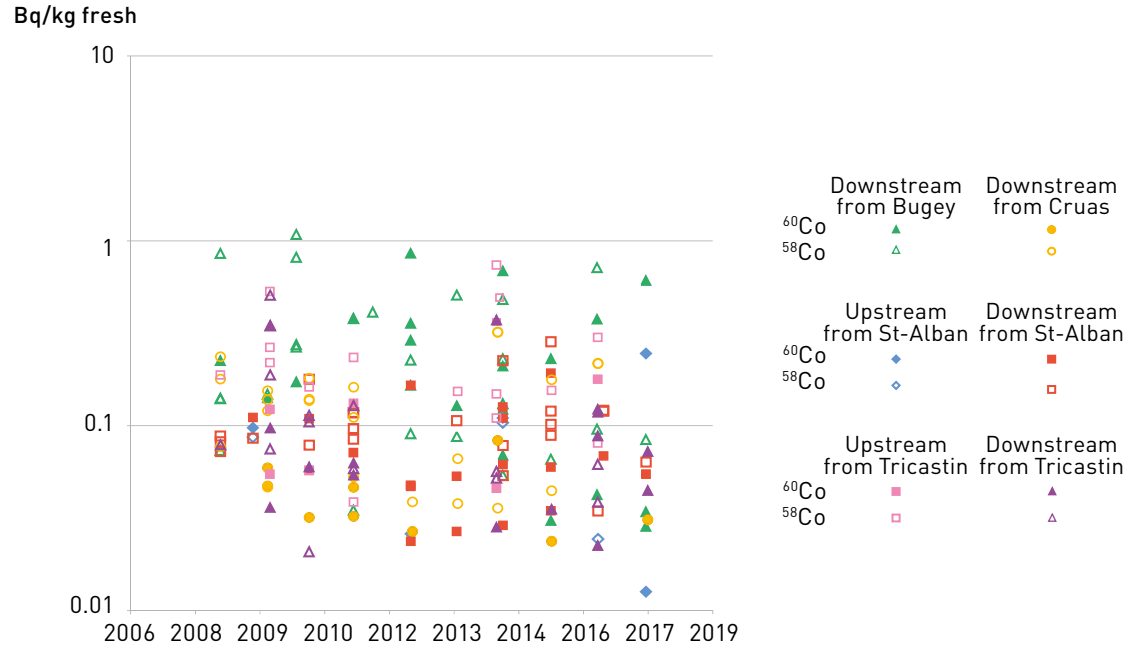


FIGURE 18 / **COBALT-58 AND 60 ACTIVITY IN AQUATIC PLANTS (mosses and phanerogams) IN SEINE, MEUSE AND MOSELLE RIVER WATER DOWNSTREAM FROM THE NOGENT, CHOOZ AND CATTENOM NPPS (Bq/kg dry)**

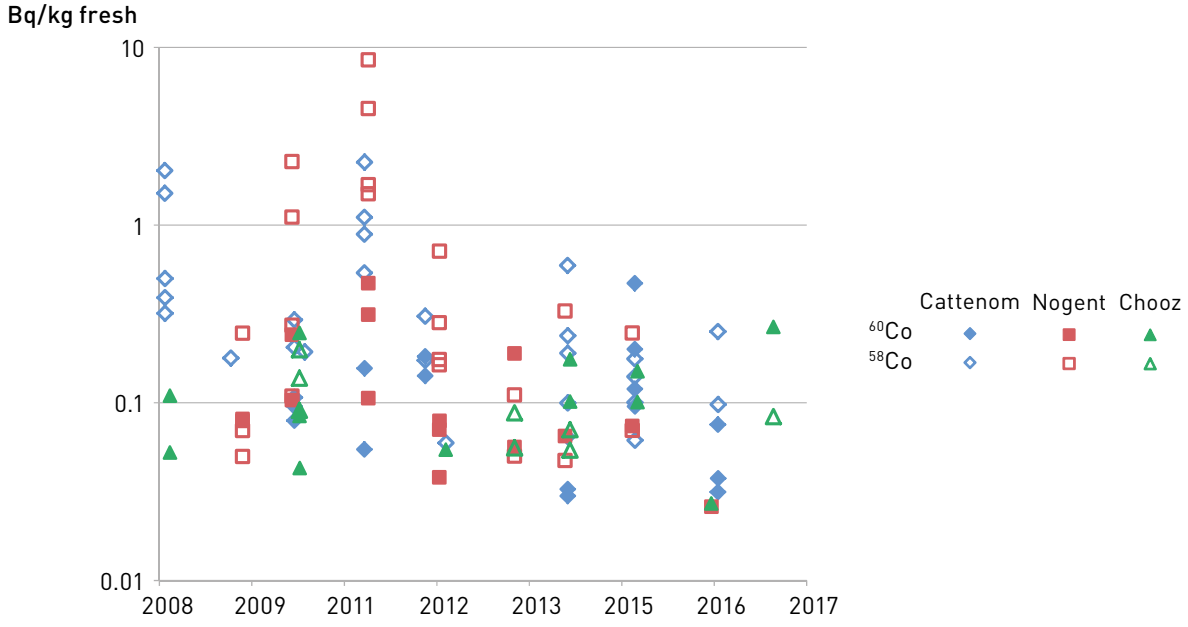
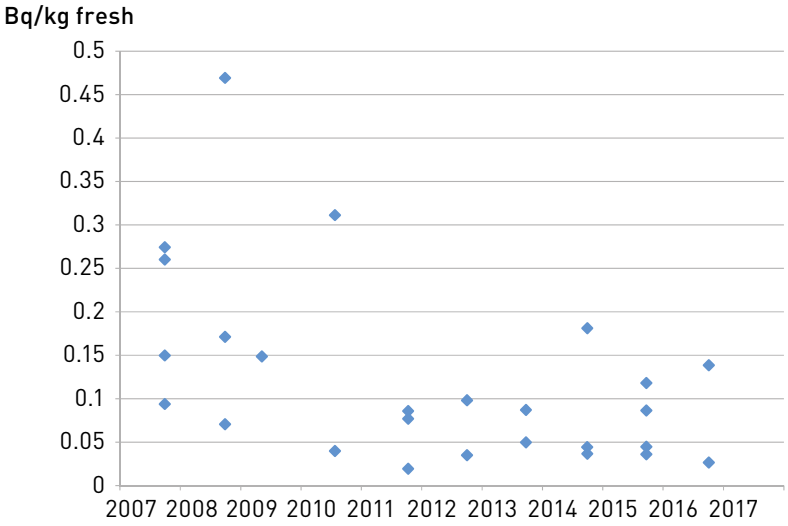


FIGURE 19 / **^{110M}Ag ACTIVITY IN AQUATIC PLANTS (mosses and phanerogams) IN THE RHÔNE RIVER DOWNSTREAM OF THE BUGEY NPP (Bq/kg dry)**



Finally, most radionuclides measured in the Channel, including near to NPPs, are discharged as part of liquid effluents from the Orano facilities in La Hague or the Sellafield plant (Great Britain, see chapter 3.3 La Hague). The contribution of liquid effluents discharged from the NPPs is probably very low, and cannot be differentiated or measured, with the exception of ^{110m}Ag, which is more specifically discharged by these facilities. This radionuclide is measured and characterised in suspended solids or settling sludges taken as samples from discharge channels (vertical or horizontal) as part of routine monitoring by IRSN. Activity levels can reach a few Bq/kg dry (with a peak value of 2.9 Bq/kg dry measured in the Gravelines sea channel in September 2014).

The activity of this radionuclide in algae and sediments is too low to be detected in the environment, with a few very rare exceptions. ^{110m}Ag activity has never been quantified in the 250 analyses in fish since 2001, however levels must be less than 0.04 Bq/kg fresh.

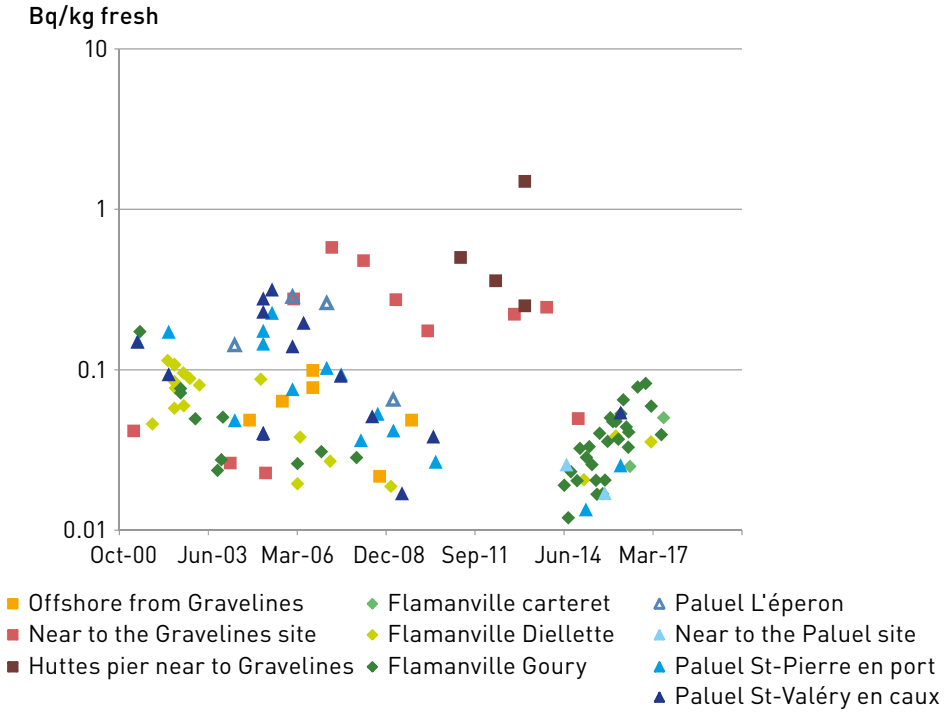
© DR

Fish (catfish) captured in the Rhône river

On the other hand, this radionuclide is measured in one in three analyses in molluscs (mussels, limpets, oysters, etc.) and shellfish (shrimp, crabs, spider crabs), on average. Activity levels do not differ significantly between the various types of food. Figure 20 shows the results for all food types, but for various sampling stations near to the Flamanville, Paluel and Gravelines sites (activity levels near to Penly are lower and rarely mesurable). Nearly all activity measurements are between 0.1 and 1 Bq/kg fresh, although results can fluctuate widely at each sampling station, as shown by the samples taken near to the discharge point at the Gravelines facility, which oscillate between activities of 0.02 Bq/kg and 0.6 Bq/kg. The highest activity measured over the last 16 years reached 1.5 Bq/kg fresh in a limpet sample taken at Huttes pier near to Gravelines in 2013.

Even for a person eating large quantities of sea food (31 kg/year of molluscs, 61 kg/year of shellfish), the potential dose of ^{110m}Ag absorbed/ingested would be extremely low according to these results, falling below 0.02 µSv/year. The dose calculated in the previous Radiological report on the basis of the results acquired at the Gravelines site alone was estimated at 0.05 µSv/year. These doses are lower than those calculated by EDF using activity measurements for the effluents discharged from the Gravelines site: 0.08 µSv/year for average consumers and 0.16 µSv/year for very regular consumers.

FIGURE 20 / ^{110M}Ag ACTIVITY IN MOLLUSCS AND SHELLFISH CAPTURED IN THE CHANNEL NEAR TO NPP (Bq/kg fresh)



Conclusions

No radiological anomaly has been detected over the last three years in the immediate environment of EDF nuclear powerplants, particularly for sampling stations fitted on an aerosol filter. The reference gross beta activity index in air (2 mBq/m^3) was only exceeded during the period due to increases in natural radioactivity (mainly lead 210), due to transient weather conditions.

Several incidents with significant environmental effects were detected by IRSN[4] for all NPPs between late-2014 and late-2016, including one event when a pipe carrying radioactive effluents started leaking at the the Bugey site towards the end of 2014. The tritium contaminated the ground water near to the site due to this incident. This contamination was measured in water samples taken up to 2017, at 2 out of the 9 routine monitoring piezometers and in the samples taken as part of a reinforced monitoring plan implemented after the incident in order to better characterise and track variation.

The other incidents had no measurable consequences on the environment as per regulatory monitoring rules. This was particularly the case for the effluents discharged into the atmosphere by the Golfech NPP on 19 October 2016, estimated at 136 GBq of noble gases. Neither the operator's ambient gamma dose rate measuring sensors installed around the site, nor IRSN's sensors, were activated by this discharge as the associated dose rate was very low after dispersal. Noble gases are also chemically inert, and will disperse in the air without contaminating the environment.

During the 2015-2017 period, the expected activities were measured in all environmental components around NPPs. These values are fairly constant compared with earlier years. The two main radionuclides found in effluent discharges are carbon-14 and tritium. Only these radionuclides can be measured in terms of the impact of NPPs in most continental aquatic and terrestrial components, particularly in food.

According to the activities measured in the air and in the terrestrial environment, the impact of effluents discharged into the atmosphere rapidly decreases with distance from the site, particularly over the first 5 kilometres, and cannot be differentiated from background radiation beyond 10 kilometres. Exposure due to inhaling air is extremely low and insignificant when compared with the potential exposure involved in eating local food, which is itself very low. The dose absorbed by eating local food, assuming the produce was grown within a 5 km radius around the site, would reach approximately 0.075 µSv/year. This dose is almost exclusively attributable to carbon-14.

The effects of liquid effluents containing carbon-14 and tritium, discharged, can be detected downstream from all NPP. These effects are measured in all aquatic components for tritium and in fish for carbon-14. The average dose absorbed if an individual occasionally eats fish captured on a leisure basis downstream from an NPP installed on a river is estimated at 0.15 mSv/year. This dose can be higher downstream from specific sites, potentially reaching 0.4 µSv/year. For information, this dose is almost entirely due to carbon-14 and only represents a few percent of the total dose absorbed by eating fish due to their natural radioactivity levels, which is estimated at 12 µSv/year.

4. FT/AV/PSN report-2018-00036: EDF-PWR, analysis of feedback; trends based on EDF declarations of incidents with significant environmental effects for the years 2015 and 2016.

Drinking river water from downstream of NPPs would lead to a dose of between 0.004 µSv/year and 0.5 µSv/year due to the presence of tritium.

Radionuclides other than carbon-14 and tritium (^{60}Co and ^{110m}Ag in particular) in NPP discharges cannot be measured in the air and in some aquatic components due to their extremely low activities, even using the best available techniques. The associated doses are insignificant compared with those of tritium and carbon-14, which are themselves low. Although NPP discharges may potentially include ^{137}Cs activity, most of these radionuclides measured in the immediate environment of NPPs are residual fallout from the Chernobyl accident and the atmospheric testing of nuclear weapons (see chapter 2).

The activities measured in the environment and the estimated doses likely to reach local residents fully match the dosimetric assessments conducted by EDF in its annual reports. These doses are more than one thousand times less than the maximum permissible dose from artificial radionuclides (excluding medical exposure) according to regulations: 1 mSv/year.

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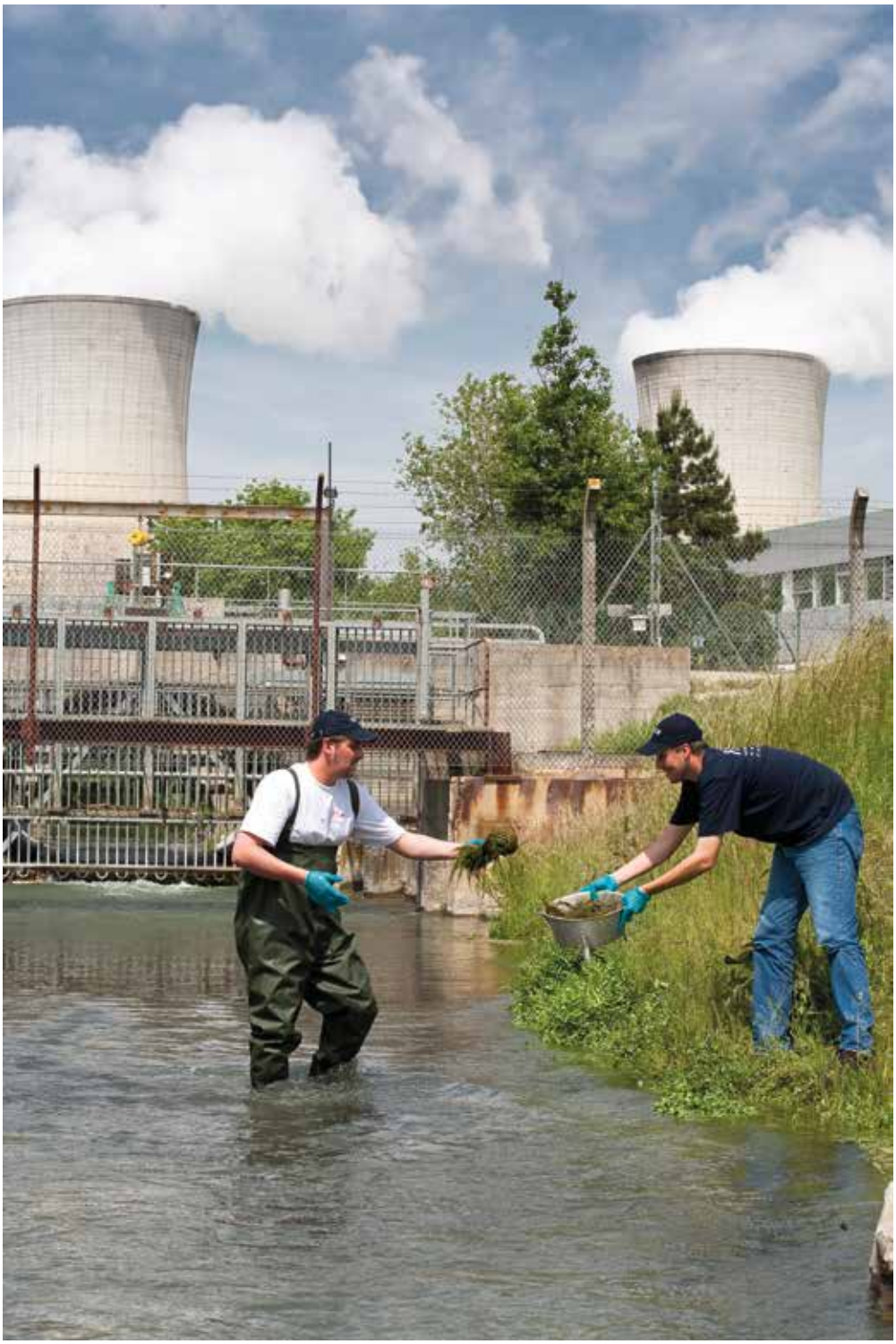
Taking moss samples on a bridge over the Rhône river



© Noak/Le bar Floréal/IRSN

Taking aquatic plant samples near to the Tricastin nuclear site

3.2. NUCLEAR POWERPLANTS IN THE DECOMMISSIONING PROCESS

Nine EDF reactors are currently being decommissioned Seven of these reactors are located at sites where reactors are operational. These reactors are covered in chapter 3.1. This chapter only describes the two sites with no operational reactors: Creys-Malville and Brennilis.

Creys-Malville site

The Creys-Malville nuclear facility is located in the Isère département, on the left bank of the Rhône river, in the municipality of Creys-Mépieu, around fifty kilometres upstream from the urban agglomeration of Lyons. The site hosts two basic nuclear facilities (INB): the Fast Neutron Reactor (FNR) powerplant which was commissioned in 1985, finally shut down in 1998 and is currently in the decommissioning phase, and a series of facilities, including the fuel storage area (APEC).

Discharges and monitoring the environment

The Creys-Malville site holds special authorisation to discharge radioactive substances into the environment, as required by regulations. The radioactive liquids discharged comprise some of the water used by the facilities. The radioactive gases discharged are output from building ventilation systems. Most of the activity discharged is tritium by far: 98 - 99.9% of of the liquid and gaseous effluents discharged. Table 1 shows the activity levels discharged over the 2011 - 2016 period. Figure 1 shows variation in tritium discharged in gaseous and liquid phases between 2002 and 2016. As shown, liquid discharges increased in 2015 and 2016 and gaseous discharges climbed progressively between 2002 and 2010 by 0.1 and 1 TBq, reaching 10 TBq between 2011 and 2013, and then 48 TBq in 2014 and 2016. In 2015, tritium gaseous discharges were 100 times lower than in 2014 and 2016. These peaks were directly caused by decommissioning operations. The Creys-Malville regulatory environmental monitoring programme is shown in figure 2. This programme is completed with annual radioecological studies entrusted to IRSN by EDF. IRSN also conducted a special study between 24 September and 9 November 2012, at the request of EDF, to characterise the environmental impact of a series of atmospheric discharges, containing tritium, in detail.

TABLE 1 / **ACTIVITY LEVELS DISCHARGED FROM THE CREYS-MALVILLE FACILITIES OVER THE 2011 - 2016 PERIOD**

	Unit	Activity level discharged					
		2011	2012	2013	2014	2015	2016
Radioactive liquids discharged							
Tritium	TBq	0.72×10^{-3}	0.91×10^{-3}	0.2×10^{-3}	2.63×10^{-3}	1.53×10^{-2}	3.86×10^{-2}
Excluding tritium	GBq	7.7×10^{-3}	1.72×10^{-2}	1.7×10^{-2}	1.22×10^{-2}	1.76×10^{-2}	4.19×10^{-1}
Radioactive gases discharged							
Tritium	TBq	13.32	15.73	14.85	47.9	3.26×10^{-1}	48.3
Activation or fission products	GBq	1.5×10^{-3}	1.5×10^{-3}	3.2×10^{-3}	5.37×10^{-3}	2.43×10^{-3}	2.31×10^{-3}
Noble gases (^{85}Kr)	GBq	0.27	0.05	0.05	0.0225	0.024	0.0375

FIGURE 1 / **VARIATION IN GASEOUS AND LIQUID TRITIUM DISCHARGED FROM THE CREYS-MALVILLE SITE BETWEEN 2002 AND 2016 (TBq/year)**

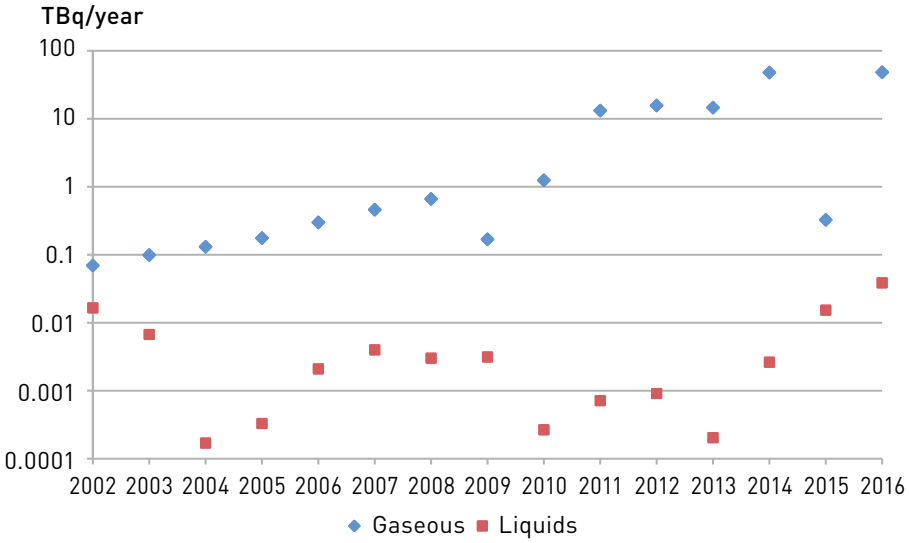
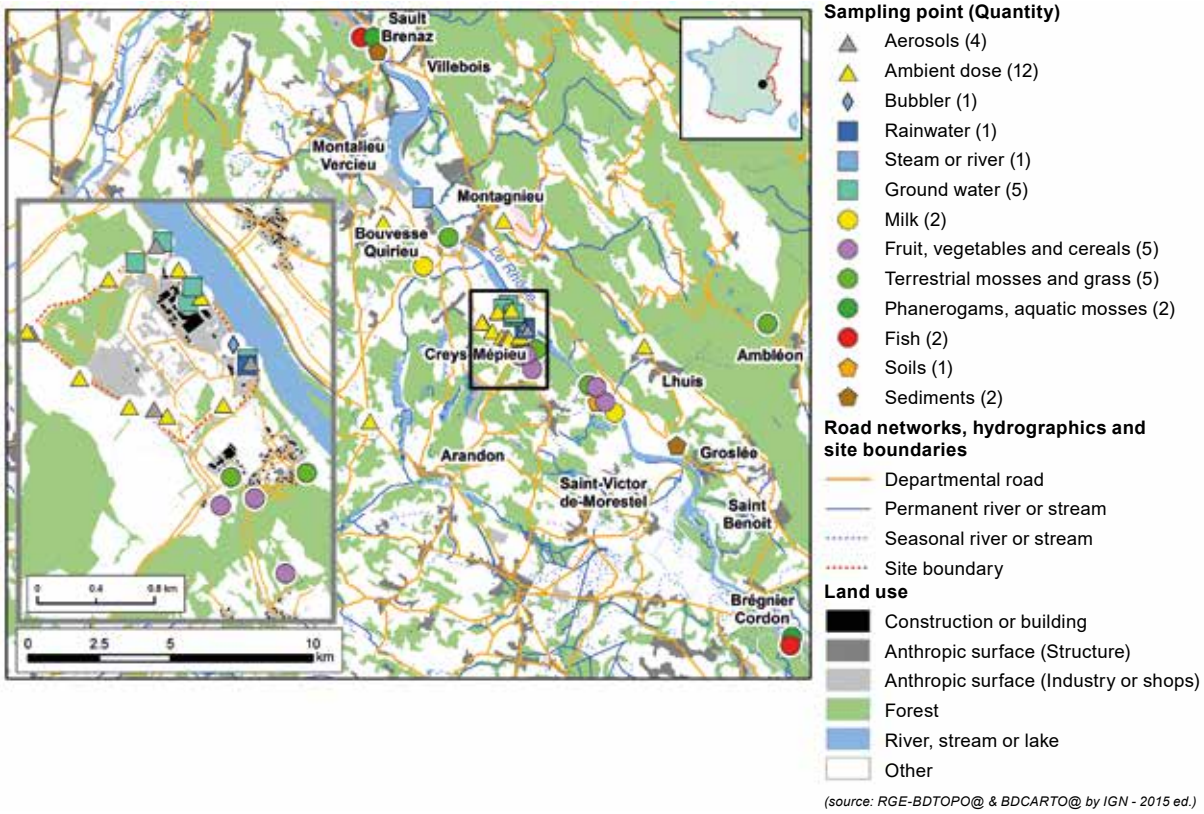


FIGURE 2 / **MAP SHOWING THE STANDARD ENVIRONMENTAL MONITORING PLAN DRAFTED BY EDF FOR THE RADIOLOGICAL MONITORING OF THE IMMEDIATE ENVIRONMENT OF THE CREYS-MALVILLE SITE**



(source: RGE-BDTOPO@ & BDCARTO@ by IGN - 2015 ed.)

TABLE 2-A / **REGULATORY MONITORING PLAN DRAFTED BY EDF FOR THE IMMEDIATE ENVIRONMENT OF THE CREYS-MALVILLE SITE**

Environment monitored or type of testing	Measurements, samples and analyses
Ambient gamma radiation	• 10 sensors around the edge of the site • 4 sensors at a distance of 1 km • 4 sensors at a distance of 5 km
Soil air	• 4 daily measuring and sampling points for gross beta activity with a filter • γ spectrometry if values > 2 mBq/m^3 • 1 monthly γ spectrometry run for combined daily filters at one single sampler • Continuous sampling based on the prevailing winds with weekly atmospheric tritium measurements
Rainwater	• Continuous sampling based on the prevailing winds with bi-monthly measurements for tritium and gross beta activity
The receiving environment for liquid effluents discharged	• Hourly aliquots taken mid-discharge: gross beta activity, potassium and tritium in filtered water samples + gross beta activity for TSS samples • Tritium activity with daily aliquots + γ spectrometry if > 140 Bq/L (during discharges) or > 100 Bq/L outside of discharges
Ground water	• 5 sampling points: monthly ^{3}H, ^{40}K and gross beta activity measurements for filtered water and gross beta activity measurements for TSS
Soils	• 1 annual sampling run for topsoil layers: gamma spectrometry
Plants	• 2 monthly grass samples (including 1 in the prevailing wind direction): γ spectrometry + annual OBT and HTO
Milk	• 2 monthly milk samples (including 1 in the prevailing wind direction): monthly gamma spectrometry runs + quarterly tritium measurements
Soils	• 1 annual sampling run: γ spectrometry
Aquatic flora	• 2 annual sampling runs (upstream/downstream: γ spectrometry
Aquatic fauna	• 2 annual sampling runs (upstream/downstream): γ spectrometry + OBT
Sediments	• 2 annual sampling runs (upstream/downstream: γ spectrometry
Farm output	• 1 annual sampling run for the main farming output: γ spectrometry, HTO and OBT

TABLE 2-B / **ANNUAL RADIOECOLOGICAL MONITORING PLAN FOR THE IMMEDIATE ENVIRONMENT OF THE CREYS-MALVILLE SITE IN 2017**

Matrix	Gamma	HTO	OBT	C-14	Ni-63
Grassland soils		1	1		
Grass	1		1		
Milk	1		1		
Terrestrial moss	2				
Oak tree leaves		2	2	2	
Sediment			2	2	2
Aquatic moss	2				2
Aquatic phanerogams			2	2	

The impact of the Creys-Malville site on its immediate environment and associated doses

The impact of tritium discharges from the Creys-Malville site cannot be clearly detected from measurements performed on environmental samples, as these discharges fluctuate over each year. Mean total tritium activity in air sampled near to the Creys-Malville site represented 4.14 Bq/m^3 in 2016, which is considerably higher than background radiation (between 0.005 and 0.01 Bq/m^3). However, this mean value was achieved due to increases over short periods (a few days) corresponding to discharge phases. Figure 3 shows tritium activity measured in the air at the Creys-Malville site by EDF between June 2011 and December 2017. As shown on this figure, the considerable increase in atmospheric tritium discharges in 2014 and 2016, compared with figures for previous years, led to an increase in the number of significant measurements, and the levels measured. On the other hand, the very low discharge levels for atmospheric tritium in 2015 also reflected a lack of significant measurements during this period.

Figure 4 shows tritium activity measured in rainwater at the Creys-Malville site by EDF and IRSN between June 2011 and December 2017. Rainwater analyses reflect an increase in activity, however this indicator is less sensitive (due to the fact that the effluents discharged are diluted in rainwater) and less frequently viable (as rain is not continuous). 93% of the 163 measurements are below the decision thresholds (approx. 5 - 6 Bq/L), only 11 measurements indicate significant values between 2.1 and 16.5 Bq/L. Transient increases in ambient activity moderately affect the other terrestrial components for a very short period. Grass, vegetable, cereal and milk samples do not integrate these transient increases. On this basis, mean tritium activity levels between 2011 and 2017 in grass (3.18 Bq/kg fresh), vegetables (2.91 Bq/kg fresh), cereals (1.64 Bq/kg fresh) and milk (1.77 Bq/L), measured as part of radioecological studies, are low and within the background radiation range for environmental tritium (from less than 1 to 3 Bq/L).

FIGURE 3 / **TRITIUM ACTIVITY MEASURED IN THE AIR IN THE IMMEDIATE VICINITY OF THE CREYS-MALVILLE SITE BETWEEN JUNE 2011 AND DECEMBER 2017 (Bq/m^3)**

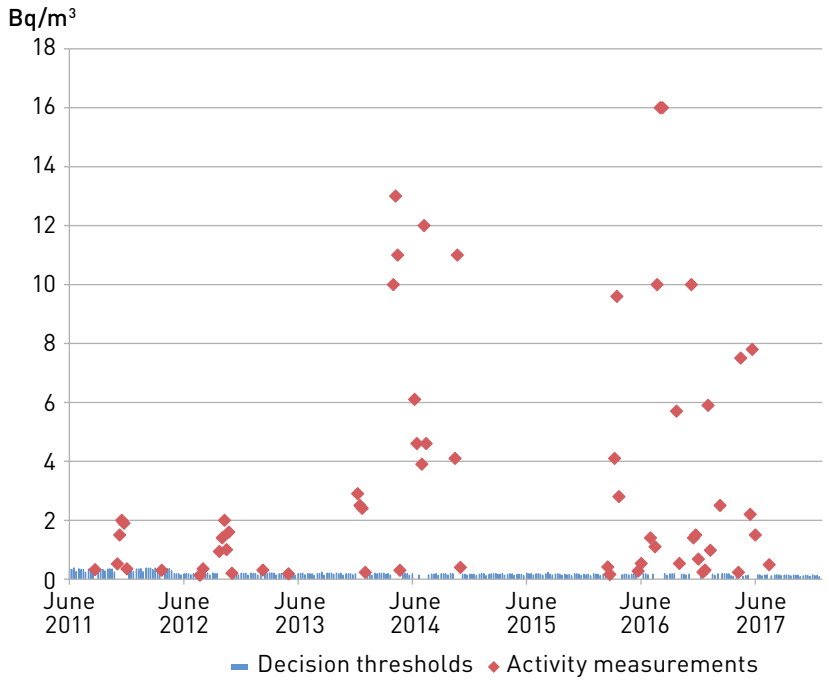
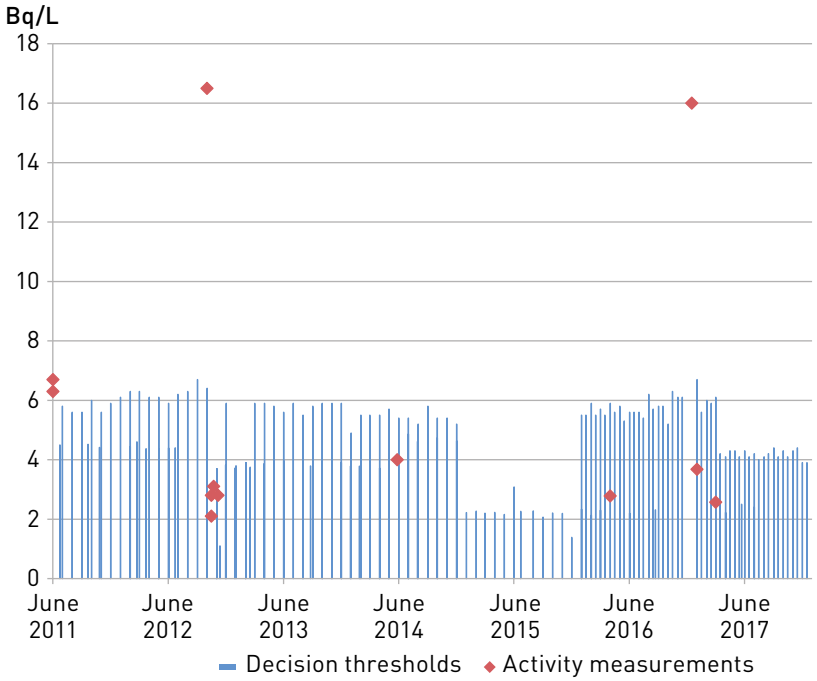


FIGURE 4 /TRITIUM **ACTIVITY MEASURED IN RAINWATER IN THE IMMEDIATE VICINITY OF THE CREYS-MALVILLE SITE FROM JUNE 2011 TO DECEMBER 2017 (Bq/L)**



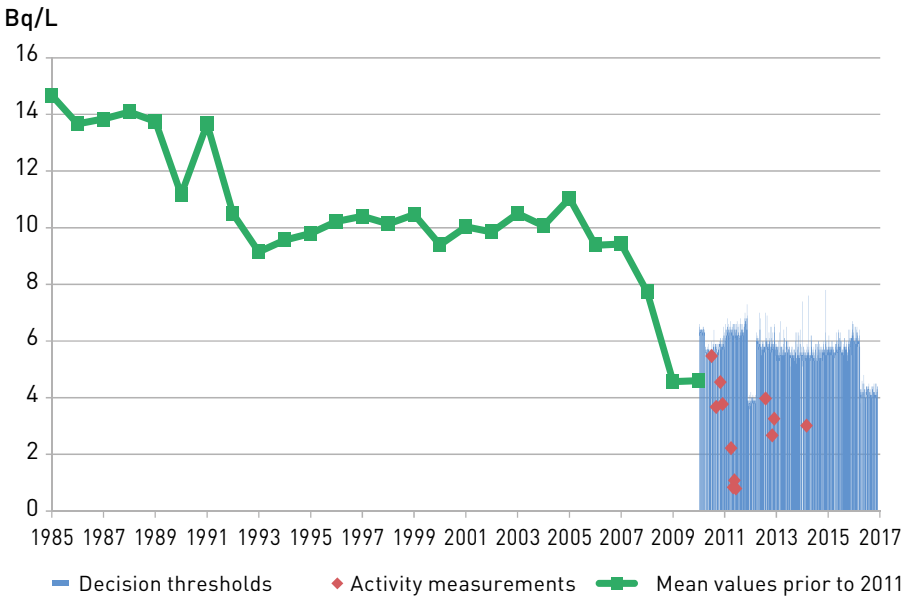
EDF asked IRSN to organise a specific measuring campaign to improve the characterisation of discharges: 12 TBq of tritium was discharged between 24 September and 9 November 2012.

This measuring campaign confirmed that the increase in tritium activity was moderate and transient after the discharge. On this basis, after a peak in ambient activity was reached at 0.96 Bq/m^3, at the same time as rainwater activity of 16.5 Bq/L, the activity levels measured in grass and milk (3.9 Bq/L) remained close to background radiation levels. Only oak leaves reached a level of 12 Bq/kg fresh. This impact is very low due to the fact that the tritium discharged is tritiated hydrogen (HT), which does not easily transfer to the living environment compared with tritiated water vapour (HTO). Plant contamination was also limited due to autumn. Tritium levels returned to normal figures from the end of November, i.e. after just a few weeks.

99% of measurements for Rhône water samples downstream from the Creys-Malville site are below decision thresholds. Tritium activity is significant for a few measurements at approx. 5 - 6 Bq/L and particularly those obtained from the water sampling system located downstream from the Creys-Malville (see figure 5). These measurements are slightly above background radiation (1- 3 Bq/L). Tritium activity is not regularly recorded in Rhône river water, upstream from this site, therefore no conclusion can be reached in terms of the source of the tritium measurements. Tritium activity measurements in ground water are all below the decision threshold (6 Bq/L).

With the exception of iodine-131 from medical sources, measured in aquatic plants, all other measurements taken in the immediate environment around the Creys-Malville site is at background radiation levels, i.e. natural radioactivity and residual fallout from the Chernobyl accident or the atmospheric testing of nuclear weapons. Bound tritium and ^{14}C measurements in fish are illustrated in chapter 3.1 "Operational NPP".

FIGURE 5 / **VARIATION IN MONTHLY TRITIUM ACTIVITY MEASURED IN THE RHÔNE RIVER DOWNSTREAM FROM THE CREYS-MALVILLE SITE (Bq/L)**



According to the study of radiological measurements for environmental samples taken in the vicinity of the Creys-Malville site, only tritium is involved in the impact of discharges from this site. However, tritium activity levels in farming output and drinking water are similar to those measured in areas unaffected by facilities. Tritium discharges from the site do not reach measurable levels in food, therefore the dose absorbed by eating local food grown near to the site cannot be assessed. On the other hand, doses absorbed by inhaling or transcutaneously can be calculated based on the concentration measured in the air. This dose is assessed for an adult spending all of their time on the site and the mean significant measurement (4.14 Bq/m^3) is used as the concentration in the air. 20 out of the 28 measurements taken in 2016 were significant and 8 were below the decision threshold. On this basis, the concentration in the air will be weighted by a coefficient of 20/28 to integrate the presence or absence of tritium activity above background radiation levels. The flow inhaled per day by local residents is taken as 24 m^3/day. Based on the above assumptions, the dose inhaled and percutaneous transfer represents approx. 0.06 µSv/year if we assume that the tritium discharged is 90% HT and 10% HTO, as shown by the study from 2012.

Brennilis site

The Monts d'Arrée site (SMA) is located in the Finistère region, in the Brennilis municipality, just 35 km to the south of Morlaix. The site is at the end of Saint-Michel lake. The site is home to the Brennilis nuclear powerplant and the Saint-Michel and Saint-Herbot hydraulic dams. The Brennilis nuclear powerplant ran from 1967 to 1985, with a rating of 70 MW. The site was definitively shut down in 1985, and is currently being decommissioned.

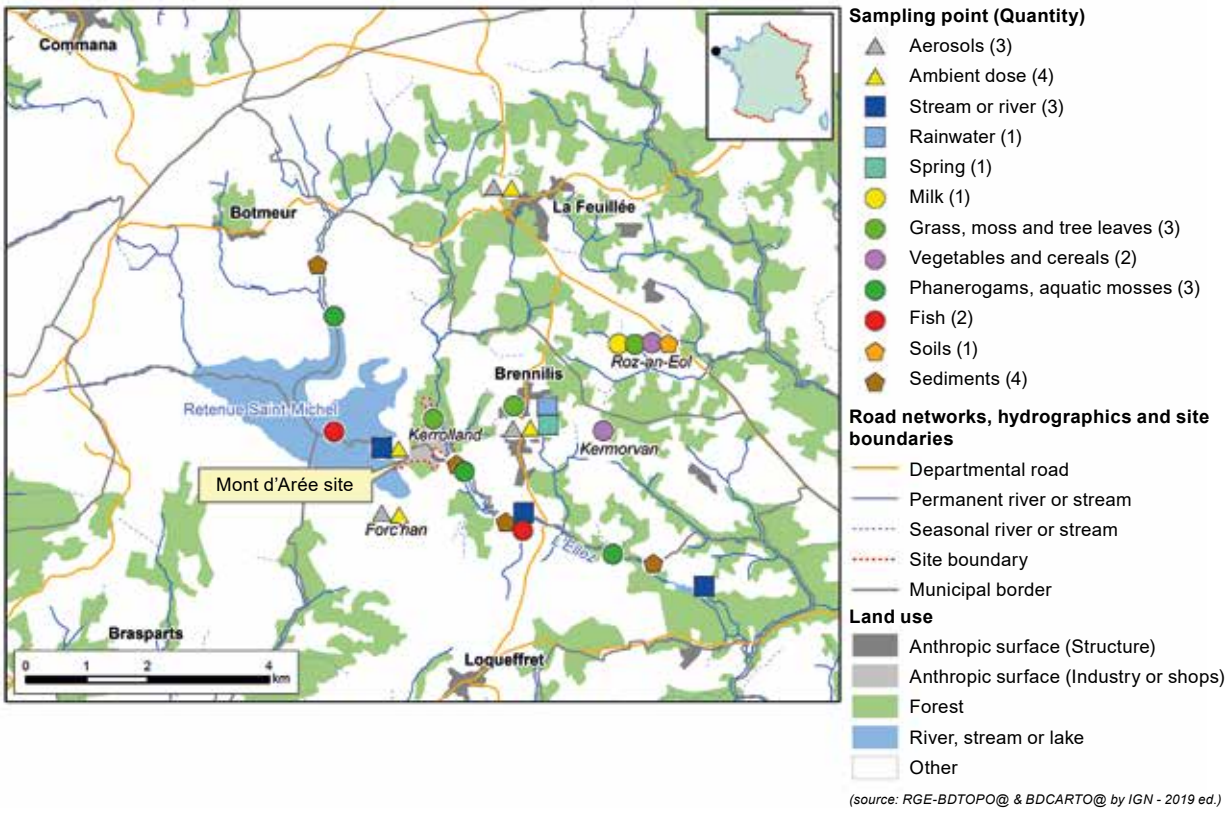
Discharges and monitoring the environment

While the plant was operating, the main gaseous and liquid effluents authorised for discharge comprised tritium. Gaseous tritium continued to be produced after the site was shut down, but at lower levels. Liquid effluents continued to be discharged into the Ellez river up to 1992 and ceased after this time. Less liquid effluents are currently sent to an external operator for processing, and these effluents do not contain tritium. The Monts d'Arrée site holds special authorisation to discharge radioactive substances into the environment, in gaseous phase, as required by regulations. The radioactive gases discharged are output from building ventilation systems. Most of the activity discharged is tritium. Table 1 shows the activities discharged for the 2012 - 2016 period. Discharge levels fluctuate due to decommissioning operations.

The Monts d'Arrée regulatory environmental monitoring programme is shown in table 2 and figure 1. This programme is completed with annual or ad hoc radioecological studies entrusted to external laboratories by EDF. This programme monitors:

- rainwater (Brennilis weather station);
- surface water (Ellez river, St-Herbot lake);

TABLE 1 / **MAP SHOWING THE LOCATIONS OF SAMPLES TAKEN UNDER THE ENVIRONMENTAL MONITORING PLAN FOR THE BRENNILIS SITE IN 2016**



(source: RGE-BDTOPO@ & BDCARTO@ by IGN - 2019 ed.)

- ground water (Vierge spring at Brennilis, ground water under the site);
- the air (Brennilis, La Feuillée, and Forc'han weather stations);
- the food chain (salads, wheat and milk at Kermorvan, Roz-an-Eol and Tromathiou);
- terrestrial plants (grass and underlying soil at Roz-an-Eol and Tromathiou, mosses at Brennilis and Landivisiau, oak leaves at Kerrolland and Landivisiau);
- sediments, aquatic plants (mosses and phanerogams) and fish in the Ellez river, upstream and downstream from the Brennilis fish;
- ambient radiation (Brennilis and La Feuillée weather stations).

The impact of the Brennilis site on its immediate environment

All environmental monitoring measuring results for the immediate environment around the site are below decision thresholds, including for tritium, reflecting the fact that no liquid effluents are discharged and gaseous discharges remain at very low levels.

EDF has run an environmental monitoring programme for the site since 2012 in order to better characterise the potential impact of decommissioning operations on the environment. According to gamma and alpha spectrometry measurements for the various samples taken in terrestrial and aquatic components, radioactivity levels can exceed mean values in France, but represent either natural radioactivity (radionuclides from the natural decay of uranium), or residual fallout from the testing of nuclear weapons (^{137}Cs and plutonium isotopes), and the Chernobyl accident to a lesser extent. High levels of natural and artificial radioactivity can be caused by specific soil and geology configurations and by high rain levels at the site respectively. In the terrestrial component, ^{3}H and ^{14}C activity levels correspond to ambient levels measured in areas unaffected by industrial operations. In the aquatic component, ^{14}C levels in fish captured upstream and downstream are approximately similar. In the same way, no ^{14}C and ^{3}H have been detected in aquatic plants since 2012. On the other hand, organically bound tritium and ^{14}C are still detected in sediments, demonstrating residual fallout at the site, as revealed in previous studies by IRSN in 2002 and 2008, and in annual radioecological monitoring. This contamination is, however, decreasing, as the site has not discharged liquid effluents since 1992.

TABLE 1 / **ACTIVITY LEVELS DISCHARGED FROM THE BRENNILIS FACILITY OVER THE 2012 - 2016 PERIOD**

Overview of atmospheric discharges (GBq/year)			
Activity levels discharged	Tritium	Other gamma- or beta-emitting activation or fission products	Carbon-14
2012	39.9	0.00118	0.0694
2013	39.8	0.000025	0.2
2014	31.6	0.0000096	0.233
2015	27.7	0.0000976	0.251
2016	26.4	0.000109	0.049

TABLE 2-A / **REGULATORY MONITORING PLAN DRAFTED BY EDF FOR THE IMMEDIATE ENVIRONMENT OF THE BRENNILIS SITE**

Environment monitored or type of testing	EDF
Ambient gamma radiation	• 4 dosimeters around the edge of the site • 5 dosimeters within a radius of 1 km • 1 dosimeter within a radius of 5 km • 1 gamma sensor within a radius of 1 km
Soil air	• 3 daily measuring and sampling points for gross beta activity with a filter • γ spectrometry if values > 2 mBq/m^3 • 1 monthly γ spectrometry run for combined daily filters at one single sampler • Continuous sampling based on the prevailing winds with weekly atmospheric tritium measurements
Rainwater	• Continuous sampling based on the prevailing winds with bi-monthly measurements for tritium and gross beta activity
Ground water	• 6 sampling points: (3 shafts + 3 pump manifolds): monthly ^{3}H, ^{40}K and gross beta activity measurements and/or γ spectrometry runs for filtered water and gross beta activity measurements for TSS
Soils	• 1 annual sampling run for topsoil layers: γ spectrometry
Plants	• 2 monthly grass samples (including 1 in the prevailing wind direction): monthly γ spectrometry analyses + annual ^{14}C, HTO and OBT
Milk	• 1 quarterly milk sample (including 1 in the prevailing wind direction): γ spectrometry + tritium + annual ^{14}C
Soils	• 1 annual sampling run: γ spectrometry
Aquatic flora	• 2 annual sampling runs (upstream/downstream: γ spectrometry
Aquatic fauna	• 2 five-year sampling runs (upstream/downstream): γ spectrometry + OBT + ^{14}C
Sediments	• 2 annual sampling runs (upstream/downstream: γ spectrometry
Farm output	• 1 annual sampling run for the main farming output: γ spectrometry, ^{14}C, HTO and OBT

TABLE 2-B / **ANNUAL RADIOECOLOGICAL MONITORING PLAN FOR THE IMMEDIATE ENVIRONMENT OF THE BRENNILIS SITE IN 2017**

Matrix	Gamma spectrometry	HTO	OBT	C-14	Ni-63	Fe-55	Alpha spectrometry
Grassland soils					2	1	
Grass	1						
Milk	1		1				
Terrestrial moss	2						
Oak tree leaves		2	2	2			
Sediment			4	4	3		4
Aquatic moss	2				2		
Aquatic phanerogams			2	2			
Fish	2						

FIGURE 2 / **ORGANIC TRITIUM ACTIVITY IN AQUATIC PLANTS AND SEDIMENTS UPSTREAM AND DOWNSTREAM FROM THE BRENNILIS SITE OVER THE 2012 - 2017 PLANT (Bq/L of combustion water)**

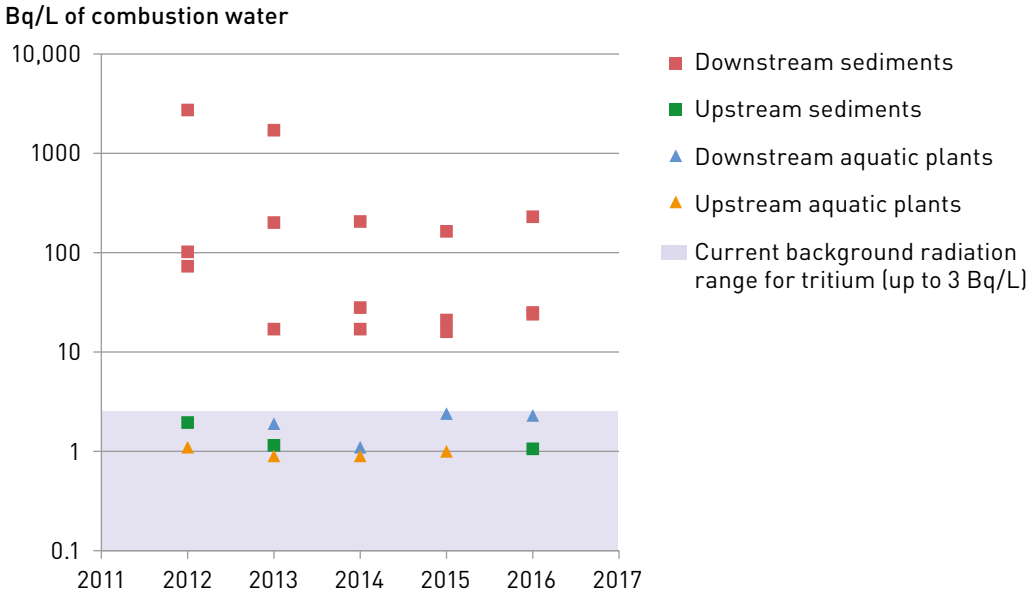
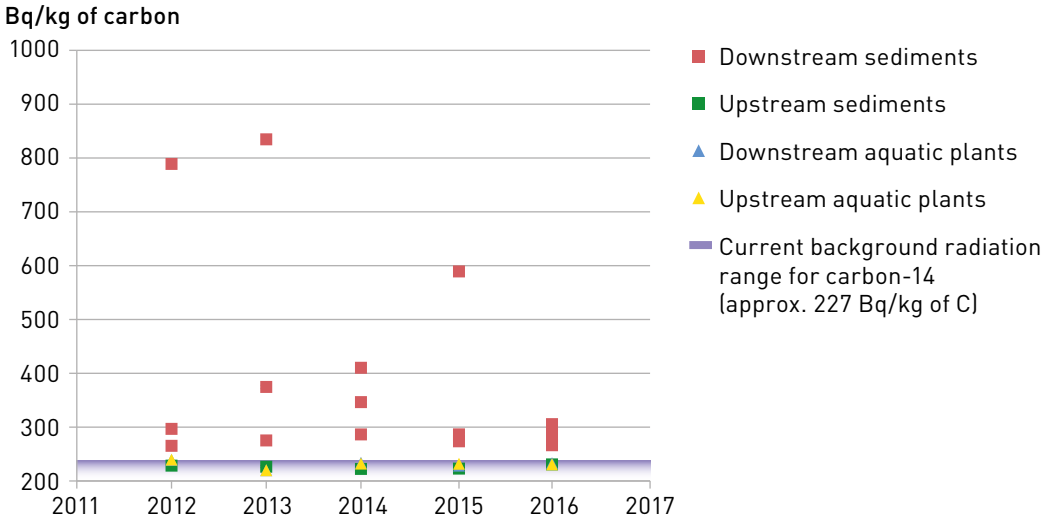


FIGURE 3 / **^{14}C ACTIVITY FOR AQUATIC PLANTS AND SEDIMENTS UPSTREAM AND DOWNSTREAM FROM THE BRENNILIS SITE OVER THE 2012 - 2017 SITE (Bq/kg of carbon)**



3.3. INDUSTRIAL SITES

Malvési site

Since 1959, the Orano plant at Malvési, just 3 km to the north of the town of Narbonne (Aude département, see figure 1), has purified uranium concentrates from mines ("yellow cake") and converted uranium into UF4. The conversion plant currently produces approximately 10,000 tons/year. The effluents discharged during the uranium purification process are treated and subsequently routed to settling and evaporation basins located on the site. In addition to the uranium conversion plant, the Orano site at Malvési is home to old effluent basins (B1/B2), currently dedicated to storing historical waste (ECRIN nuclear facility).

Discharges and monitoring plans

Discharges from the Malvési plant only contain uranium radionuclides. The liquid effluents discharged only contain rainwater and industrial water *via* the Tauran canal, which runs alongside the Malvési site. The Tauran canal runs to the Robine canal, which crosses the town of Narbonne before reaching Bages-Sigean lake. 0.2 kg of uranium was discharged in 2016, which is equivalent to 0.005 GBq of natural uranium. Uranium discharges into the atmosphere were halved between 2008 and 2009 and have remained fairly constant since that time despite fluctuations from year to year. (see figure 2). 24 kg of uranium was discharged into the atmosphere in 2016 by the different plant workshops, which is equivalent to 0.6 GBq of natural uranium.

FIGURE 1 / **LOCATION OF ORANO'S SITE IN THE AUDE DÉPARTEMENT**

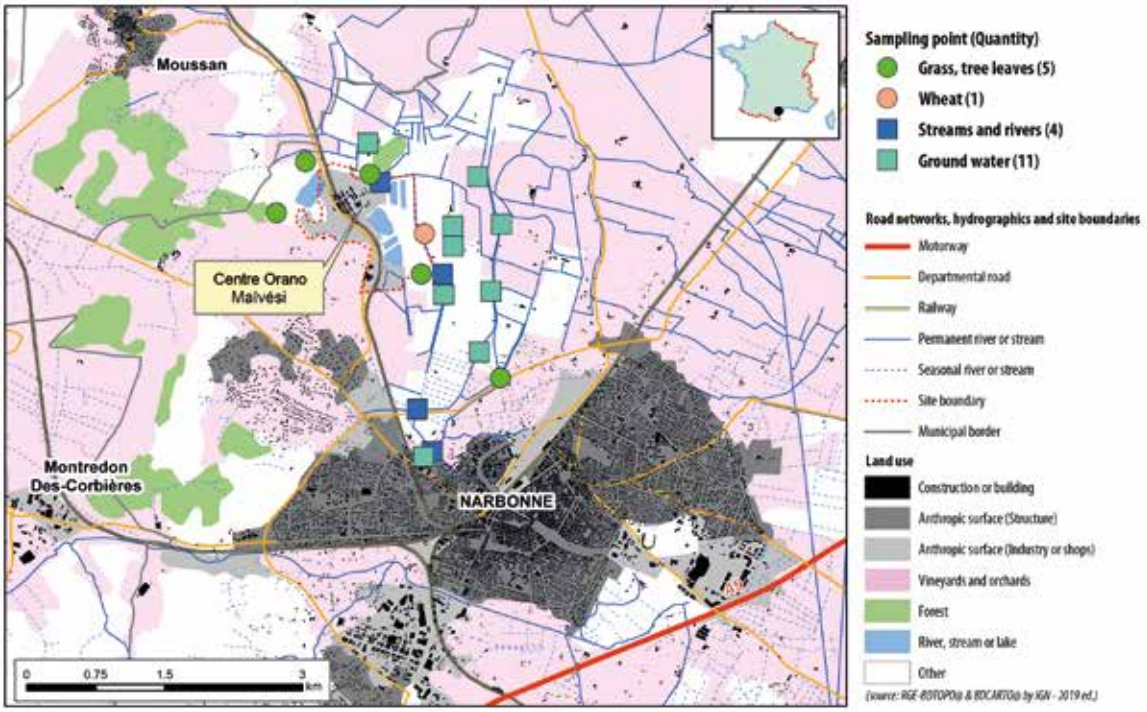
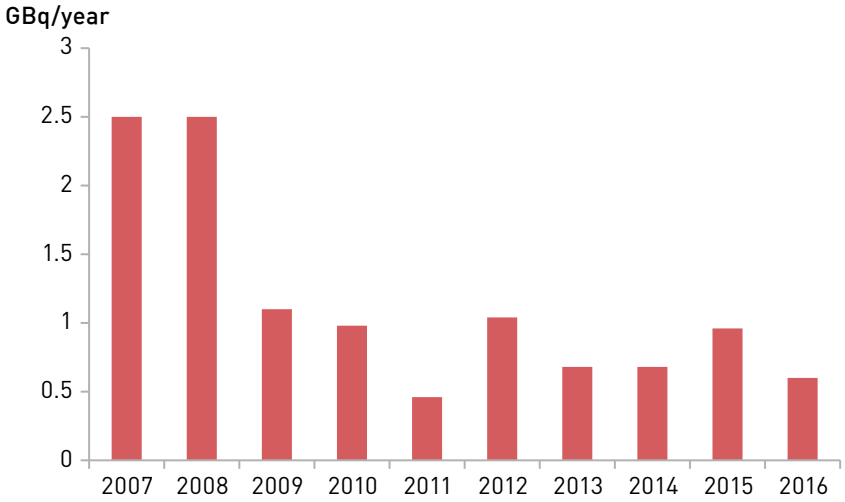


FIGURE 2 / **TIMELINE FOR RECURRENT ATMOSPHERIC URANIUM DISCHARGES FROM THE MALVÉSI PLANT (GBq/year)**



The ECRIN nuclear plant also discharges radionuclides in addition to the effluents discharged from plant operations. Small quantities of dust are released and suspended in the air due to wind. They then diffuse, despite the covers fitted on basins B1/B2 since 2007. Rainwater is collected from the nuclear facility and sent to evaporation basins or discharged into the Tauran canal, after processing. The ECRIN facility is mainly likely to release thorium-230, which is a natural decay product for uranium-238, and plutonium, an artificial radionuclide, to a lesser extent.

Finally, a tank of uranyl nitrate at the Malvési workshops leaked on July 2016. ASN classified this incident at level 1 on the INES scale (which has 7 levels), and the leak had no significant consequences on site personnel or the immediate environment.

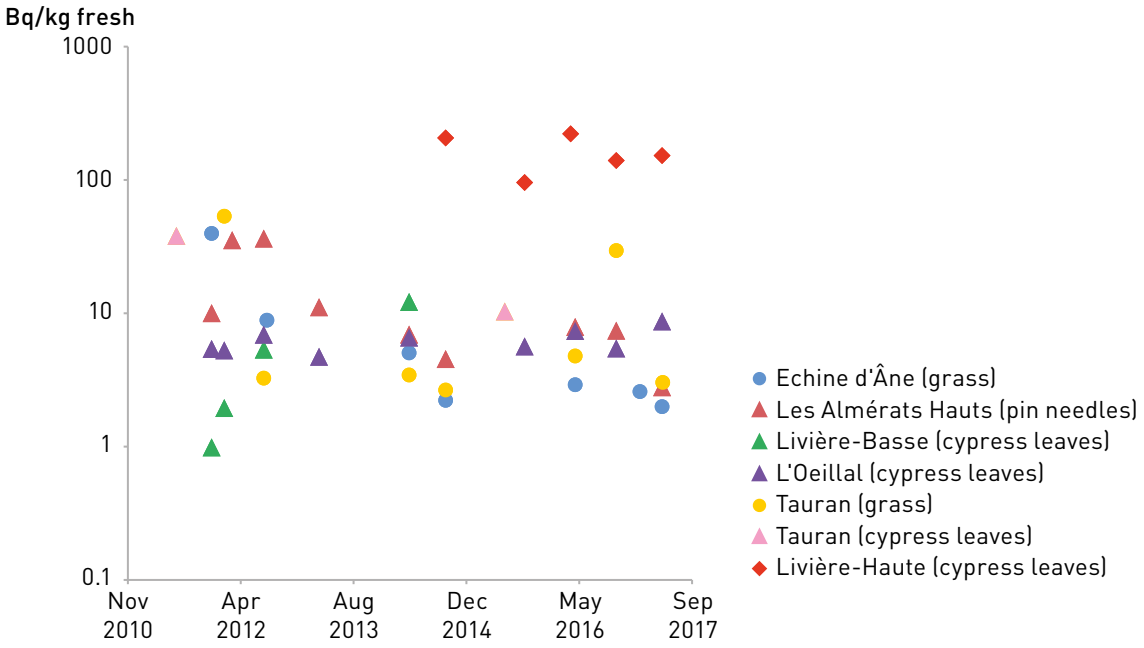
The uranium conversion plant at Malvési must comply with the rules applicable to Environmentally-Classified Sites (ICPE) and with the provisions of the prefectoral order on monitoring the environment. ECRIN nuclear facility monitoring is defined by ASN decisions from a regulatory viewpoint and is also part of the plant's monitoring plan. Orano takes aquatic samples from the Tauran canal on a periodic basis, both upstream and downstream from the discharge point. Additional samples are also taken farther downstream, in the town of Narbonne (Robine canal) up to the Bages-Sigean lake. The uranium concentration in the ground water samples taken near to the site is also measured both in the immediate vicinity of the site and in a local well approximately one kilometre from the site. The operator also analyses local farming output (fruit and vegetables). In the Malvési environment, IRSN prefers to measure uranium in surface water (the Tauran canal) and terrestrial plants (tree leaves, grass and wheat).

The impact of the Malvési site on its immediate environment and public exposure

The impact of the Malvési site is most visible in the terrestrial and aquatic environment for uranium isotopes (^{234}U, ^{235}U and ^{238}U). In fact, uranium discharges from the conversion process increase the uranium activity of atmospheric dust at local level. This dust then settles on terrestrial plants and surface water, as well as aquatic plants.

Cypress leaf samples have been taken to the north (in the Œillal village), and south east (Tauran) of the Orano site (figure 3) since 2011. The sampling site used in the south (Livière-Basse) between 2011 and 2013 was moved to the east of the site (Livière-Haute) from 2014. Samples of other plant matrices (pine needles and grasslands) were also taken to the west (Almérats Hauts and Échine d'Âne) and to the east of the site (Tauran), respectively. The highest uranium-238 activity levels (over 100 Bq/kg) were recorded to the east of the site at Livière-Haute, under the prevailing winds from the Orano site. Activity levels above 10 Bq/kg are occasionally measured at other sampling points, under the prevailing winds to the east (Tauran) or under secondary winds to the west of the site (Almérats Hauts and Échine d'Âne). This configuration means that the activity levels detected in terrestrial plants reflect the impact (to varying degrees depending on the sampling site) of the uranium discharged from the Orano site at Malvési, when compared with measurements for plant samples taken in areas unaffected by discharges from the nuclear industry (0.1-1 Bq/kg dry).

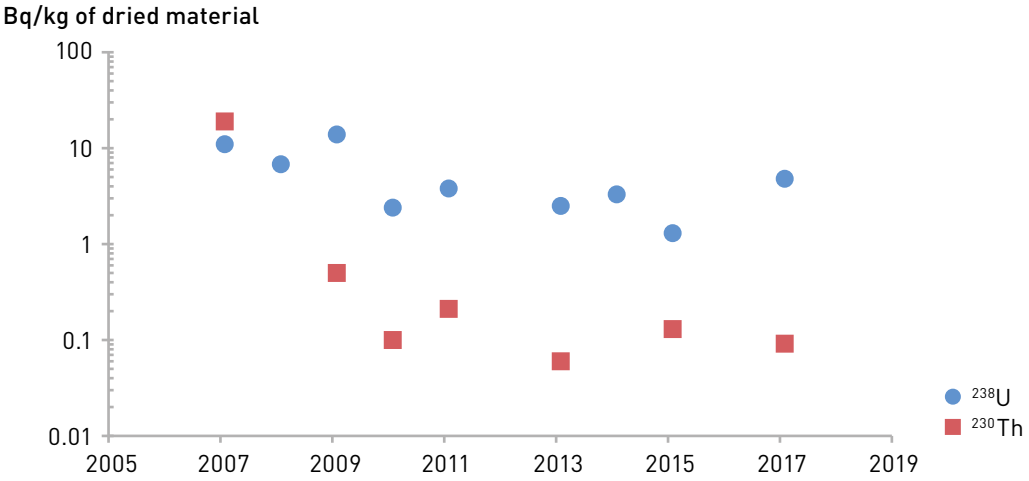
FIGURE 3 / **URANIUM-238 ACTIVITY BY MASS IN PLANT SAMPLES TAKEN IN THE TERRESTRIAL ENVIRONMENT AROUND THE ORANO SITE AT MALVÉSI BETWEEN 2011 AND 2017 (Bq/kg fresh)**



Uranium-238 activities measured in wheat stalk samples collected from around the eastern edge of the Malvési site are relatively high (mean value: 3.0 Bq/kg over the 2014-2017 period) and similar to the values recorded over the previous period (mean value: 3.2 Bq/kg for the 2011-2014 period) (figure 4). Although the measurements recorded since 2010 are lower than those recorded over the previous three years, they remain well above the values measured by IRSN in areas unaffected by nuclear discharges (activity between 0.011 and 0.17 Bq/kg).

On this basis, uranium-238 levels in plants over the 2014-2017 period are generally similar to levels during the previous period (2011-2014), demonstrating that atmospheric uranium-238 activity was similar over the two periods, with a mean value of 30 µBq/m^3 of air. This mean value was established using measurements taken during the 2009-2010 period using a high-flow sampler installed by IRSN. This mean can be compared with the uranium activity observed in France in areas unaffected by fuel cycle facilities: approx. 0.2 µBq/m^3 of air.

FIGURE 4 / **URANIUM-238 AND THORIUM-230 ACTIVITY BY MASS FOR WHEAT EAR SAMPLES TAKEN TO THE EAST OF THE ORANO SITE AT MALVÉSI BETWEEN 2007 AND 2017 (Bq/kg dry)**



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Aerial view of the Malvési site

The concentration by volume of uranium in the surface water samples taken upstream from the discharge points (Tauran canal) is below the decision threshold (0.5 µg/L) 63% of the time. Downstream from the discharge point, the mean concentration by volume of uranium fell over time, dropping from 4.0 µg/L between 2011 and 2014 to 1.7 µg/L between 2011 and 2017 (equivalent to mean uranium-238 activity of 0.02 Bq/L) (figure 5). Figure 6 clearly shows how the mean value has dropped substantially since the early years of the 21st century.

In addition, the mean concentration by volume in water samples taken downstream remains below the WHO's guide value (30 µg/L).

FIGURE 5 / **URANIUM CONTENT OF TAURAN CANAL RIVER WATER UPSTREAM AND DOWNSTREAM FROM THE MALVÉSI SITE DISCHARGE POINTS BETWEEN 2011 AND 2017 (µg/L)**

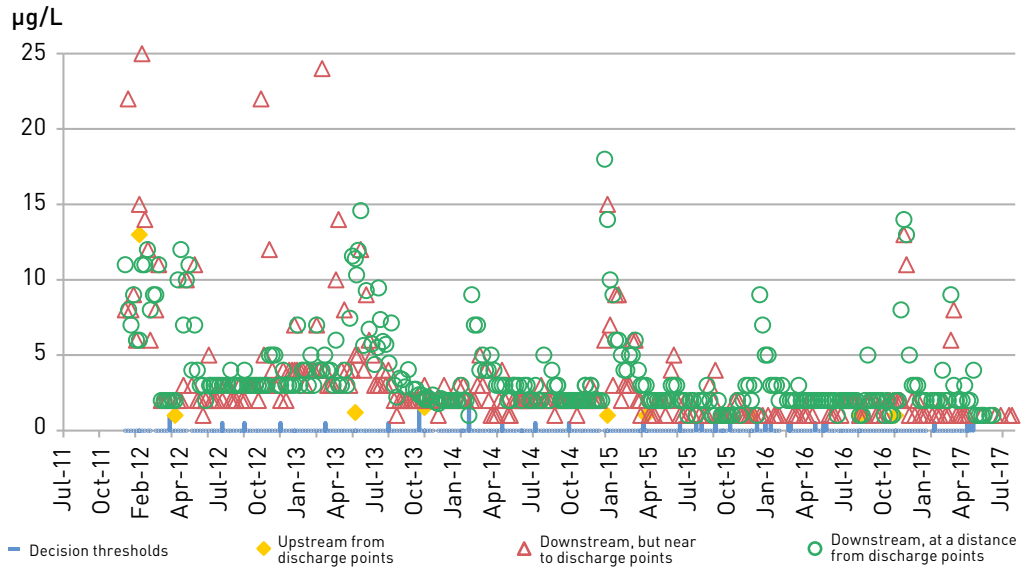
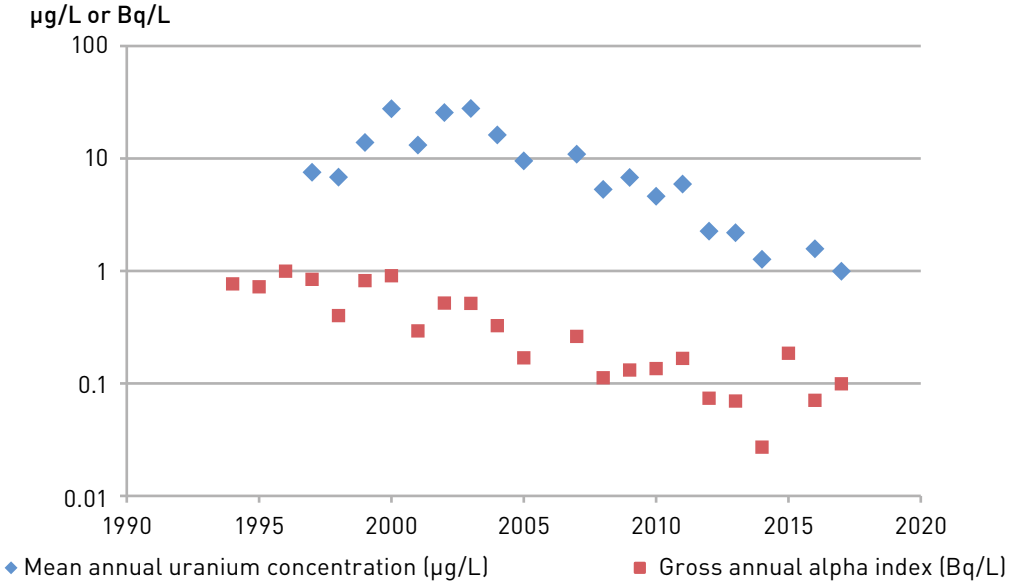


FIGURE 6 / **TIMELINE FOR RECURRENT URANIUM CONCENTRATIONS BY VOLUME IN TAURAN CANAL RIVER WATER BETWEEN 1997 AND 2017 (µg/L)**

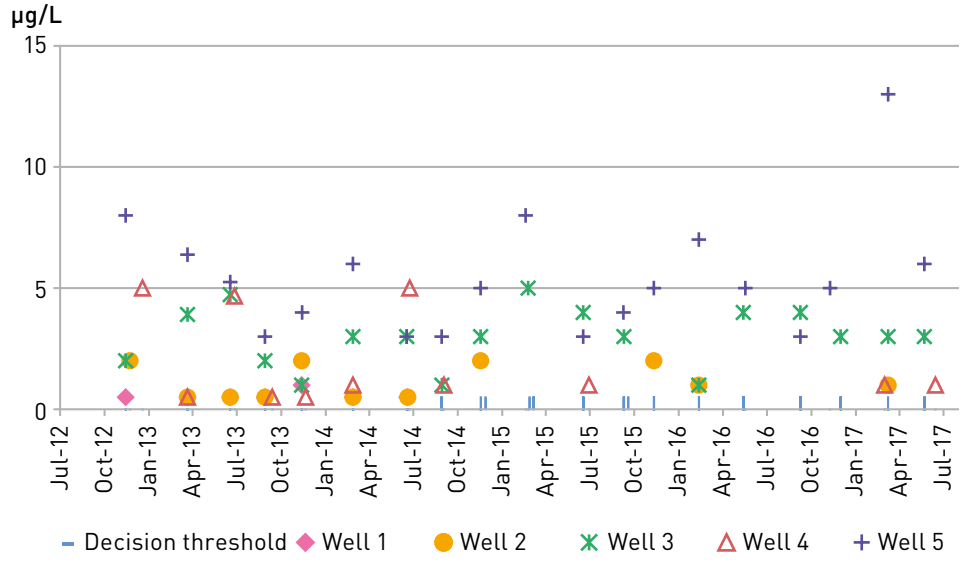


In addition, according to the analyses of ground water samples taken on the premises of local residents, the concentration of uranium by volume varies between sampling points (figure 7). However, the uranium concentration for any given sampling location is fairly constant over time. The mean ^{238}U concentration represents 2.5 µg/L, which is equivalent to a mean activity for this radionuclide of 0.031 Bq/L [1], although the source of the uranium may remain uncertain (natural or due to the site).

Other radionuclides have been detected in the immediate environment of Malvési, in addition to uranium, however, in far smaller quantities. These radionuclides, which include thorium-230 and plutonium-239+240, are released by the ECRIN nuclear facility. On this basis, ^{230}Th activity recorded in wheat samples taken from the edge of the site has decreased considerably since since 2007 (see figure 4). ^{230}Th activity in wheat (0.1 Bq/kg) since 2010 has remained within the data bracket established by IRSN in areas unaffected by discharges (between 0.009 and 0.2 Bq/kg).

According to measurements for discharges and environmental activity, uranium isotopes are the main cause of potential exposure for local residents to discharges from the site. Residents in an area affected by atmospheric discharges to the east of the plant would absorb an effective dose by inhaling uranium dust equal to 2.0 µSv/year. This figure is similar to the values calculated by the operator assuming that residents inhale dust at the edge of the site: 1.7-19 µSv/year. According to the various food surveys carried out in France, the wheat and other cereal by-products eaten by consumers are rarely grown locally. In addition, these wheat plots are owned by Orano and used for sowing. Despite this, eating one kg of wheat grown at the edge of the site would involve a dose of 0.01 µSv/kg. In the same way, local residents do not regularly drink Tauran canal water. However, if they did (e.g. to fill a water bottle), drinking 1 L of it would lead to an extremely low uranium dose of 0.002 µSv/L.

FIGURE 7 / **URANIUM CONCENTRATION BY VOLUME MEASURED IN THE WATER SAMPLES TAKEN FROM FIVE WELLS NEAR TO THE ORANO PLANT AT MALVÉSI (µg/L)**



1. The order of 11 January 2007, on reference limits for raw water quality and water intended for human consumption, does not define the maximum value for drinking water for alpha-emitting radionuclides such as uranium, but does however state that a specific radionuclide analysis is necessary if gross α activity exceeds 0.10 Bq/L.

Tricastin site

The Tricastin site is located in the Rhône valley between Bollène and Pierrelatte, near to the EDF NPP, and is home to several uranium enrichment and conversion sites (see figure 1). Orano also operates in the sector of uranium chemistry (mainly uranium defluoridation and denitration), dismantles former enrichment plants based on gaseous diffusion and maintains uranium transport containers.

SET (Société d'Enrichissement du Tricastin) enriches uranium using centrifugal techniques at the Georges Besse II plants, while the EURODIF gaseous diffusion enrichment plant was shut down in June 2012. Finally, SOCATRI is responsible for treating effluents containing uranium, and for treating, storing and disposing of radioactive and conventional waste.

In 2017, seven basic nuclear facilities (INB) and one secret basic nuclear facility (INBS) existed at the Tricastin site. The site is also home to two SEVESO-classified environmentally-classified (ICPE) sites.

Radioactive discharges at the Tricastin site

Although a high percentage of the industrial activity at the site involves uranium, artificial radionuclides, fission or activation products, are discharged by the Tricastin site facilities (see figures 2 and 3). Discharge levels are fairly constant since 2010. Carbon-14 and tritium are the main radionuclides in atmospheric discharges, at similar quantities (1.7 and 1.3 GBq/year respectively in 2015). Uranium activities discharged into the air, for all isotopes, are approximately 100 times lower (0.04 GBq/year, 2015 data) and are mainly discharged from the conversion unit. Transuranic elements (mainly plutonium isotopes) and fission products represent 0.0002 and 0.005 GBq/year respectively (2015 data). As the prevailing winds in the Rhône valley (80% N-NE and 15% S-SW) disperse discharges to the north or (predominantly) to the south of the site, this is the main area affected by atmospheric discharges from the Tricastin site.

After activity levels have been checked and treated, process effluents are routed to the Donzère-Mondragon canal, to the east of the site. In 2015, liquid radioactive discharges from the site mainly comprised uranium isotopes, of which approx. 4.4 GBq/year are discharged into the canal each year. Most of the uranium discharged

FIGURE 1/ **LOCATION OF AREVA'S SITE AT TRICASTIN**

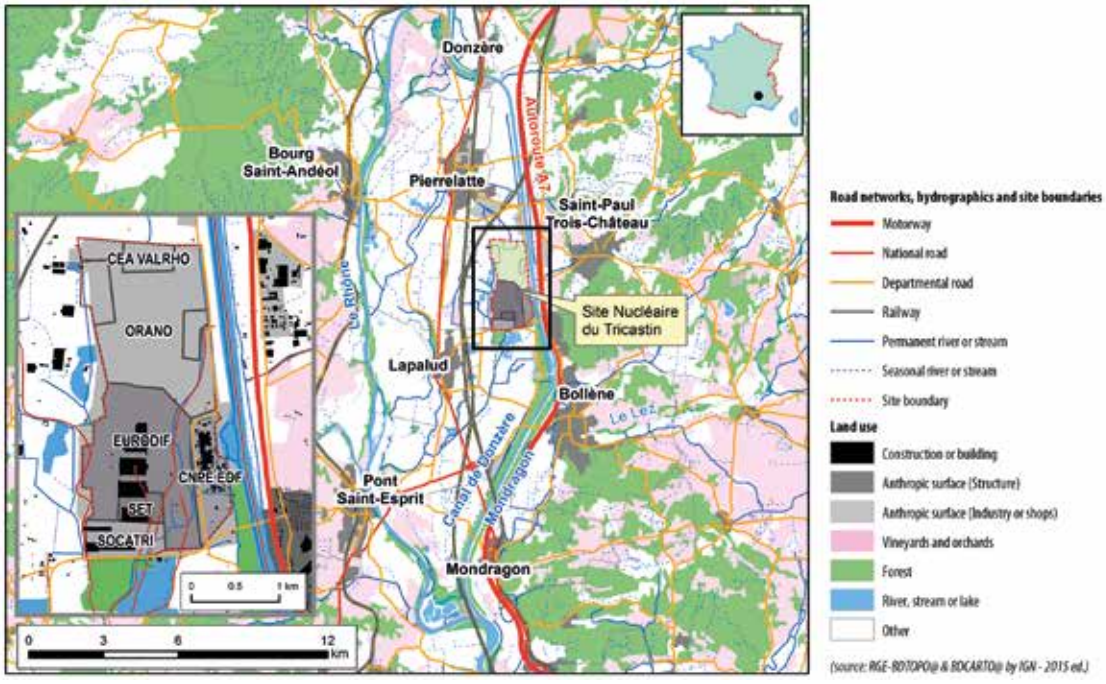


FIGURE 2 / **TIMELINE FOR RECURRENT ATMOSPHERIC DISCHARGES FROM ORANO'S SITE AT TRICASTIN OVER THE 2009-2016 PERIOD (GBq/year)**

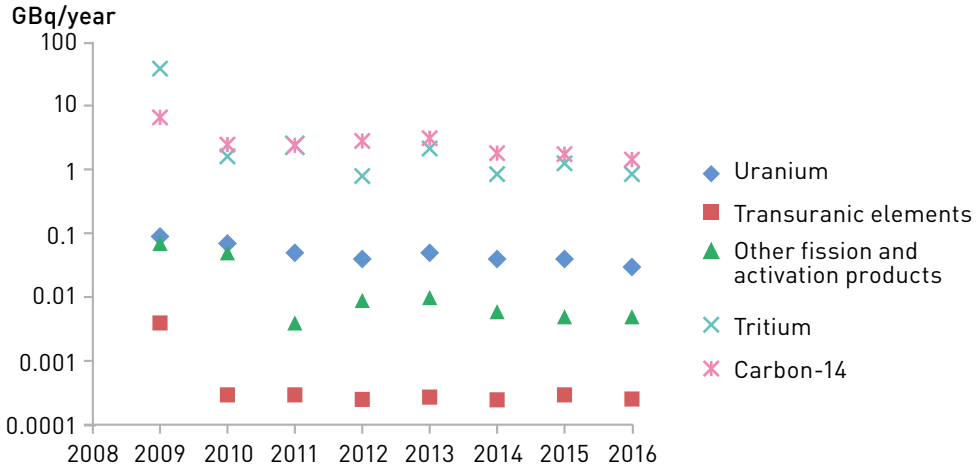
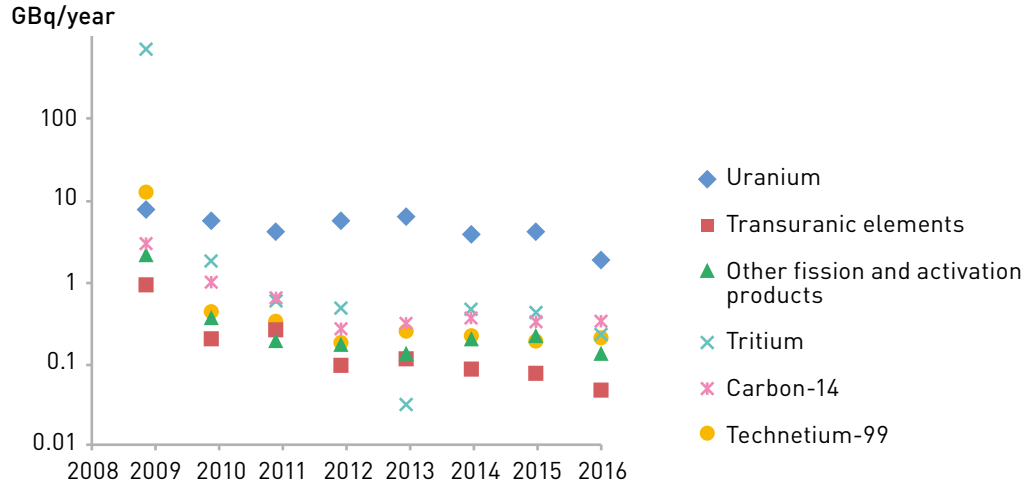


FIGURE 3 / **TIMELINE FOR RECURRENT LIQUID DISCHARGES FROM ORANO'S SITE AT TRICASTIN OVER THE 2009-2016 PERIOD (GBq/year)**



comes from the INBS. The aqueous effluents discharged from the Orano site at Tricastin also include artificial radionuclides such as carbon-14 (0.3 GBq/year), tritium (0.4 GBq/year), other fission products (0.23 GBq/year) and transuranic elements (0.08 GBq/year).

Two events at Orano's facilities in Tricastin were declared by the operator and led to low level discharges into both the atmosphere and the Donzère-Mondragon canal in August 2015 and September 2016 respectively. The consequences of these discharges cannot be detected in uranium measurements as part of monitoring, mainly because the quantities involved are not large enough. For example, if a facility normally discharges 1.7 kg of uranium into the atmosphere each year, 22.8 g of this uranium cannot be detected in the environment.

Monitoring the immediate environment of Orano's site at Tricastin

Orano is supported by a terrestrial and aquatic sampling network for monitoring radioactivity in the immediate environment of the Tricastin site: the Environmental Monitoring Network (Réseau de Surveillance de l'Environnement - RSE). Surface water samples from the Donzère-Mondragon canal are taken upstream and downstream from the discharge points in order to measure the concentration by volume of uranium and tritium. Uranium levels are also monitored in La Gaffière, a river which crosses the site and joins Trop-Long lake to the south of the site. Finally, Orano can access a network of piezometers to sample ground water and detect any effects downstream from the site. The terrestrial component is monitored based on a network of samplers located at points potentially affected by atmospheric discharges from the site. Grass and farming output are sampled at these locations, primarily for uranium and tritium measurements.

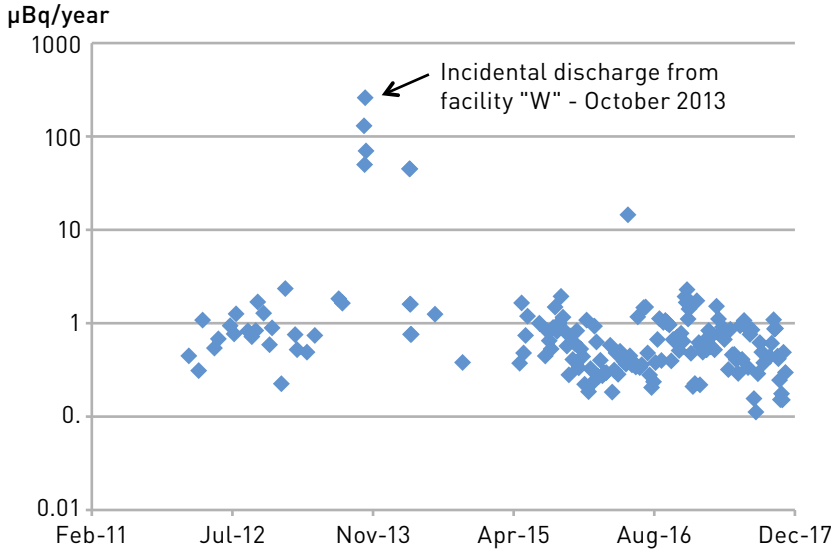
IRSN also takes samples from the main rivers mentioned above in order to detect any effects of the Tricastin site on the uranium concentration of water, aquatic plants and sediments. Transuranic elements are also measured in sediments. In the terrestrial component, IRSN monitors activity by taking plant and food samples at various locations, in view of measuring uranium, tritium and carbon-14. In addition, since 2014, IRSN has taken aerosol samples and uranium isotope measurements to the south east of the site, to complement the atmospheric measurements taken since 2011.

The impact of the Tricastin site and public exposure

Uranium isotopes

According to aerosol measurements taken by IRSN between April 2014 and November 2017, mean uranium-238 activity represents 1.1 µBq/m^3 of air, which is very similar to the value recorded between January 2012 and August 2013 (0.9 µBq/m^3 of air). This concentration by volume, which is higher than the uranium activity level measured in areas unaffected by discharges from fuel cycle units (0.2 µBq/m^3 of air), and the proportion of uranium-235 in the air, reflect the local effects of uranium discharges from the Orano facilities at Tricastin in the atmosphere. In addition, activity levels by volume considerably exceeded mean values (i.e. more than 10 µBq/m^3 of air) on two occasions (April 2014 and May 2016), although the source of the extra activity was not clearly identified (figure 4). It is also important to remember that the incidental discharge of depleted uranium from facility "W" (October 2013) led to ambient ^{238}U activity of more than 100 µBq/m^3 of air.

FIGURE 4 / ^{238}U ACTIVITY MEASURED IN AMBIENT AIR TO THE SOUTH OF ORANO'S SITE AT TRICASTIN SINCE 2012 (µBq/m^3 of air)



Living near to the sampler or at a similar distance from the site under the prevailing winds would lead to a dose after inhaling uranium dust of 0.06 µSv/year; this estimate is very similar to that for the previous period: 0.05 µSv/year.

This ambient activity leads to uranium-238 concentrations in plants, and particularly in the grass samples taken by Orano as part of regulatory monitoring. The activity levels measured are fairly stable and remain between 0.32 and 0.52 Bq/kg dry on average, depending on the sampling site (table 1). If we compare these figures with the 2011-2014 period, a slight increase in uranium activity in this matrix becomes apparent.

Uranium-238 activity in the tree leaf samples taken in the same area is higher (mean value: 2 Bq/kg) and varies between species. All of these measurements reflect the impact of ambient uranium activities and therefore site discharges on plants. Uranium-236, an artificial uranium isotope, measurements in these matrices also confirm these conclusions.

On the other hand, uranium-238 activity by mass in wheat samples taken to the south of the site in 2016 is surprisingly low (0.01 Bq/kg) compared with previous values, and is at the lower end of the bracket for IRSN data for areas unaffected by fuel cycle facilities (activity levels between 0.011 and 0.17 Bq/kg).

TABLEAU 1 / **MEAN URANIUM-238 ACTIVITY BY MASS IN GRASS SAMPLES TAKEN FROM THE ENVIRONMENTAL MONITORING NETWORK DURING THE 2015-2017 AND 2011-2014 PERIODS (Bq/kg dry)**

	2015-2017 Uranium-238 (Bq/kg)	2011-2014* Uranium-238 (Bq/kg)
ID1 - Faveyrolles	0.35	0.14
ID2 - Prés Guérinés	0.50	0.20
ID3 - Bollène-la-Croisière	0.52	0.24
ID4 - Lapalud	0.32	0.11

** The activity levels provided for 2011-2014 from the RNM database were incorrect. The data shown here were calculated using the U concentrations by mass measured during this period.*

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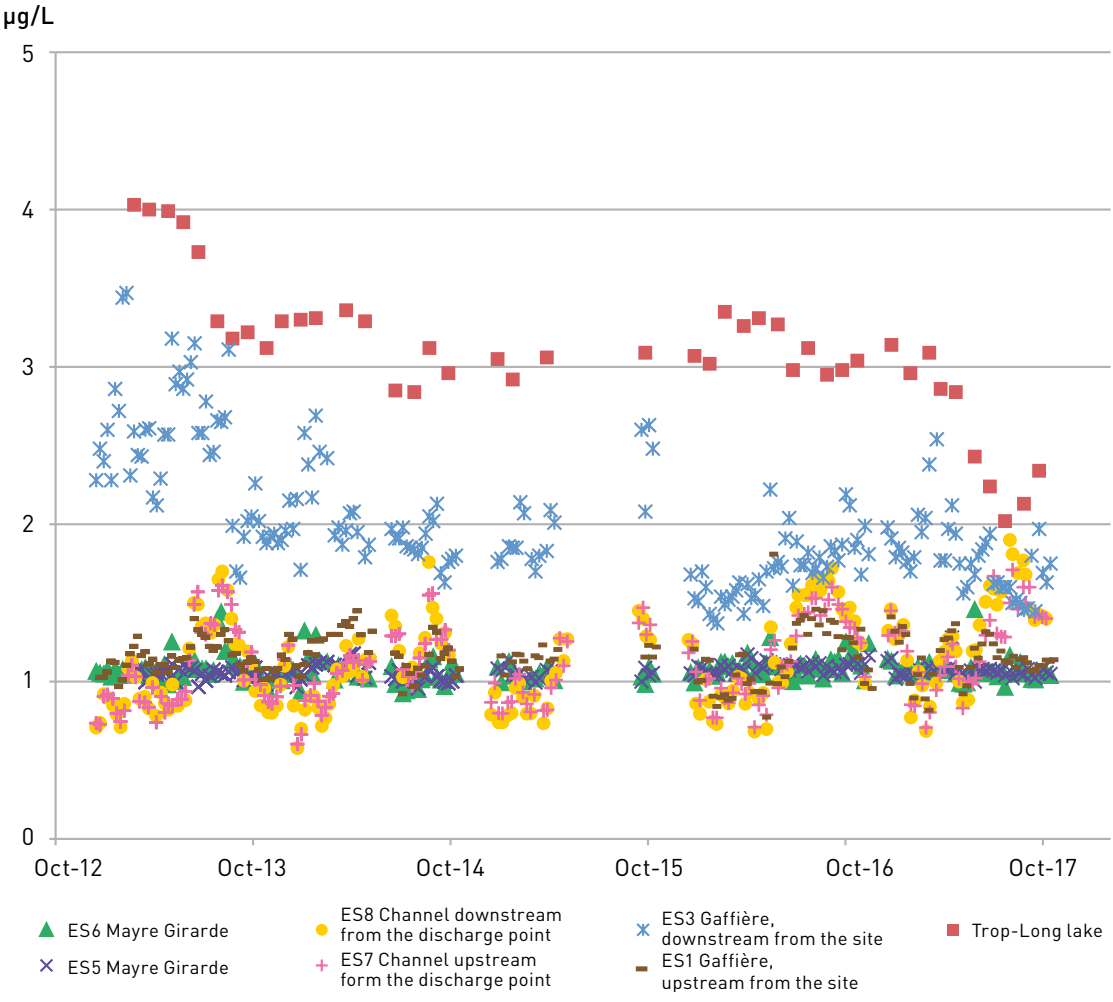
Aerial view of the Tricastin site

A slightly higher mean concentration was recorded at Gaffière, downstream from the site (1.8 µg/L, which gives a mean uranium-238 activity of 0.02 Bq/L) when compared with upstream activity (1.1 µg/L on average) (see figure 5). Considering all of the surface water samples analysed, the Trop-Long lake samples contain the highest uranium levels by far (2.9 µg/L on average for the 2015-2017 period, corresponding to mean uranium-238 activity of 0.03 Bq/L), although the concentration by volume decreased over the 2011-2014 period (3.6 µg/L on average, over this period).

A higher mean uranium isotope activity was recorded in Gaffière sediments downstream from the Orano site (mean uranium-238 activity of 26 Bq/kg in sediments) when compared with upstream activity (mean uranium-238 activity of 9.1 Bq/kg in sediments (see table 1). Uranium-238 activity in aquatic plants is more homogeneous than in sediments and no uranium contamination was found in this matrix downstream from the site (see tableau 2). Based on these observations, we can conclude that the Gaffière sediments and surface water are contaminated by uranium from the site. However, sediment contamination levels downstream from the site are very low compared with mean uranium-238 activity in sediments in France measured by IRSN, which represents 40 Bq/kg dry. Local residents do not drink Gaffière river or Trop-Long lake water. However, if they did (e.g. to fill a water bottle), drinking 1 L of it would lead to an extremely low uranium dose of 0.003 µSv/year.

FIGURE 5 / **URANIUM CONCENTRATION BY VOLUME MEASURED IN THE SURFACE WATER SAMPLES TAKEN FROM IMMEDIATE ENVIRONMENT OF THE ORANO SITE AT TRICASTIN SINCE 2012 (µg/L)**



According to samples and measurements for Donzère-Mondragon canal water, no significant difference exists between the uranium concentration downstream and upstream of the discharge point (1.15 and 1.18 µg/L on average, respectively). The same is true for sediment and aquatic plant samples taken downstream from the discharge point in the Donzère-Mondragon canal, which are not contaminated by uranium or transuranic elements (tables 2 and 3).

If we compare figures for surface water and sediment water samples taken in the immediate vicinity of the Orano site in Tricastin, it becomes apparent that the mean concentration of uranium by volume is globally constant at approx. 1.2 µg/L (see figure 6). Uranium contamination of sediment water at a few points, mainly to the south of the site, has persisted since the study conducted by IRSN in 2010, in the same way as at Mas de Flore, where the mean concentration is stable (12 µg/L).

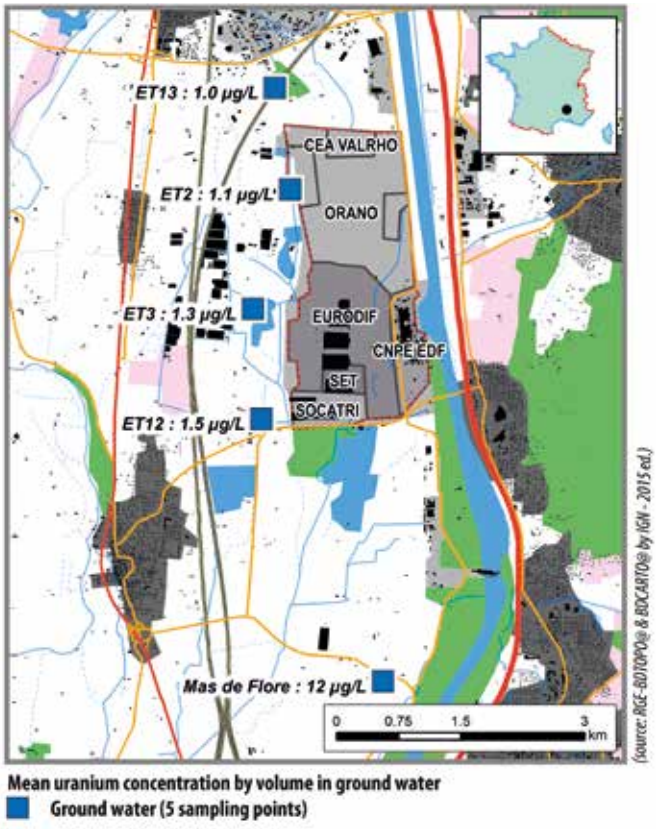
TABLE 2 / **URANIUM, PLUTONIUM AND AMERICIUM (^{241}Am) ISOTOPE ACTIVITY BY MASS IN SEDIMENT SAMPLES TAKEN IN THE AQUATIC ENVIRONMENT AROUND THE ORANO SITE AT TRICASTIN BETWEEN 2015 AND 2017 (Bq/kg dry)**

	Uranium-234 (Bq/kg dry)	Uranium-235 (Bq/kg dry)	Uranium-238 (Bq/kg dry)	Plutonium (239+240) (Bq/kg dry)	Américium-241 (Bq/kg dry)
Donzère-Mondragon canal, upstream from discharges	18	0.8	17	0.10	0.05
Donzère-Mondragon canal, downstream from discharges	15	0.6	15	0.05	0.05
Gaffière, upstream from discharges	9.4	0.4	9.1	0.09	< 0.05
Gaffière, downstream from discharges	27	1.3	26	0.12	0.18
Lauzon	6.2	0.4	6.6	< 0.05	0.06

TABLE 3 / **URANIUM ISOTOPE ACTIVITY BY MASS IN AQUATIC PLANT SAMPLES TAKEN IN THE AQUATIC ENVIRONMENT AROUND THE ORANO SITE AT TRICASTIN BETWEEN 2015 AND 2017 (Bq/kg dry)**

	Uranium-234 (Bq/kg)	Uranium-235 (Bq/kg)	Uranium-238 (Bq/kg)
Donzère canal - Upstream from the NPP	1.0	0.04	1.0
Donzère canal - Downstream from the NPP	2.1	0.1	2.0
Gaffière - Upstream from the NPP	1.2	0.05	1.1
Gaffière - Downstream from the NPP	1.1	0.05	1.0

FIGURE 6 / **MAP SHOWING THE MEAN URANIUM CONCENTRATION BY VOLUME MEASURED IN THE GROUND SURFACE WATER SAMPLES COLLECTED USING THE DIFFERENT PIEZOMETERS IN THE IMMEDIATE ENVIRONMENT OF THE ORANO SITE AT TRICASTIN BETWEEN 2015 AND 2017 (µg/L)**



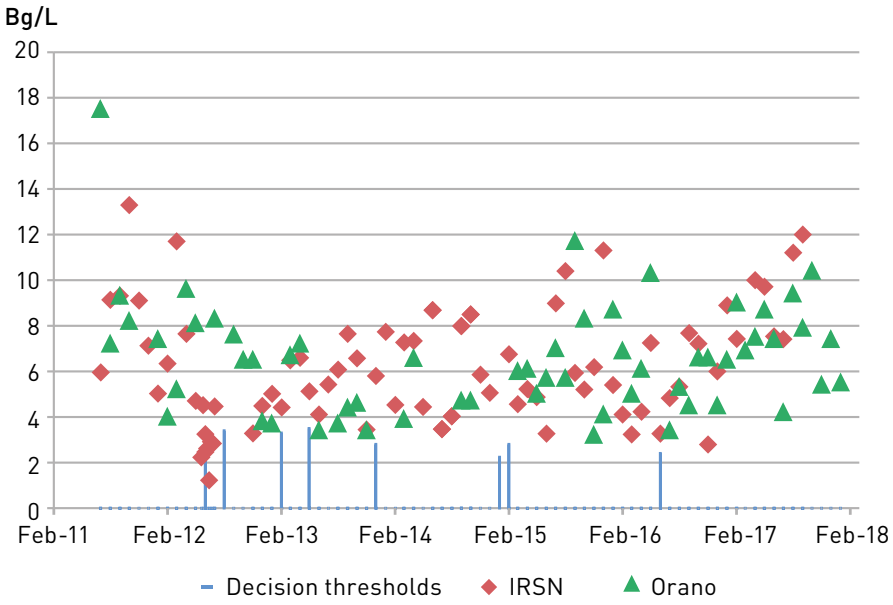
Tritium and carbon-14

Carbon-14 activity in fish captured in the Rhône river at Mornas in 2015 and 2016 (86 and 89 Bq/kg fresh respectively) exceeds background radiation in the aquatic environment (approx. 20 to 25 Bq/kg fresh), as recorded upstream of NPPs. Reminder: fish and mollusc samples in the Rhône river are affected by the carbon-14 discharged from NPPs located on the river, and ^{14}C activity increases downstream, reaching peak values of approx. 150 - 170 Bq/kg fresh (see. figure 5 in chapter 3.1). On this basis, fish measurements based on samples from Mornas cannot be used to differentiate between carbon-14 from the Tricastin nuclear site, particularly as discharges from Orano's facility at Tricastin containing this radionuclide (0.35 GBq/year in 2016) are much lower than those for the Tricastin NPP (40.6 GBq/year).

In the terrestrial component, the carbon-14 contamination of plants is extremely discreet and only affects the immediate site environment. On this basis, it can only be detected using a very sensitive indicator: specific activity. This indicator represented 269 Bq/kg C on average in 2014-2016 in the grass sample affected by discharges, which is slightly above the expected value in areas unaffected by discharges (approx. 230 Bq/kg C). While we cannot identify the percentage of this added activity discharged by Orano, we can take note that this activity (1.43 GBq/year) is 200 times less than that of the nearby EDF NPP (413 GBq/year).

With tritium, the probable predominance of EDF NPP discharges over environmental activities is even clearer. Mean tritium activity measurements for Donzère-Mondragon canal water samples

FIGURE 7 / **TRITIUM ACTIVITY BY VOLUME MEASURED IN DONZÈRE-MONDRAGON CANAL RIVER WATER SAMPLES DOWNSTREAM FROM THE DISCHARGE POINTS AT ORANO'S SITE AT TRICANSTIN BETWEEN 2011 AND 2017 (Bq/L)**



taken by Orano and IRSN between 2015 and 2017 are very similar: 6.3 and 6.7 Bq/L respectively (see figure 7). These values are also close to the synthetic values recently calculated by IRSN for this part of the Rhône river (4.7 Bq/L downstream from Tricastin on average). These activities are mainly attributable to discharges from the EDF NPP (see chapter on EDF NPPs). Tritium discharges from the Orano site (0.3 GBq/year in 2016) are indeed very low compared with discharges from the adjacent EDF NPP (42,000 GBq in 2016). In addition, the NPPs located upstream also discharge this radionuclide, which transfers easily and can be measured in water. Tritium activity in food is generally low: mean values of 5.7 and 3.5 Bq/L were detected in goat's milk from Lamotte-du-Rhône and Mondragon respectively and 3.3 Bq/L of combustion water in Bollène-la-Croisière lettuce. Tritium activity levels in food correspond to those expected in an environment which is relatively little or not affected by local discharges.

Conclusions

The impact of the Orano site at Tricastin can be detected using environmental measurements, but is low and mainly comprises ambient uranium, contaminated terrestrial plants near to the site and the Gaffière river. According to ambient measurements, local residents could inhale a dose of approximately 0.06 µSv/year. This dose is similar to, although lower than that modelled by Orano on the basis of the activities discharged in 2016 (0.13 µSv/year). According to these calculations, this dose inherent to inhaling uranium would represent almost 60% of the total dose likely to be absorbed due to discharges from Orano facilties. The impact of atmospheric carbon-14 discharged from the Orano site cannot be differentiated in environmental measurements due to the effluents discharged from the EDF NPP located on the site. The Orano effluents may rank second in terms of its contribution to the total dose.

The tritium activity levels measured in Donzère-Mondragon canal water samples, and carbon-14 activity levels measured in fish from the same canal, are mainly attributable to liquid effluents discharged by EDF, from the Tricastin NPP, as well as NPP located farther downstream.

Romans-sur-Isère site

The FRAMATOME site at Romans-sur-Isère in the Isère valley is home to two basic nuclear facilities (figure 1). The first facility (INB63) is specialised in producing fuel elements for research reactors. The second facility (INB98) produces nuclear fuels used in pressurised water reactors. This INB transformed 620 tonnes of enriched uranium into fuel assemblies in 2016.

Discharges and monitoring plans

Aqueous effluents which potentially contain uranium (such as process water, soil washing water, washing effluents, etc.) are directed to a water treatment plant known as Neptune. After the water has been treated, the main radionuclides discharged into the Isère include uranium isotopes, and, to a lesser extent, fission products and transuranic elements (figure 2). These radionuclides are also discharged into the atmosphere *via* the plant stacks (figure 3). Levels of uranium isotope activity discharged have progressively decreased since 2008. The sudden decrease in gaseous discharges containing uranium isotopes since 2015 is the outcome of the temporary shutdown of the recycling workshop, which has been progressively restarted since 2017.

The monitoring plan implemented by FRAMATOME aims to measure these radionuclides in the different matrices of the terrestrial and aquatic environment. On this basis, in the aquatic component, surface water, sediment, moss, reed and fish samples are taken from the Isère river, both upstream and downstream of discharge points (figure 1). In the terrestrial component, plant (tree leaves, grass, terrestrial mosses) and wheat (wheat) samples are taken in areas affected by atmospheric discharges from the site (S and N of the site) and areas unaffected by discharges. In addition, samples (aerosols and tree leaves) and measurements are also taken at the site, in all four directions, to assess the consequences of atmospheric discharges near to sites.

FIGURE 1 / **MAP SHOWING THE LOCATIONS OF SAMPLING POINTS IN THE IMMEDIATE ENVIRONMENT OF THE ROMANS-SUR-ISÈRE PLANT**

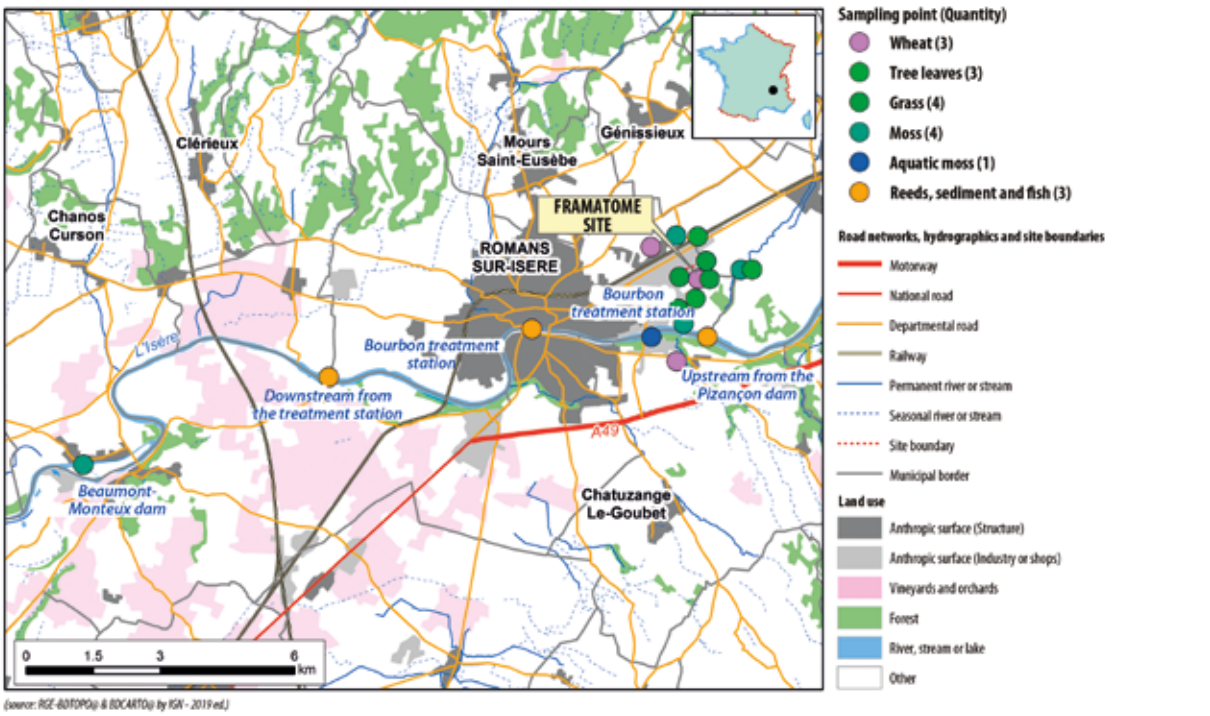


FIGURE 2 / **TIMELINE FOR RECURRENT LIQUID DISCHARGES FROM FRAMATOME'S FACILITY AT ROMANS-SUR-ISÈRE (GBq/year)**

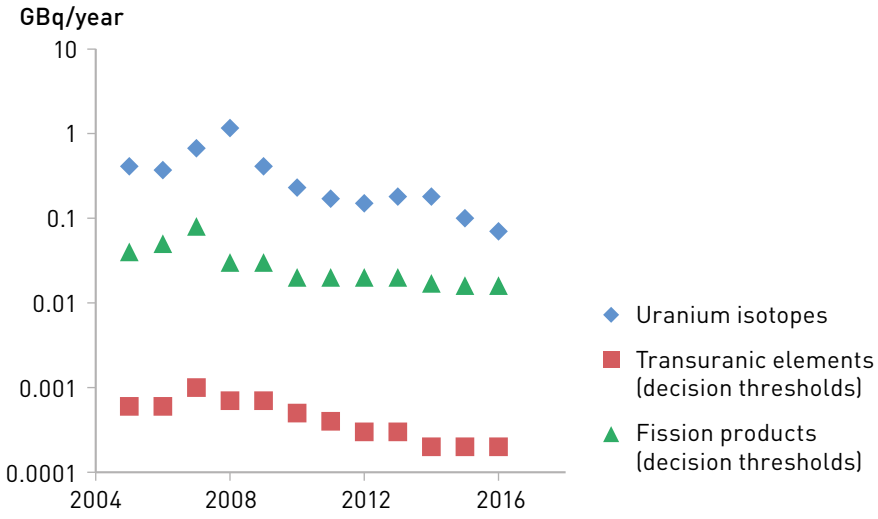
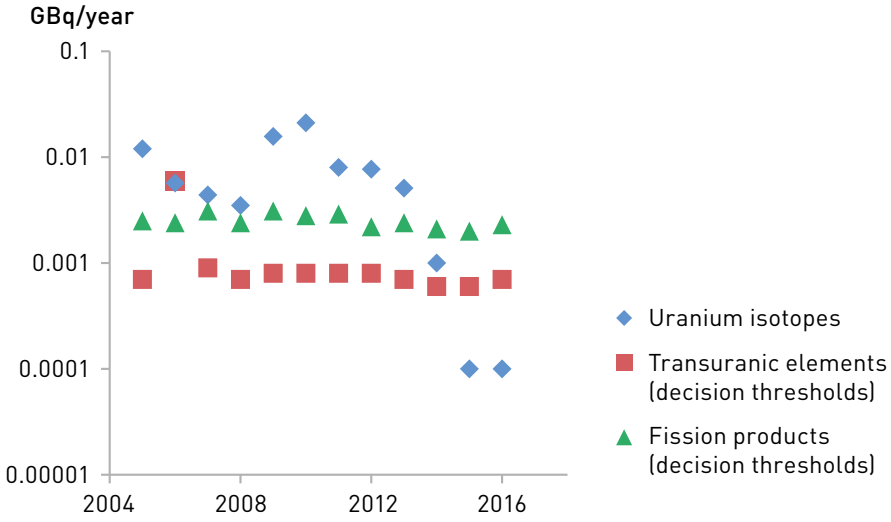


FIGURE 3 / **TIMELINE FOR RECURRENT ATMOSPHERIC DISCHARGES FROM FRAMATOME'S FACILITY AT ROMANS-SUR-ISÈRE (GBq/year)**



Ambient uranium isotopes discharged lead to an increase in atmospheric aerosol activity levels. On this basis, the mean uranium isotope activity measured in aerosol samples taken at the site is between 0.19 and 0.20 µBq/m^3 and between 0.86 and 1.10 µBq/m^3 for uranium-235 and uranium-238 respectively (table 1). The decrease in mean ambient activity by volume compared with the previous study period (2011-2014: 1.5 - 2.1 µBq/m^3 for uranium-238) correlates to the annual decrease in total effluents discharged (figure 3). These values must be compared with the uranium activity levels recorded in France in areas unaffected by fuel cycle facilities: approx. 0.2 µBq/m^3 of uranium-238.

These atmospheric aerosols contaminated by site effluents settle on the tree leaves, leading to detectable levels of uranium activity. The highest uranium concentration by mass is measured inside the site, in the south part, and a mean concentration of 47 µg/kg dry was recorded (figure 4). The mean uranium concentration by mass is lower in other parts of the site, e.g. 17 µg/kg to the east of the site. Although the reduction in activity detected since 2012 is far less sudden, this decrease is due to the reduction in effluents discharged as the recycling unit has been shut down.

The concentrations measured in tree leaf samples collected off-site are lower than on-site and vary between 0.6 and 1.8 µg/kg dry. The mean uranium concentration in the other plant samples taken in the immediate environment around the site are slightly higher (table 2). On this basis, on average, uranium concentrations by mass in grass samples are higher to the north and south (11.5 and 12 µg/kg respectively) when compared with measurement results to the east and west (4.7 and 5.2 µg/kg respectively).

No increase in uranium concentration was detected in Isère water analyses taken downstream from the discharge point compared with upstream sample results. In fact, weighted concentrations are similar both upstream and downstream (1.69 and 1.74 µg/L respectively). Mean weighted uranium concentrations in ground water samples are similar (0.40 - 1.06 µg/L). Variations are undoubtedly due to the characteristics of the aquifers.

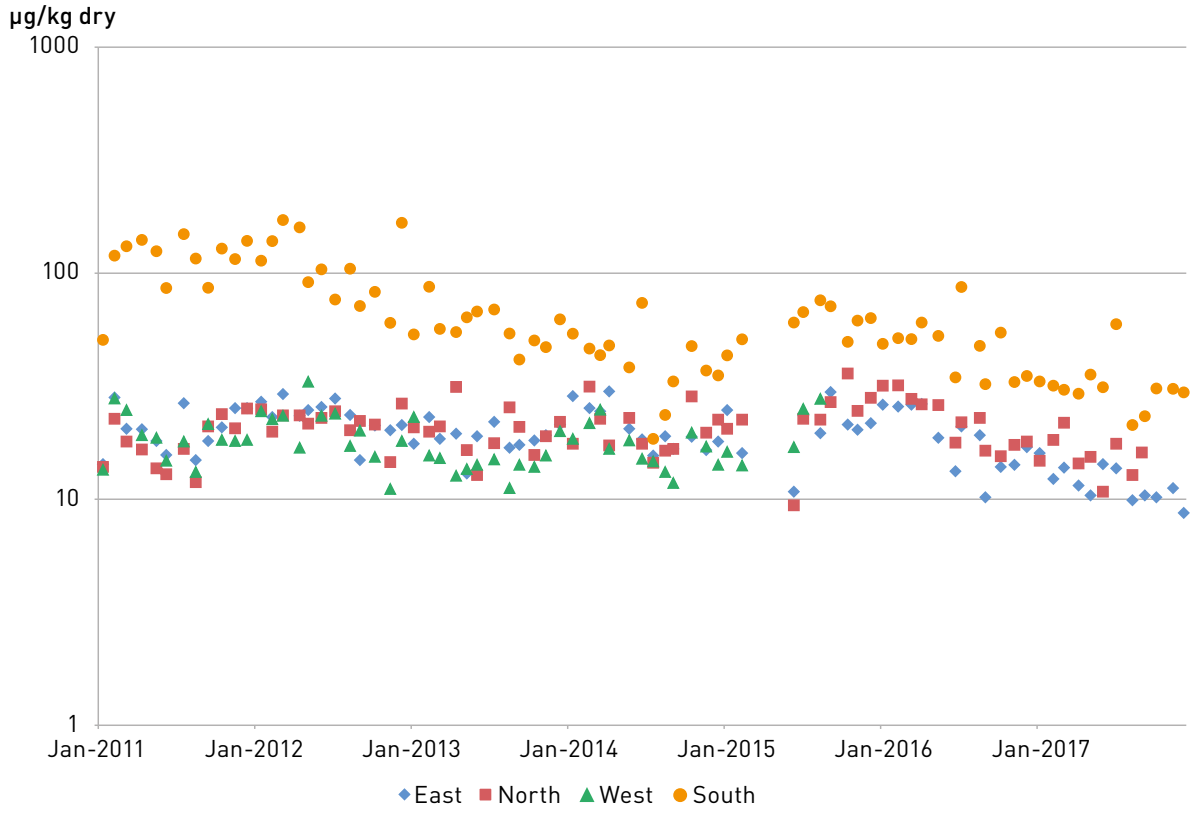
TABLE 1 / **MEAN ACTIVITY LEVELS FOR URANIUM ISOTOPES IN AEROSOLS SAMPLES TAKEN AT FRAMATOME'S SITE AT ROMANS-SUR-ISÈRE BETWEEN 2015 AND 2017 (µBq/m^3)**

	^{234}U (µBq/m^3)	^{235}U (µBq/m^3)	^{236}U (µBq/m^3)	^{238}U (µBq/m^3)
East	< 14	0.20	< 0.22	0.86
North	< 13	0.19	< 0.22	0.88
West	< 13	0.19	< 0.22	1.10
South	< 12	0.19	< 0.21	1.00

TABLE 2 / **WEIGHTED URANIUM CONCENTRATION IN PLANT SAMPLES TAKEN IN THE IMMEDIATE ENVIRONMENT OF FRAMATOME'S SITE AT ROMANS-SUR-ISÈRE (µg/kg dry)**

	Location of sampling points	North	East	South	West
Grass	**Distance from the site (m)**	200	200	750	1200
	Uranium (µg/kg dry)	11.5	4.7	12	5.2
Terrestrial mosses	**Distance from the site (m)**	750	1000	1250	
	Uranium (µg/kg dry)	114	156	145	
Wheat	**Distance from the site (m)**		200	2000	750
	Uranium (µg/kg dry)		2.7	2	< DT

FIGURE 4 / **WEIGHTED URANIUM CONCENTRATION IN PINE NEEDLE SAMPLES TAKEN AT FRAMATOME'S SITE AT ROMANS-SUR-ISÈRE, BETWEEN 2011 AND 2017**



According to the results of uranium isotope analyses in sample matrices from the Isère river, no additional uranium isotopes are present downstream from the discharge point compared with upstream samples (table 3). Uranium-238 activity levels measured in reeds, sediments and fish are similar upstream and downstream (uranium-238 in sediments: 5.7 and 5.3 Bq/kg fresh respectively). Furthermore, no uranium-236, an artificial uranium isotope, was detected as per the results of analyses on samples from the aquatic environment.

According to the levels of environmental activity measured, uranium isotopes are the main cause of potential exposure for local residents to atmospheric discharges from the site. Residents in an area affected by atmospheric discharges from the plant would absorb a maximum dose by inhaling uranium dust equal to 0.15 µSv/year. This dose is below the estimated value from the previous study period (2011-2014: 0.5 µSv/year), as uranium discharges have decreased significantly, and the proportion of uranium-234 in the air, based on more precise estimates, is lower (4 µBq/m^3 of air).

TABLE 3 / **MEAN URANIUM ISOTOPE ACTIVITY MEASURED IN SAMPLES TAKEN IN THE ISÈRE RIVER UPSTREAM AND DOWNSTREAM OF THE DISCHARGE POINT AT FRAMATOME'S SITE AT ROMANS-SUR-ISÈRE**

		Discharges 1.5 km upstream	Discharges 250 m upstream	Discharges 2.5 km downstream	Discharges 6 km downstream	Discharges 9 km downstream
		Upstream from Pizançon dam	Pizançon dam	Romans sur-Isère town centre	Downstream from the Romans-sur-Isère wastewater treatment plant	Beaumont-Monteux dam
Reeds (Bq/kg fresh)	^{234}U	< 0.11		< 0.11	< 0.11	
	^{235}U	0.0001±0.00003		0.00016±0.00004	0.00007±0.00002	
	^{236}U	< 0.0011		< 0.0012	< 0.0011	
	^{238}U	0.0011±0.0003		0.0014±0.0003	0.007±0.001	
Aquatic mosses (Bq/kg fresh)	^{234}U		2.9±0.6			1.8±0.4
	^{235}U		0.4±0.1			0.20±0.04
	^{236}U		< 0.012			< 0.018
	^{238}U		7.7±0.2			3.3±0.7
Sediment (Bq/kg fresh)	^{234}U	< 28		< 30	< 28	
	^{235}U	0.3±0.05		0.3±0.06	0.4±0.08	
	^{236}U	< 0.3		< 0.4	< 0.3	
	^{238}U	5.3±1.1		5.7±1.1	6.7±1.3	
Fish (Bq/kg fresh)	^{234}U	< 0.11		< 0.09	< 0.08	
	^{235}U	0.00004±0.00001		0.0002±0.00004	0.00009±0.00002	
	^{236}U	< 0.001		< 0.001	< 0.0008	
	^{238}U	0.001±0.003		0.004±0.0009	0.002±0.0005	

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Aerial view of the Romans-sur-Isère site

La Hague site

The facilities at the Orano Cycle site (formerly the AREVA NC site) at La Hague are used for the first stage in processing spent fuels post-nuclear reactor operations. The site is adjacent to the radioactive waste storage facility on the Channel (CSM) run by ANDRA. This storage facility collected almost 530,000 m^3 of highly and weakly radioactive waste between 1969 and 1994 (see figure 1). The CSM no longer receives waste and is currently monitored.

Given that these two sites are next to each other, monitoring data is combined into one single chapter as part of this radiological report.

Discharged effluents

Figure 2 shows the activities of the main radionuclides discharged in gaseous effluents from the Orano Cycle site at La Hague. Annual activity levels for discharges have remained fairly constant over time since the late 1990's. Krypton-85 is the main contributor by far, followed by tritium and carbon-14. Iodine-129 ranks 4th and is the principal component of iodine discharges. Much lower amounts of other β–γ emitting radionuclides are found in discharges, particularly including ruthenium-106 and antimony-125, preventing quantification. The values shown in figures 2 and 3 for β–γ and α emitters are total decision thresholds.

FIGURE 1 / **AERIAL VIEW OF THE ORANO CYCLE SITE AT LA HAGUE AND ANDRA CSM**

FIGURE 2 / **OVERVIEW OF ATMOSPHERIC DISCHARGES FROM ORANO'S FACILITY AT LA HAGUE (TBq/year)**

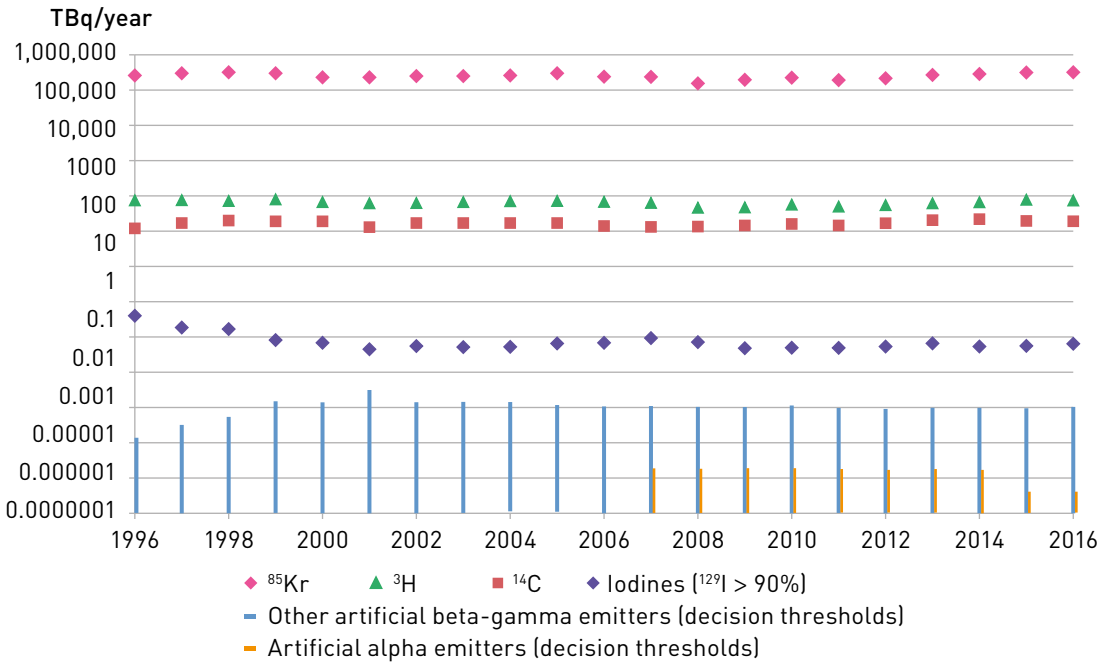


FIGURE 3 / **OVERVIEW OF LIQUID DISCHARGES FROM ORANO'S FACILITY AT LA HAGUE (TBq/year)**

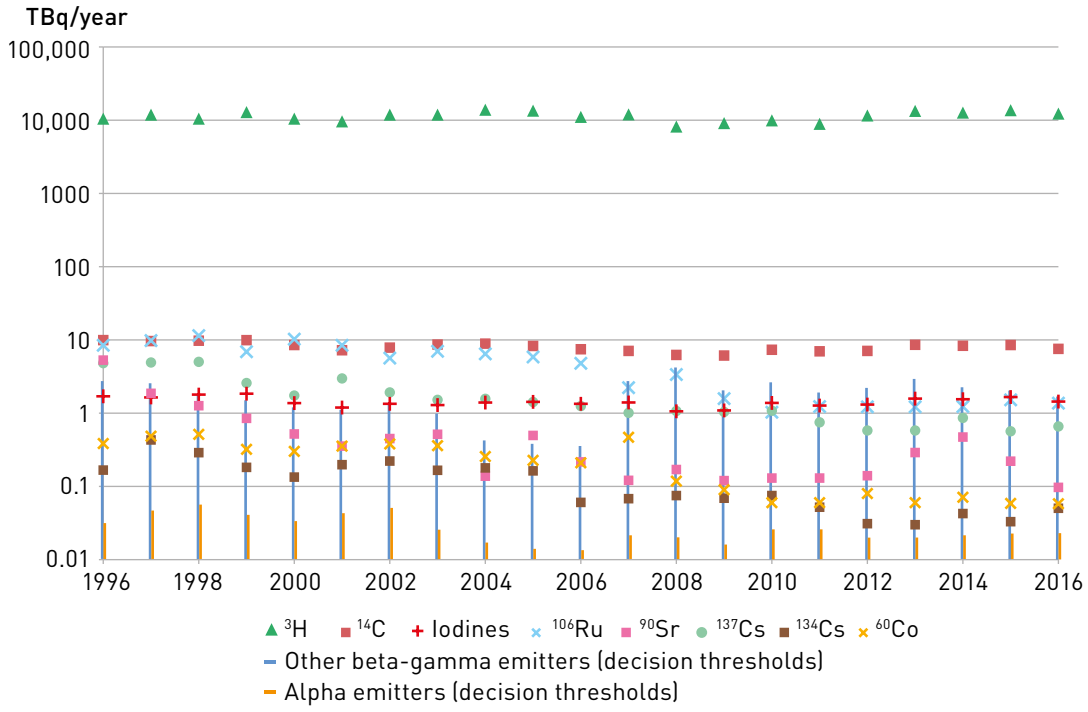
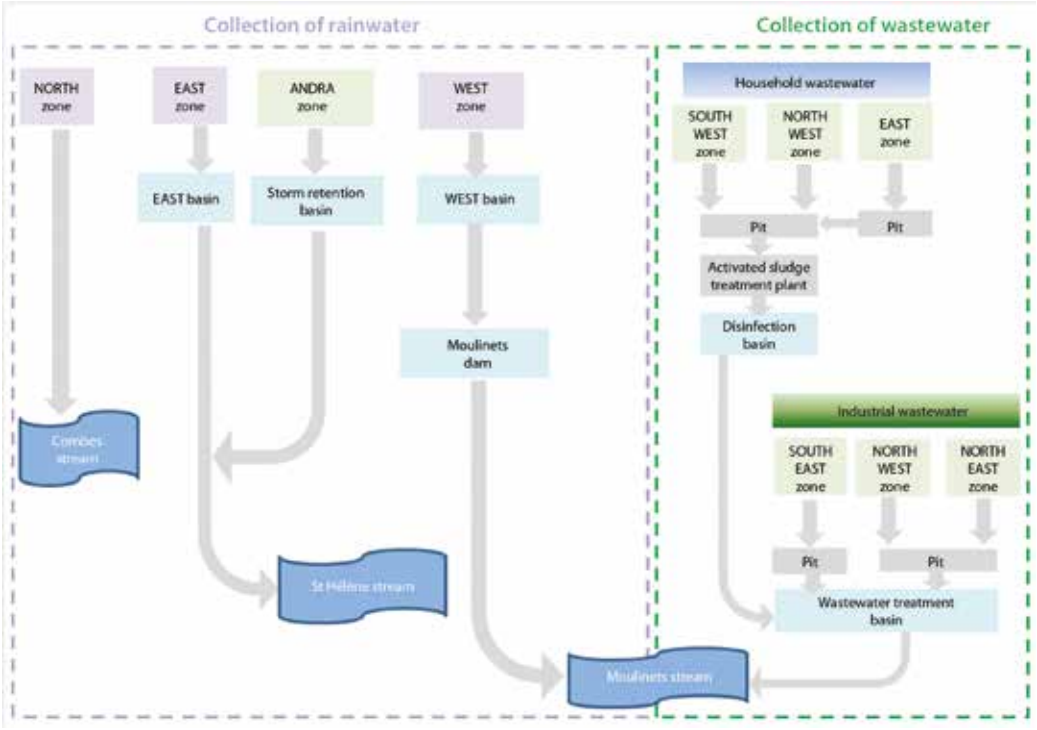


FIGURE 4 / **RAINWATER AND WASTEWATER DISCHARGES FROM ORANO'S SITE AT LA HAGUE**



Tritium is the main radionuclide discharged in liquid effluents by far, followed by carbon-14 and iodine isotopes, particularly iodine-129 to a lesser extent. The respective proportions are similar to those detected for gaseous discharges (see figure 3). Liquid effluents are discharged at sea, *via* a duct which discharges approximately 5 km offshore from Goury port.

Rainwater and wastewater are discharged into three streams based on their sources: les Combes, St-Hélène and les Moulinets.

Drainage from the liquid effluents discharged from the Channel centre, which are currently covered and planted, are collected and routed to the Orano site for discharge at sea. The activity levels in question are insignificant compared with those recorded in Orano discharges. Tritium is the main radionuclide discharged in liquid effluents (2.1 GBq in 2016).

Monitoring plans for the immediate environment of the La Hague site

Details of the regulatory monitoring plan implemented by Orano in the immediate environment of the La Hague site and IRSN's monitoring plan can be found in Tables 1 and 2. The monitoring plan is particularly large in scope due to the number of radionuclides discharged by the facilities and the different matrices potentially affected.

Figure 5 shows the locations of monitoring points, where terrestrial, continental aquatic and atmospheric samples are taken. Figure 6 shows details of the locations of marine sampling sites.

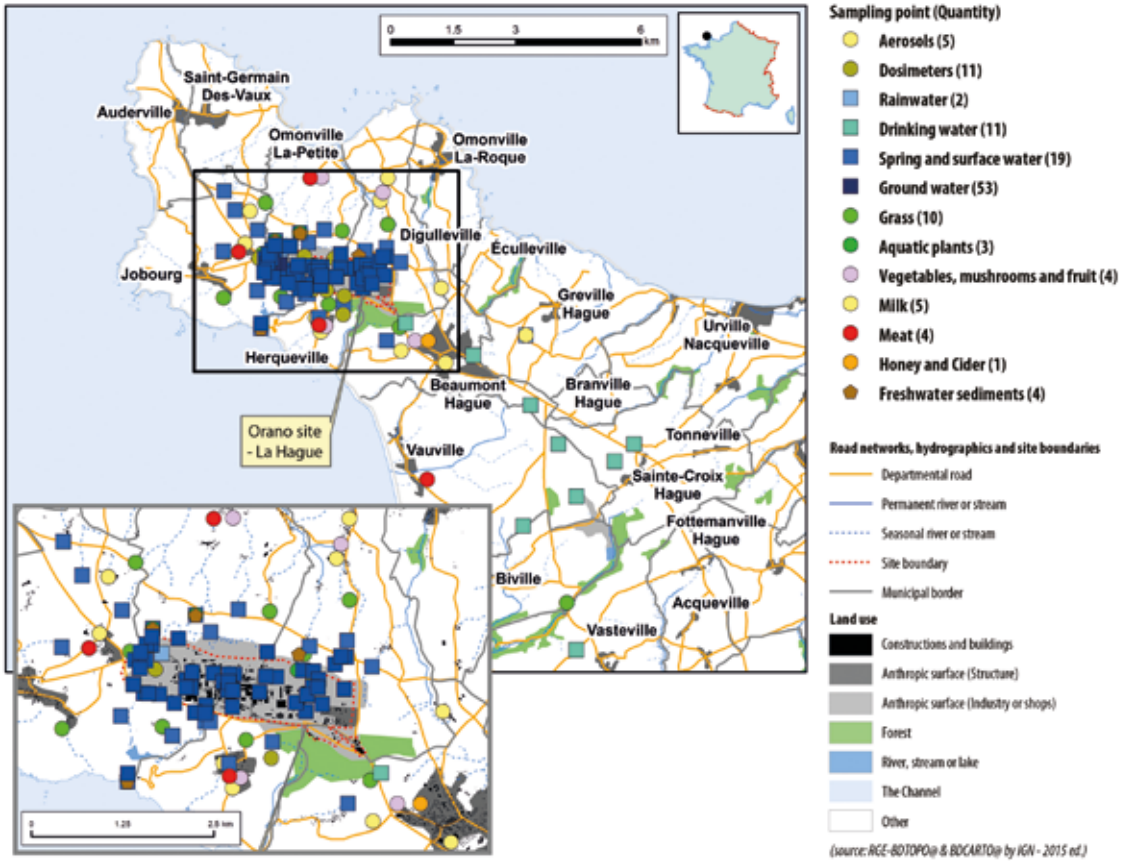
TABLE 1 / **TERRESTRIAL ENVIRONMENTAL MONITORING PLANS FOR THE LA HAGUE SITE, DRAFTED BY ORANO AND BY IRSN**

Environment monitored or type of testing	Orano	IRSN
Soil air	• 5 sampling points; gross alpha and beta activity measurements with a daily filter • γ spectrometry if gross β activity > 2 mBq/m^3 • Alpha spectrometry for total monthly value for the filter, Iodines with a weekly cartridge, weekly ^{3}H, bimonthly ^{14}C, monthly ^{85}Kr	• 1 station; gross α and β and γ spectrometry measurements with a weekly filter, one monthly Pu measurement with a weekly filter (1st period), iodines with a weekly cartridge, bimonthly ^{3}H
Dosimeter	• 11 fence locations, monthly measurements	
Rain	• 2 samplers for weekly free tritium measurements • gross α and β and γ spectrometry if the α or β count is significant	• 1 sampler, monthly free tritium measurements
Ground water	• 53 samplers, including around a dozen off-site; monthly gross α and β, and free tritium measurements	-
Drinking water	• 12 samplers; monthly gross α and β, and free tritium measurements	-
Stream and spring water	• 7 samplers for 6-monthly or weekly gross α and β, free tritium and γ spectrometry measurements • Monthly ^{90}Sr and γ spectrometry measurements for 4 springs	• 6 annual to quarterly sampling points; gross α, gross β, γ spectrometry and free tritium measurements
Soils	• 7 sampling points; quarterly γ spectrometry measurements	-
Grass	• 10 points; monthly or quarterly γ spectrometry bound tritium, ^{14}C, and ^{129}I measurements; annual α spectrometry	• 1 monthly sampling point; ^{14}C, bound and free tritium and γ spectrometry measurements
Milk	• 5 points; monthly γ spectrometry ^{90}Sr, ^{129}I, ^{14}C and free tritium measurements	• 3 quarterly sampling points; ^{90}Sr, ^{129}I, ^{14}C, free tritium and γ spectrometry measurements
Meat	• 2 to 3 annual samples; γ spectrometry, α spectrometry, free and bound tritium, ^{14}C, and ^{129}I measurements and ^{90}Sr measurements for one sample.	• 1 annual sample; bound ^{3}H, ^{14}C, γ spectrometry and ^{90}Sr measurements
Other food (vegetables, eggs, honey, etc.)	• 10 to 12 annual samples; annual γ spectrometry, α spectrometry, bound tritium, ^{14}C, and ^{129}I measurements (Pu, ^{244}Cm) and ^{90}Sr measurements.	• 1 annual cereal sampling run; α spectrometry (Pu/Am), ^{90}Sr; γ spectrometry, ^{14}C, and bound spectrometry measurements.
Aquatic plants	• 3 sampling points used to collect 12 annual samples; γ spectrometry and bound tritium measurements	-
Sediments/beach sand	• 26 points: 10 off-shore and 13 low-tide sampling points; quarterly α and γ spectrometry measurements	• 10 annual to quarterly sampling points; α spectrometry (Pu/Am and Cm for 3 samples), ^{90}Sr, γ spectrometry measurements

TABLE 2 / **MARINE ENVIRONMENTAL MONITORING PLANS FOR THE LA HAGUE SITE, DRAFTED BY ORANO AND BY IRSN**

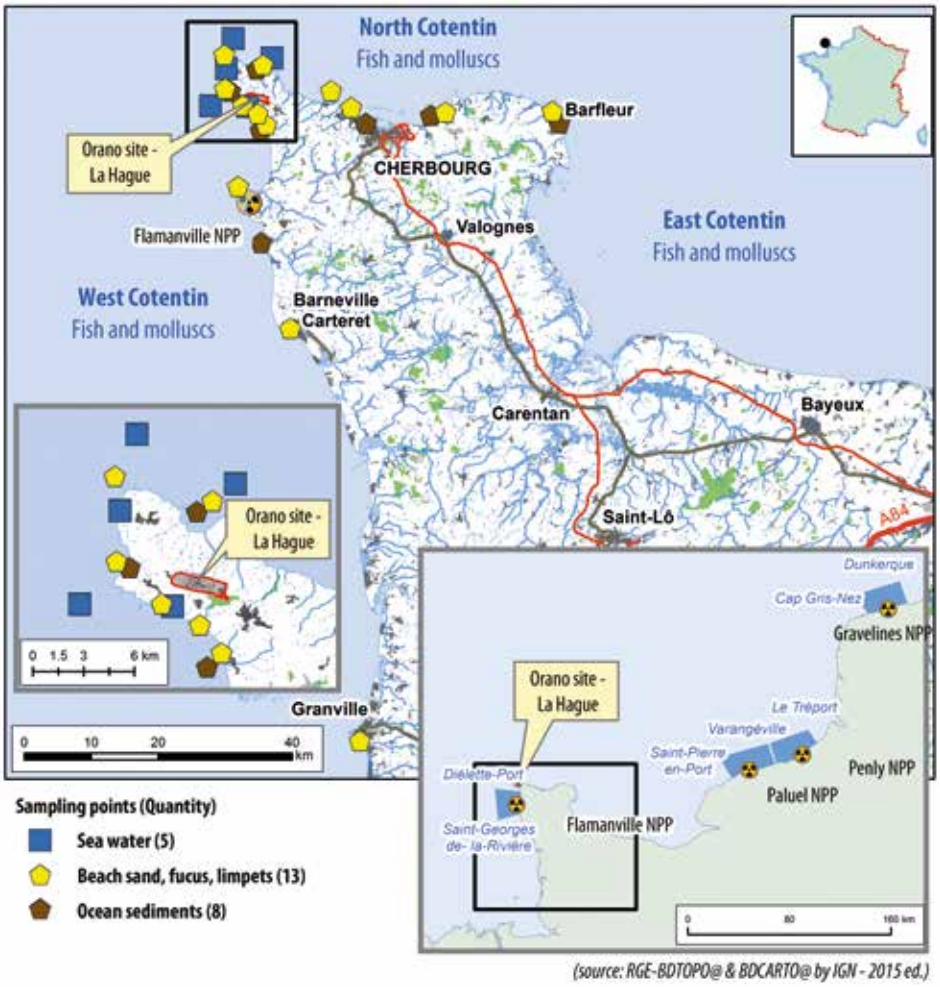
Environment monitored or type of testing	Orano	IRSN
Seawater	• 5 points: 2 on the coast, 3 offshore; daily ^{129}I and free tritium measurements at Anse des Moulinets; monthly or quarterly ^{90}Sr and α spectrometry measurements	• 1 sampling points; quarterly free tritium measurements
Algae	• 6 sampling points used to collect 24 annual samples; α and γ spectrometry, ^{129}I, ^{14}C measurements	• 3 quarterly sampling points; α spectrometry (Pu/Am/ Cm), ^{90}Sr and γ spectrometry measurements
Fish	• 3 sampling points used to collect 24 annual samples; α and γ spectrometry, ^{129}I and ^{14}C measurements	• 3 annual sampling points; α spectrometry (Pu/ Am), ^{90}Sr and γ spectrometry measurements
Molluscs	• 5 to 6 sampling points used to collect 40 to 50 annual samples; α and γ spectrometry, ^{129}I and ^{14}C measurements	• 3 quarterly to 6-monthly sampling points; α spectrometry (Pu/Am/ Cm) and γ spectrometry measurements
Shellfish	• 3 sampling points used to collect 12 annual samples; γ spectrometry, ^{129}I and ^{14}C measurements	-

FIGURE 5 / **MAP SHOWING THE LOCATION OF THE LA HAGUE SITE, AND THE MUNICIPALITIES AND SAMPLERS USED FOR TERRESTRIAL AND ATMOSPHERIC SAMPLING**



Due to the strong ocean currents near to the discharge channel at La Hague, the impact of Orano discharges at sea can be detected beyond the immediate environment of the site and the Channel in general. The measurements taken by EDF near to coastal NPP (Flamanville, Penly, Paluel et Gravelines) and by IRSN can also be used to characterise these discharges. Figure 6 shows the locations of marine sampling points near to EDF's nuclear powerplants.

FIGURE 6 / **MAP SHOWING THE LOCATIONS OF THE MARINE SAMPLERS AROUND THE LA HAGUE SITE**



FOCUS ARTICLE
IRSN'S OMONVILLE-LA-PETITE SAMPLER

Since 1994, IRSN has accessed a test zone at Omonville-la-Petite, to the north of the Orano site at La Hague. This technical zone is located under the prevailing winds and is home to various measuring instruments, which IRSN uses to monitor atmospheric discharges from the La Hague facility and run studies, particularly focusing on the behaviour of tritium in the air and in ecosystems.

In 2017, IRSN decided to combine the different measuring systems and other equipment used at Omonville-la-Petite for the purposes of regular monitoring:

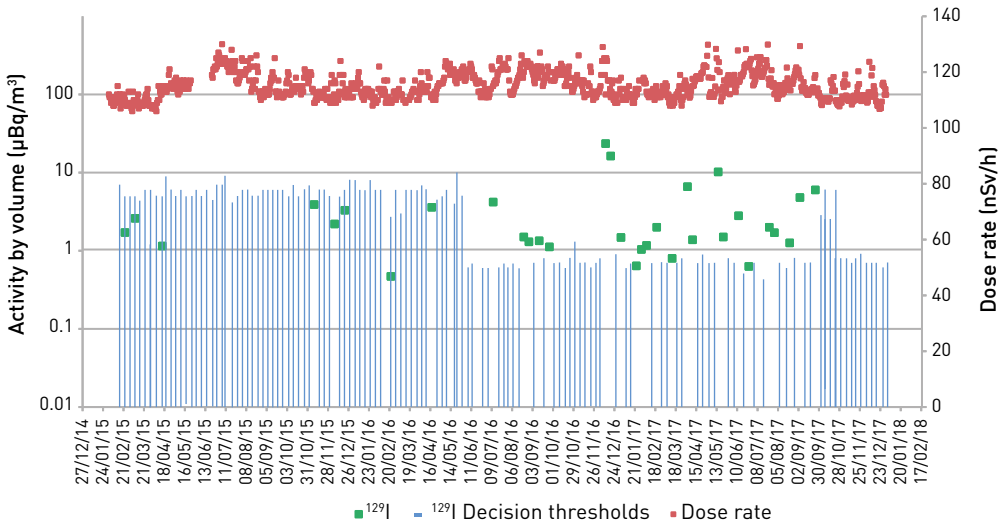
- Téléray sensor (proportional counter) and gamma spectrometry system
- tritium bubbler
- passive tritium trap;
- OPERA-AIR 80 aersol sampler;
- rainwater collector.

FIGURE A / **INSTRUMENTATION INSTALLED AT THE IRSN SAMPLER AT OMONVILLE-LA-PETITE**

The sampling station in IRSN's new OPERA-AIR 80 network has been installed at Omonville since 2014 and can be used to filter particles (aerosols) by taking in ambient air at a flow rate of 80 m^3/h and trapping the gaseous iodine in a specific channel (3 m^3/h) using a sampling system comprising a specific cartridge. The filter and cartridge are replaced on a weekly basis and sent to the laboratories at Vésinet for analysis.

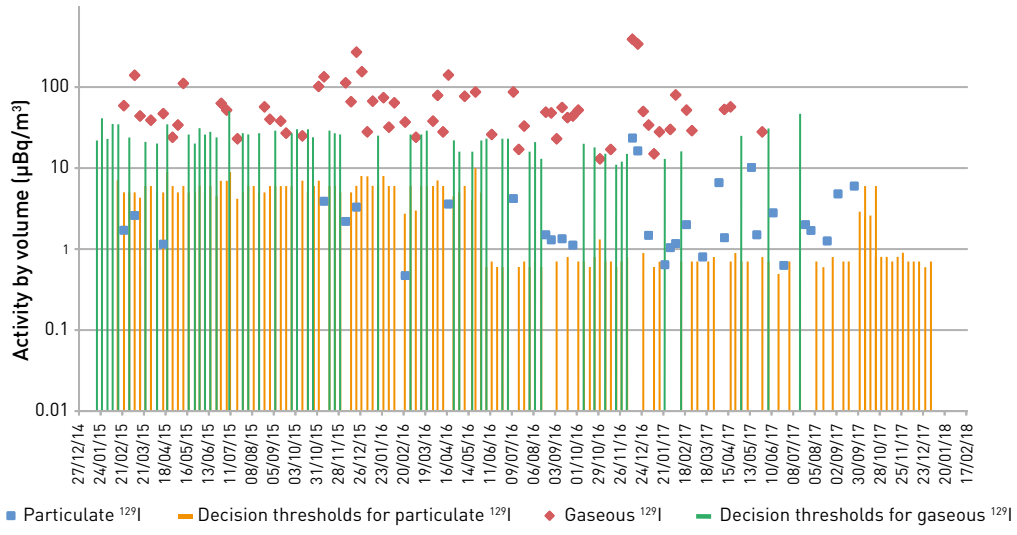
Figure B shows particulate ambient iodine-129 activity by volume, which is one of the only artificial radionuclides to still be regularly detected by IRSN at this station. Beryllium-7 and lead-210 are the other two radionuclides systematically measured by gamma spectrometry. Both are natural in origin. This figure also shows the link between the presence of iodine-129 in the air and the increased dose rate attributable to La Hague effluents (see focus article on krypton-85 on page 146). Finally, the particulate iodine-129 measurement illustrates the efforts made by IRSN to continue to improve metrological performances after the acquisition of sensors with an anti-cosmic system in 2016 and the switch to 24-hour counting for aerosol filters. Efforts are still being made to reduce decision thresholds by using more compact filters, after a series of conclusive tests launched since 1 January 2018.

FIGURE B / **PARTICULATE IODINE-129 ACTIVITY BY VOLUME FOR THE IRSN SAMPLER AT OMONVILLE-LA-PETITE**



The following figure shows particulate and gaseous iodine-129 activity by volume for the Omonville sampler. It would appear that iodine-129 activity by volume mainly comprises gaseous iodine trapped in activated carbon cartridges with other iodine isotopes discharged from the La Hague facilities (iodine-131 and iodine-133).

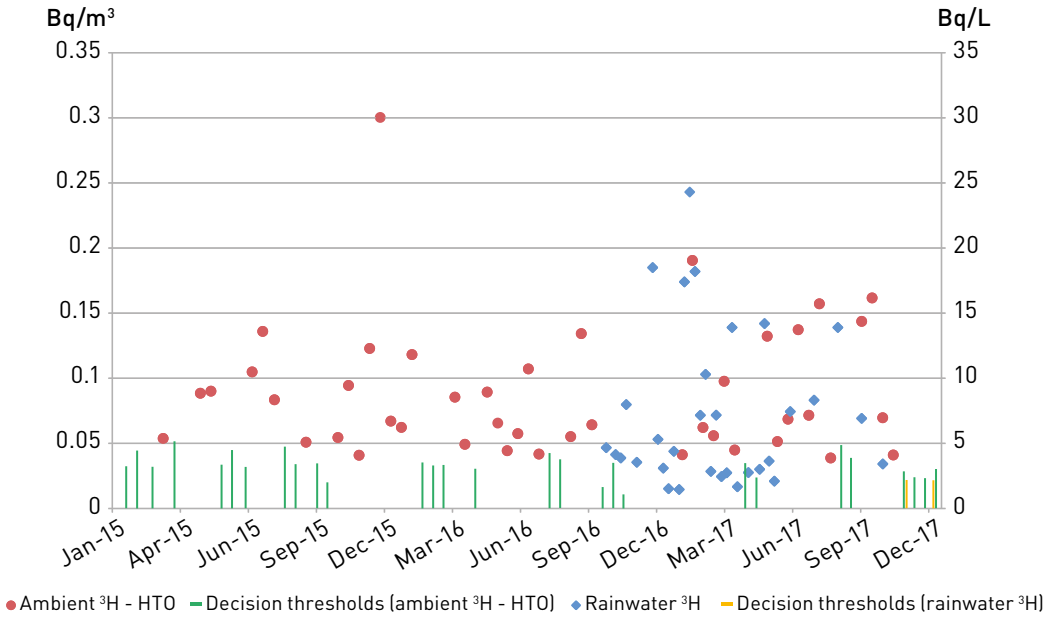
FIGURE C / **PARTICULATE AND GASEOUS IODINE-129 ACTIVITY BY VOLUME FOR THE IRSN SAMPLER AT OMONVILLE-LA-PETITE**



IRSN uses various sampling systems to monitor tritium discharges in the atmosphere from the facilities at La Hague in addition to monitoring dose rate and aerosols. Discharges have been monitored with a bubbler set up at Omonville since 2015. The bubbler traps ambient tritium in the form of water vapour (HTO) and aquatic tritium as a gas (HT) prior to analysis by liquid scintillation. A rainwater collector was added to the system in 2017, and is used to collect wet deposits.

Combining these different units at the same sampling station means that measurements can be compared, in addition to monitoring activity levels in the different atmospheric components. Figure D shows the relationship between tritium (HTO) measurements in ambient water vapour and in rainwater. This figure also shows the low activity levels currently recorded in the atmosphere, and the measuring equipment required to detect significant tritium values (< 5 Bq/L).

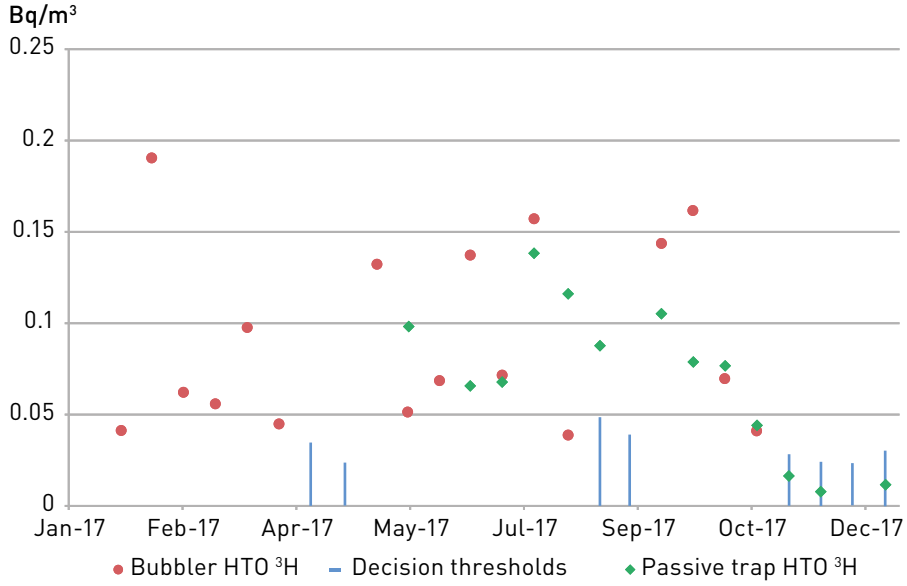
FIGURE D / **AMBIENT HTO TRITIUM ACTIVITY MEASURED IN AIR AND RAINWATER AT THE IRSN SAMPLING STATION AT OMONVILLE-LA-PETITE**

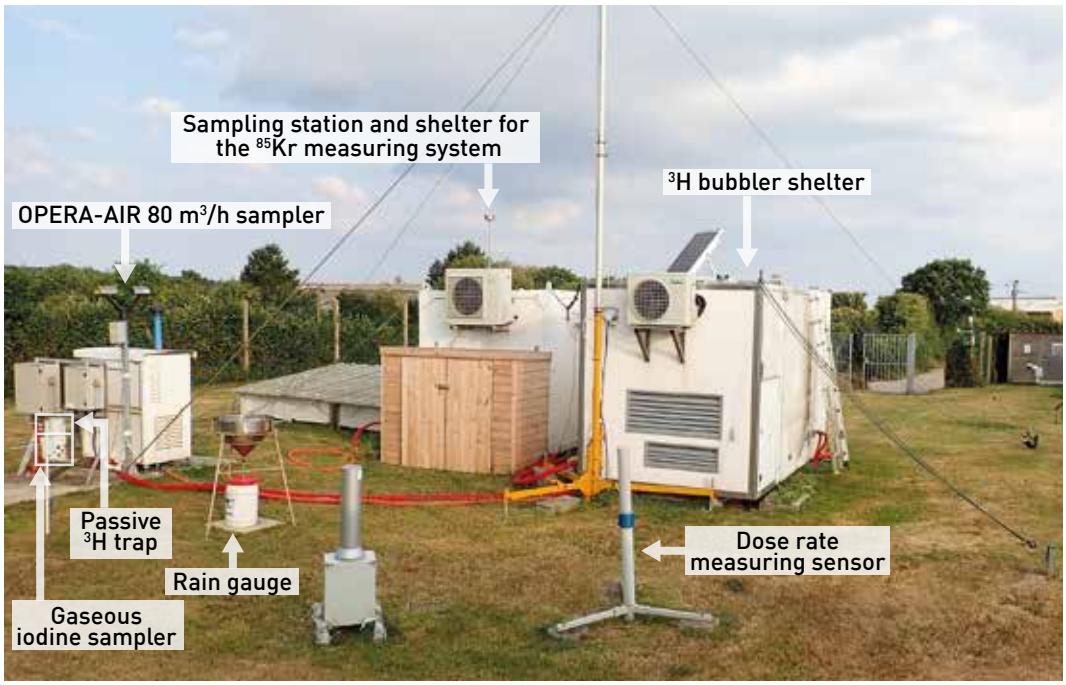


IRSN developed a "passive" system able to trap atmospheric tritium as HTO using absorbent material (a molecular sieve) exposed to the environment, with a special geometric format (see focus article on passive traps; pp. 14-15) to complete its panel of ambient tritium sampling resources. After a specific sampling period, the sieve is processed to desorb the trapped water prior to counting the tritium by liquid scintillation analysis.
This system has been tested at the Omonville station since 2017 to complement the bubbler.

Figure E compares the ambient tritium (HTO) activities recorded using the two sampling techniques. Activity measurements are in the same range, indicating that results are reliable. It is also worth taking note that the passive trap samples, when used with suitable metrological devices, systematically give values above the decision threshold for the period, unlike the bubbler.

FIGURE E / **AMBIENT HTO TRITIUM ACTIVITY MEASURED AT THE IRSN SAMPLER (bubbler and passive trap) AT OMONVILLE-LA-PETITE**





The impact of the La Hague site on its immediate environment and associated public exposure

The main radionuclides in the liquid and gaseous discharges from the facilities on the La Hague site are also those most frequently measured in the environment, with the highest activity levels. These radionuclides include krypton-85 in the air, carbon-14 and tritium in all components and iodine-129 in terrestrial and marine components.

Krypton-85

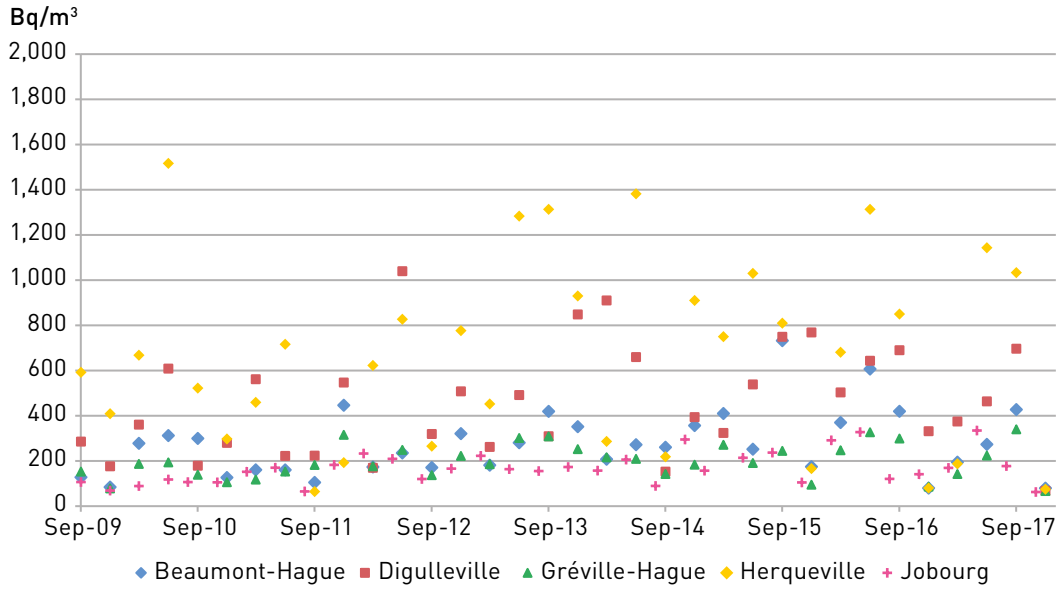
Krypton-85 is a noble gas and disperses in the air without settling on the ground. Krypton-85 discharges have no effect on the terrestrial components and food in particular.

This radionuclide is regularly measured at the five village samplers located around the La Hague site: Beaumont-Hague, Digulleville, Gréville-Hague, Herqueville and Jobourg.

Ambient activities by volume fluctuate between a few dozen and several thousand Bq/m^3, with mean values calculated over the last three years, from 2015 to 2017, representing approx. 200 Bq/m^3 at Jobourg and Gréville-Hague and up to 680 Bq/m^3 around Herqueville (see figure 7). This noble gas will only lead to external exposure for local inhabitants. Estimated effective doses due to this activity range from 1.6 µSv/year at Jobourg, through 2.7 µSv/year at Beaumont-Hague and up to 5.4 µSv/year at Herqueville. These doses match those assessed by Orano based on discharge data from 2016: 1.2 µSv/year per adult living in Goury and 8.1 µSv/year per person living in the Digulleville canton.

Krypton-85 bursts lead to regular, but transient, increases in the equivalent dose rate for ambient gamma, however the levels reached can be high. The extra dose due to these bursts can be calculated thanks to the Omonville-la-Petite sampling station, where IRSN has installed a Téléray sensor combined with a gamma spectrometer. This dose reached approx. 3.3 µSv/year in 2017 (see focus article on Detecting bursts of ^{85}Kr; p. 146), which corroborates estimates based on ambient ^{85}Kr activity measurements near to the site.

FIGURE 7 / **QUARTERLY MEAN VALUES FOR AMBIENT KRYPTON-85 ACTIVITY BY VOLUME MEASURED AT THE FIVE VILLAGE SAMPLERS LOCATED NEAR TO THE LA HAGUE SITE (Bq/m^3) SINCE SEPTEMBER 2009**



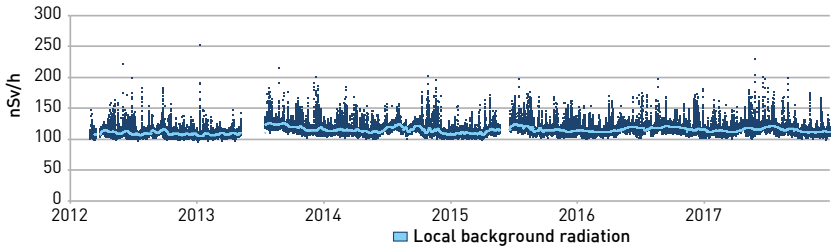
FOCUS ARTICLE
USING THE TELERAY NETWORK TO DETECT BURSTS OF KRYPTON-85

IRSN equipment at the Omonville-La-Petite sampler regularly detects increases in the equivalent dose rate expressed in nanoSievert per hour (1 nSv/h = 0.001 µSv/h). The Téléray sensor (proportional counter) can issue one measurement every 10 minutes, and detect increases of over 100 nSv/h (figure A) during these episodes.

© IRSN

Téléray sensor (on the left, in the foreground), at the 'Omonville-la-Petite sampling site

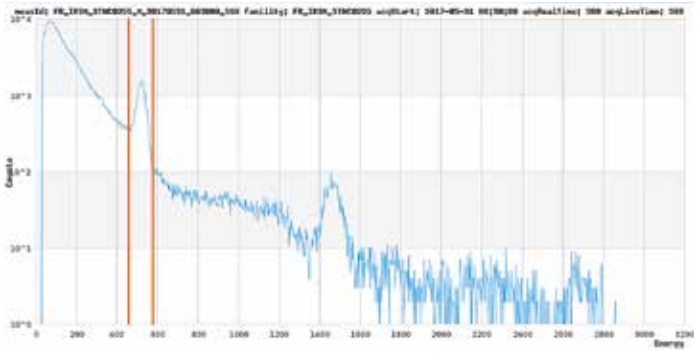
FIGURE A / **DOSE RATE (nSv/h) MEASURED USING THE TÉLÉRAY NETWORK SENSOR AT OMONVILLE-LA-PETITE**



These increases are sometimes caused by natural phenomena with the particulate daughter products of radon, however they are generally caused by krypton-85 discharged from Orano's plant at La Hague.

A gamma spectrometry sensor has been installed with the Téléray sensor since October 2016. The krypton peak from industrial discharges can be clearly identified at 514 keV (figure B).

FIGURE B / **SPECTRUM FOR THE GAMMA SPECTROMETRY SENSOR DURING A KRYPTON-85 BURST – Omonville–la-Petite sampling station (the number of hits depends on energy levels)**



Spectra can be processed in order to differentiate between artificial increases and natural increases by calculating an indicator for the presence of artificial radionuclides, and isolating the radionuclides causing these increases, e.g. by extracting the number of hits attributed to krypton-85.

At the Omonville-la-Petite sampling station, the presence of artificial radionuclides correlates strongly with the identification of krypton-85 (figure C).

FIGURE C / **CORRELATION BETWEEN THE INDICATOR FOR THE PRESENCE OF ARTIFICIAL RADIONUCLIDES AND THE NUMBER OF HITS ATTRIBUTED TO KRYPTON-85**

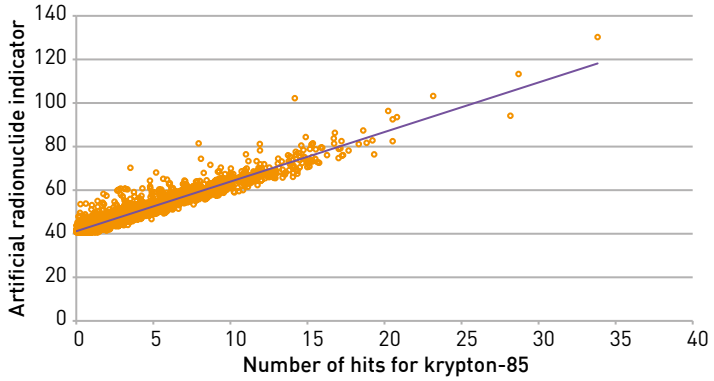
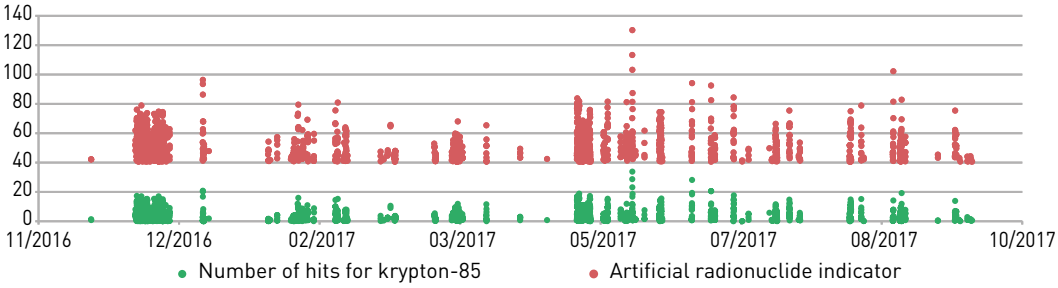
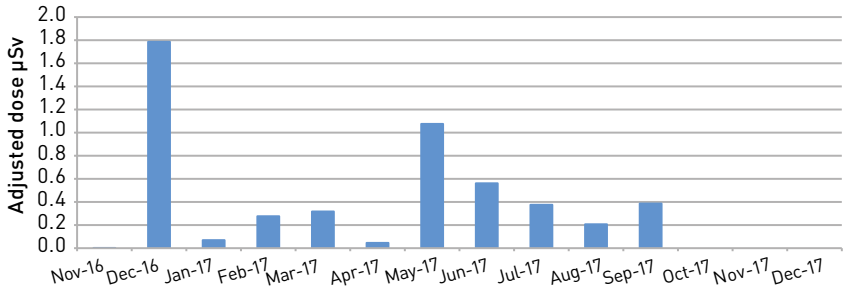


FIGURE D / **IDENTIFICATION OF VALUES FOR A KRYPTON-85 BURST – Omonville–la-Petite sampling station**



The dose added due to krypton-85 discharges can be determined after identifying significant results from the discharge of artificial radionuclides (figure D), and removing their reference background radiation value. The total value can be used to calculated an additional dose of 3.3 µSv for the year 2017. The graphic shown in figure E gives monthly variations in this additional dose, with a maximum value of 1.8 µSv recorded in the month of December 2016 alone at the Omonville-la-Petite sampling station.

FIGURE E / **MONTHLY ADDITIONAL DOSE DUE TO KRYPTON-85 FROM NOVEMBER 2016 TO SEPTEMBER 2017 – Omonville-la-Petite sampling station (µSv/mois)**



Tritium

Most of the tritium discharged from Orano's plant in La Hague is trapped as tritiated water and then released to sea. A very small fraction of the tritium is discharged as gas. These gaseous discharges only have a moderate effect on the atmosphere.

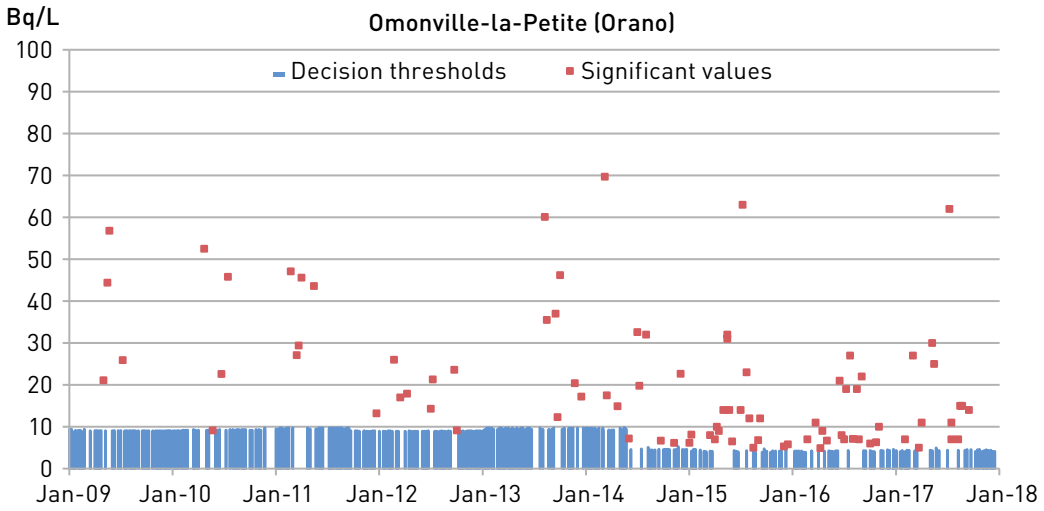
Due to the decision thresholds used by Orano for routine monitoring (approx. 0.4 Bq/m^3, i.e. 40 times ambient background tritium radiation from either natural sources or nuclear testing), measurements by Orano can only rarely be used to quantify total tritium activity (HTO+HT) in the air as per samples from the 5 samplers located in the villages near to the site. The highest number of significant values [1] (only 3% of values exceeded the DT of 0.4 Bq/m^3) was recorded at the Herqueville sampler to the south east of the plant between 2015 and 2017. On the other hand, it is regularly measured in the rainwater collected at the 3 samplers installed at Omonville-la-Petite for Orano, Digulleville for ANDRA and Gréville-Hague for IRSN (see figure 8). Activity levels per volume can occasionally exceed 30 Bq/L for the two samplers most exposed to the prevailing winds (Digulleville and Omonville-la-Petite).

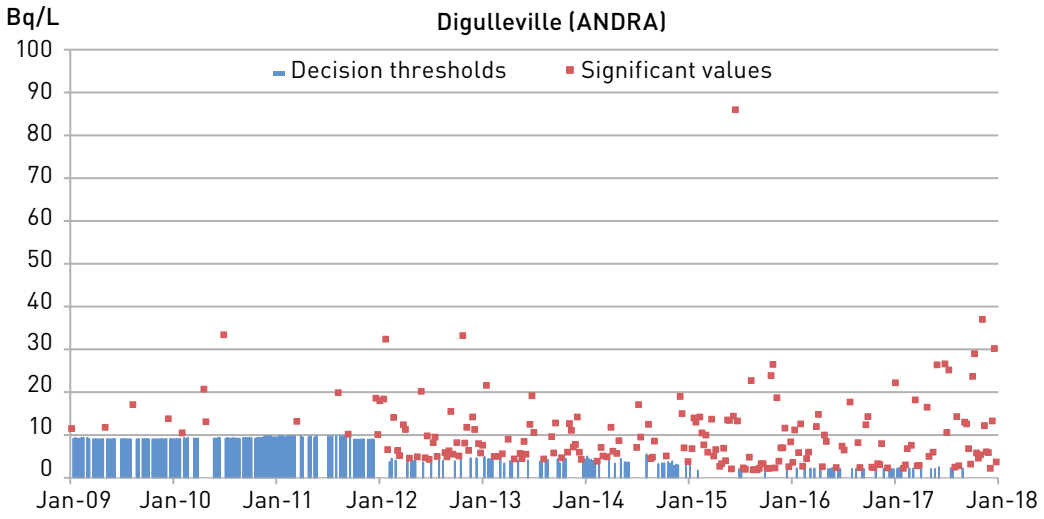
IRSN has run a bubbler to monitor atmospheric tritium at Omonville-la-Petite since 2015, to complement monitoring by Orano. Thanks to this system and the more advanced measuring systems used for expertise (see focus article on the "Omonville-la-Petite samplers"; p. 141), ambient tritium activity can be measured, particularly in the form of water vapour (HTO) and tritiated hydrogen (HT) (see figure 9). Since 2017, IRSN has also installed its rainwater collector at this sampling station to complement the existing measuring systems (bubblers, aerosol samplers, Téléray sensors and spectrometers). Mean ambient tritium values (HTO and HT) measured at this location between 2015 and 2017 reach 0.07 Bq/m^3 and 0.14 Bq/m^3 respectively. Mean tritium activity in rainwater samples at Omonville-la-Petite in 2017 represented 7.1 Bq/L. This figure corroborates the ambient measurement recorded for HTO.

At Omonville-la-Petite, ambient tritium levels will lead to an extremely low internal dose due to exposure by inhaling (estimated effective dose: less than 0.01 µSv/year), however tritium in HTO form will also lead to transcutaneous external exposure. The estimated effective dose is equal to the calculated inhaled dose. The total atmospheric tritium dose is therefore less than 0.02 µSv/year. This dose is approximately equal to the figures calculated by Orano based on discharge data from 2016: 0.04 µSv/year per adult living in Goury and 0.1 µSv/year per person living in the Digulleville canton. The differences are mainly due to the locations of the samples assessed depending on distance from the discharge point and prevailing wind direction.

1. In this document, a "significant value" is defined as a measurement which is above the decision threshold (DT). The definition applies throughout this document.

FIGURE 8 /TRITIUM **(HTO) ACTIVITY BY VOLUME MEASURED IN RAINWATER IN THE IMMEDIATE VICINITY OF THE LA HAGUE SITE (Bq/L)**





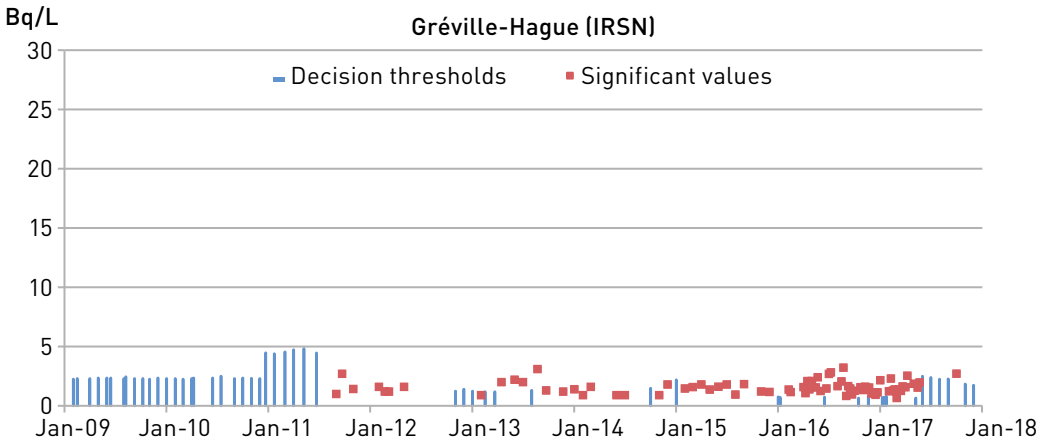
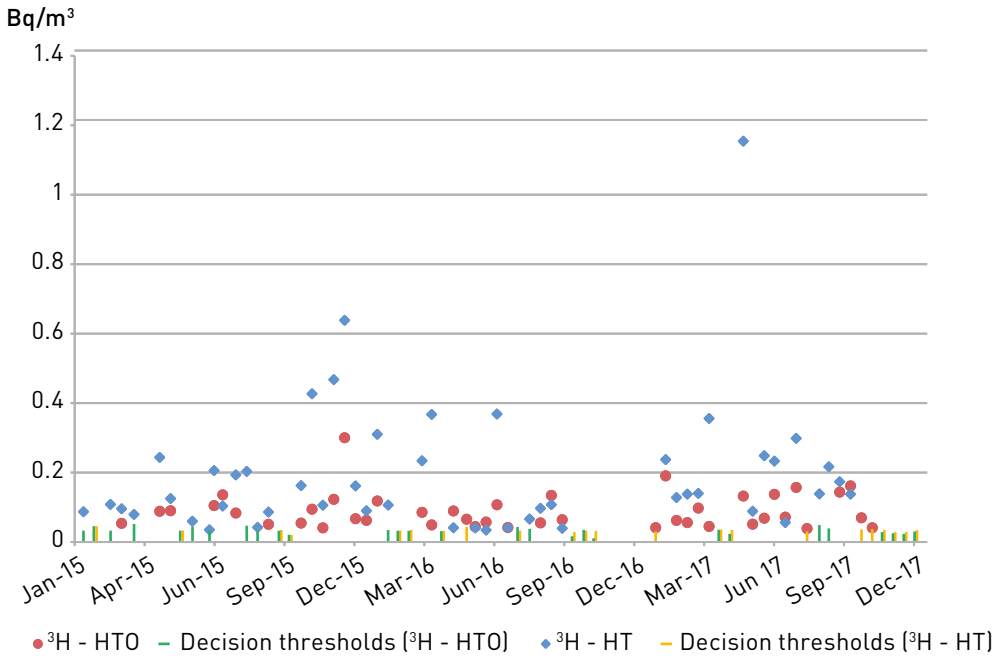


FIGURE 9 / **AMBIENT TRITIUM (HT and HTO) ACTIVITY BY VOLUME MEASURED AT THE IRSN SAMPLER AT OMONVILLE-LA-PETITE SINCE 2015 (Bq/m³)**



The low bound tritium activity levels by mass measured in the grass samples are attributable to these atmospheric activities. Mean values for the 2015 - 2017 period range from 1.1 to 3.5 Bq/kg fresh (see figure 10), depending on the sampler, which is slightly above local backgrond radiation. The highest activity levels were recorded near to the site in the municipality of Digulleville, under the prevailing winds north east of the site.

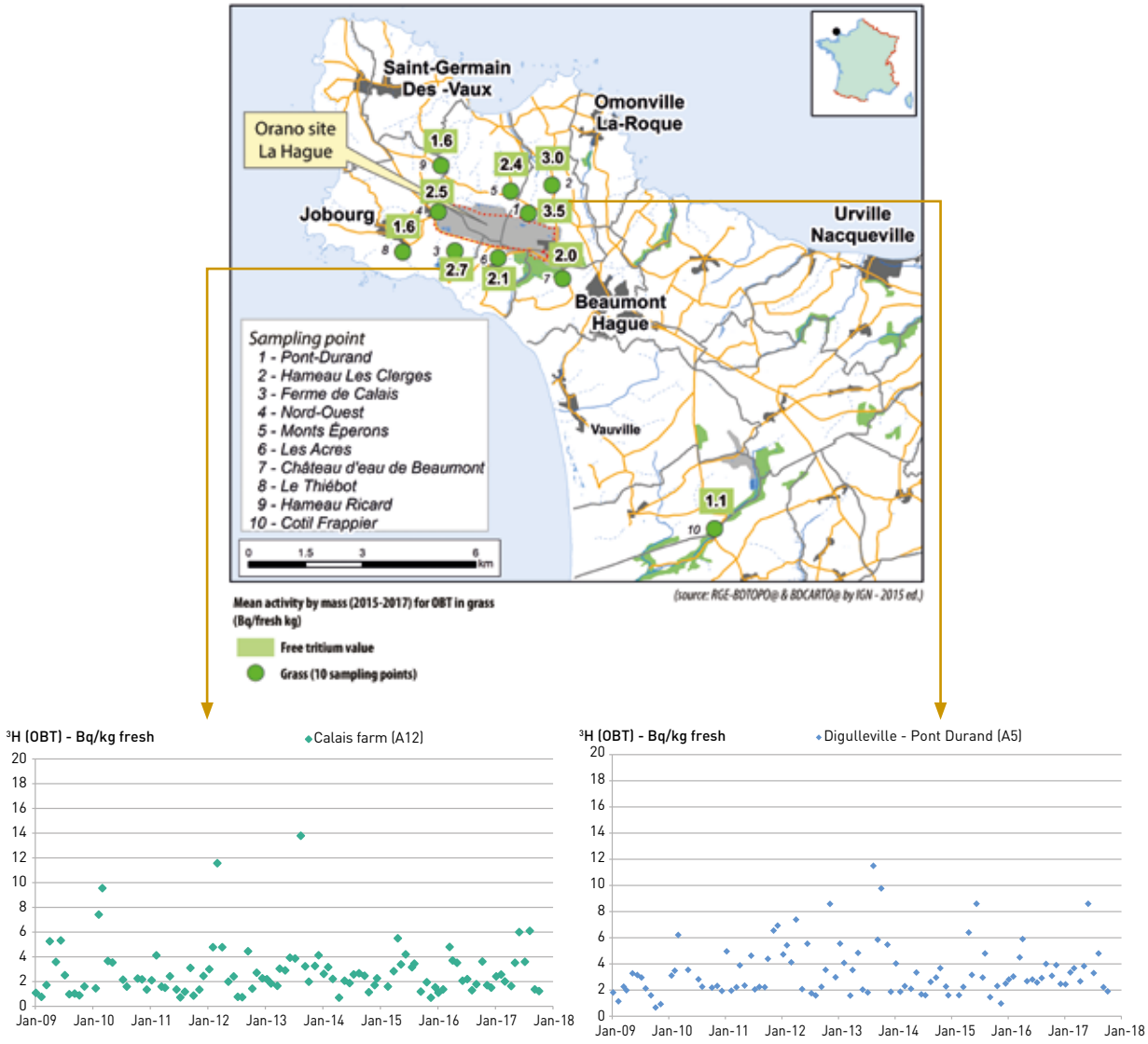
The geographic distribution of the activities measured is as expected based on the prevailing winds at the site (see figure 21).

Activity levels by mass measurements for bound tritium (OBT) in leaf vegetables (leaks, cauliflowers, parsley, etc.) represent between 0.5 and 2.2 Bq/kg fresh, which is above background radiation levels (mean value: 1.1 Bq/kg fresh). Free tritium (HTO) measurements were only obtained for two cauliflower samples. Significant values reaching between 2 and 8 times background radiation were recorded for both samples. Results were similar in root vegetables (carrots and potatoes), with a mean value of 1.2 Bq/kg fresh for bound tritium and 5.4 Bq/kg fresh for free tritium.

Free tritium (HTO) activity by volume in milk is generally below the decision threshold (< 4.5 Bq/L). Between 2015 and 2017, the highest number of significant values (21% of values) was recorded for milk from Digulleville, with peak activity of 10 Bq/L. Bound tritium activity levels by mass quantified in meat can be differentiated from background radiation thanks to mean values over the study period of 5.3 Bq/kg fresh for poultry, 2.1 Bq/kg fresh for sheep and 3.6 Bq/kg fresh for wild rabbits.

Mean activity by mass for honey and eggs are at similar levels (4.9 and 1.7 Bq/kg fresh respectively). These values are similar to those recorded in 2011-2014.

FIGURE 10 / **MEAN TRITIUM ACTIVITY BY MASS FOR THE 2015-2017 PERIOD IN GRASS SAMPLES COLLECTED AT THE 10 SAMPLERS NEAR TO LA HAGUE (Bq/kg fresh) AND TIMELINE FOR RECURRENT ACTIVITY LEVELS MEASURED AT TWO OF THESE SAMPLERS SINCE JANUARY 2009 (Bq/kg fresh)**

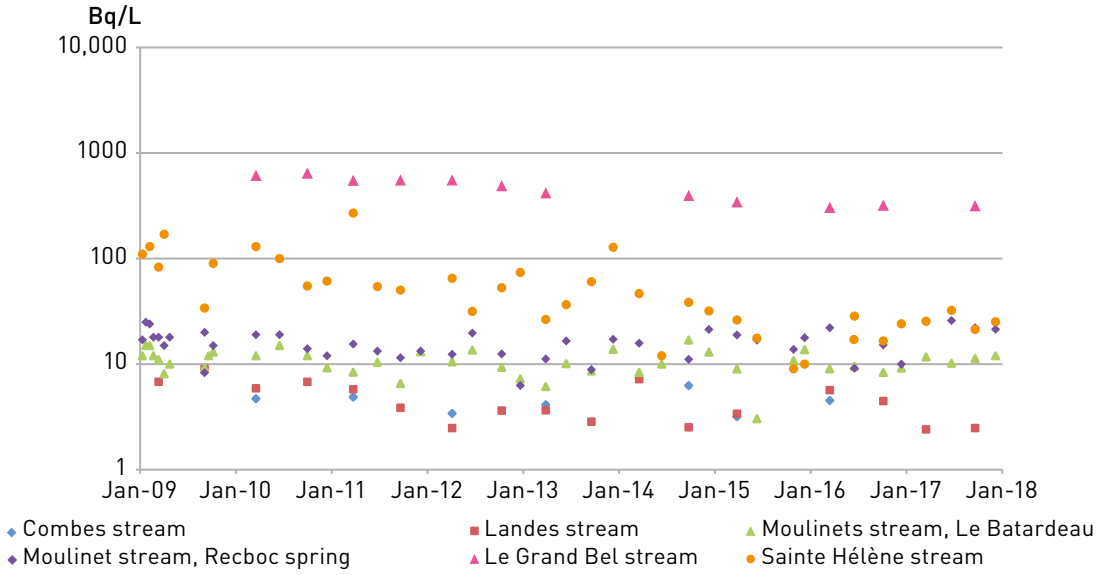


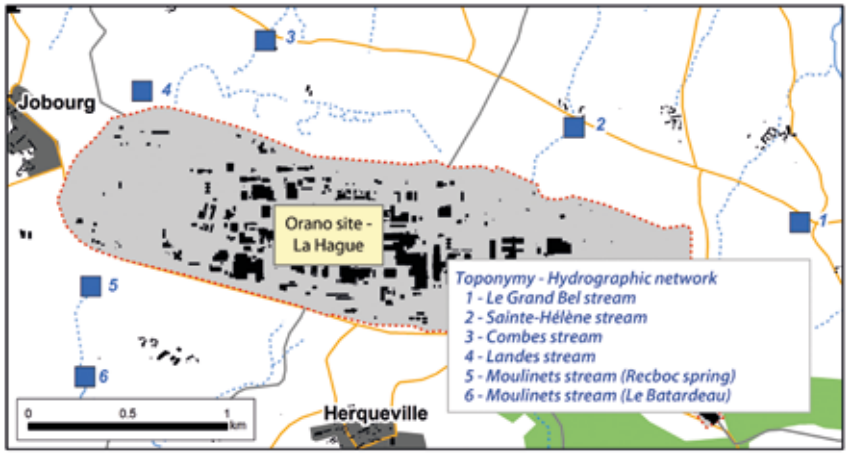
The terrain and narrow configuration of the Cotentin peninsula are home to small coastal rivers, which all run to the Channel. Tritium activity levels by volume were measured in water samples taken in all streams in the immediate environment around the site (see figure 11). Only 3 of these samples regularly include tritium activity levels in excess of 10 Bq/L: Moulinets stream (recboc spring), Sainte-Hélène and Grand Bel with mean activities by volume of 18 Bq/L, 21 Bq/L and 319 Bq/L respectively, calculated by IRSN over the 2015-2017 period.

The Sainte-Hélène steam and its tributary, the Grand Bel, carry rainwater and drainage water from the area to the east of the Orano La Hague site and the ANDRA site, after storage in a storm retention basin (see figure 4). Tritium contamination is still present further to historical pollution from the 1970's.

The Moulinets stream collects rainwater from the area west of the Orano site and wastewater. Finally, the Combes stream collects rainwater from the area north of the site.

FIGURE 11 / **FREE TRITIUM (HTO) ACTIVITY BY VOLUME IN RIVER WATER SAMPLES COLLECTED AT 6 IRSN MONITORING POINTS NEAR TO LA HAGUE (Bq/L) SINCE JANUARY 2009 AND LOCATION OF THE DIFFERENT SPRINGS**

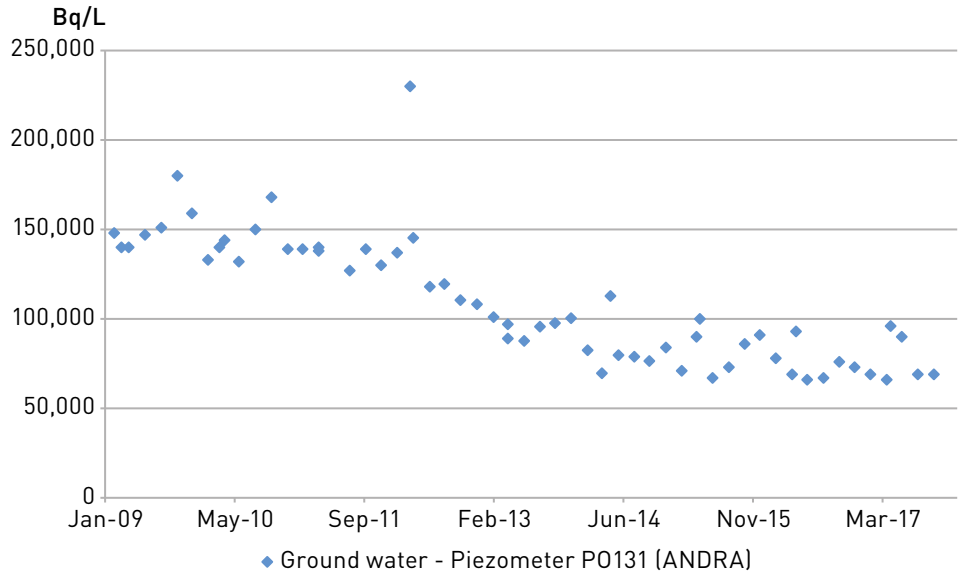




Thanks to the improvements in metrological performance for the systems used by the operator over the 2015-2018 period, tritium (HTO) activity by volume in drinking water has been characterised in more detail. Significant tritium activity can still be detected at the 12 samplers monitored by Orano around the La Hague site. Activity levels by volume for the closest Hameau Fabien borehole to the site, located in the municipality of Beaumont-Hague, are between 7 and 17 Bq/L, with a mean activity by volume of 9.8 Bq/L. Ignoring this borehole, the activity levels measured are mainly below 10 Bq/L, if they are significant at all. Drinking 2 L of water daily from the Hameau Fabien borehole would lead to an effective dose of 0.13 µSv/year.

The ground water under the La Hague site, and specifically under the CSM, has high tritium contamination levels, and can peak at an activity by volume of 100,000 Bq/L based on data recorded since 2014 using the most affected piezometer. The ground water downstream from the CSM is affected by historical tritium contamination due to an incident on a storage unit in 1976. The radionuclides are currently in the decay phase (see figure 12). This ground water is not used for any purpose.

FIGURE 12 / **TOTAL TRITIUM ACTIVITY BY VOLUME IN GROUND WATER SAMPLES COLLECTED NORTH EAST OF AND ABOVE THE CSM SITE USING PIEZOMETER P0131 (Bq/L) SINCE JANUARY 2009**



Contamination by tritiated liquid effluents discharged by the La Hague site, as well as the British Sellafield plant, to a lesser extent, is clearly measurable throughout the Channel.

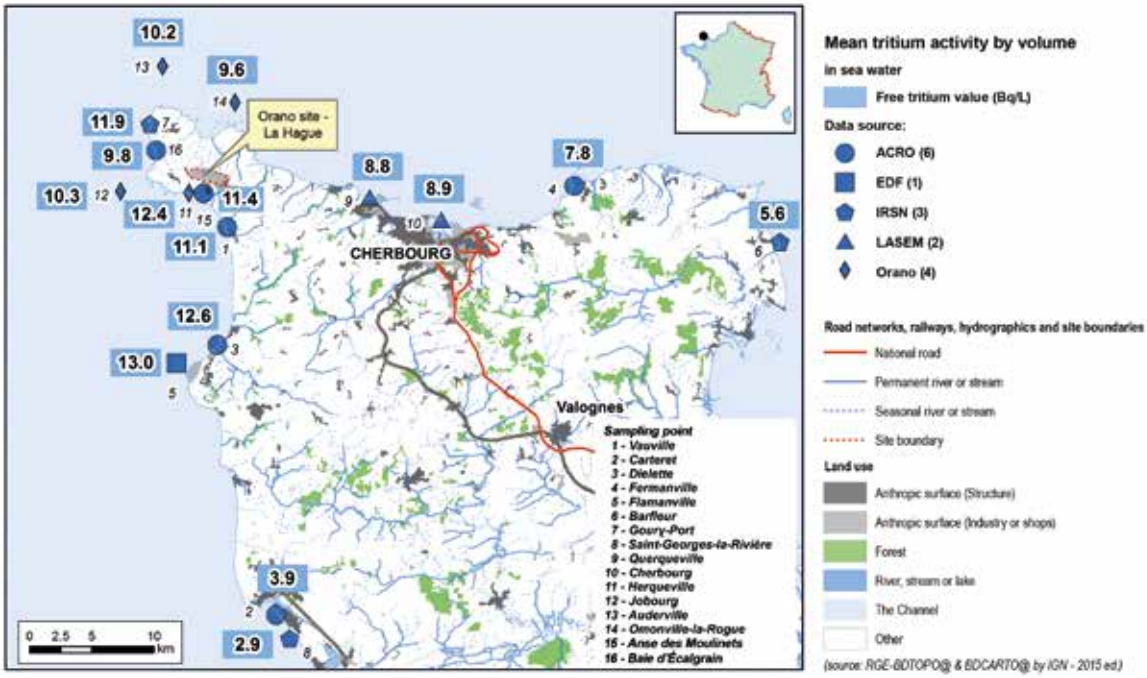
Mean tritium activity by volume in seawater over the 2015 - 2017 period (see figure 13) is approximately 12 Bq/L near to La Hague (compare this value with natural background radiation of approx. 0.1 - 0.2 Bq/L). This figure progressively decreases with distance. Note: these mean values mask significant variations within periods of just a few hours (see the focus article in the *IRSN radiological report* from 2012).

Tritium activity in marine organisms, plants and animals is in equilibrium with that of water, therefore activities by mass are similar. Mean activity by mass in fish captured on the west coast of the Cotentin peninsula represents 3.7 Bq/kg fresh for bound tritium (OBT) and 6.8 Bq/kg fresh for free tritium (HTO). In terms of molluscs, the two Saint-Jacques samples taken on the north coast of the Cotentin peninsula exceed background radiation; mean activity by mass is equal to 3 Bq/kg fresh for bound tritium and 6.7 Bq/kg fresh for free tritium. The two limpet samples taken near to Herquemoulin record similar levels, although mean activity by volume for free tritium is slightly higher (10.3 Bq/kg fresh). These activity levels are similar to and corroborate sea water data, as tritium is at equilibrium between seawater and fish.

The potential dose absorbed due to tritium discharged by the site by eating local food (vegetables, fish, meat, etc.) is extremely low. This dose is estimated at less than 0.01 µSv/year for an adult eating items grown near to the La Hague site, on the basis of the mean activity levels measured in food during the study period (2015-2017). A diet (see table 5) corresponding to that of people living in the north of the Cotentin peninsula, with a fisherman at the head of the household, was assumed. This diet is representative of an ordinary diet with fairly high fish contributions. Diet data and self-sufficiency data were taken from the CREDOC survey[2]. This dose is insignificant compared with those absorbed for krypton-85 discharged in effluents and described above.

2. Consumption Planning Department (Département Prospective de la consommation) (1998) Enquiry on food consumption in the north of the Cotentin peninsula on behalf of COGEMA CREDOC.

FIGURE 13 / **MEAN FREE TRITIUM ACTIVITY MEASURED IN SEA WATER AROUND THE COTENTIN PENINSULA OVER THE 2015-2018 PERIOD (Bq/L)**



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La Hague site as viewed from Anse des Moulinets

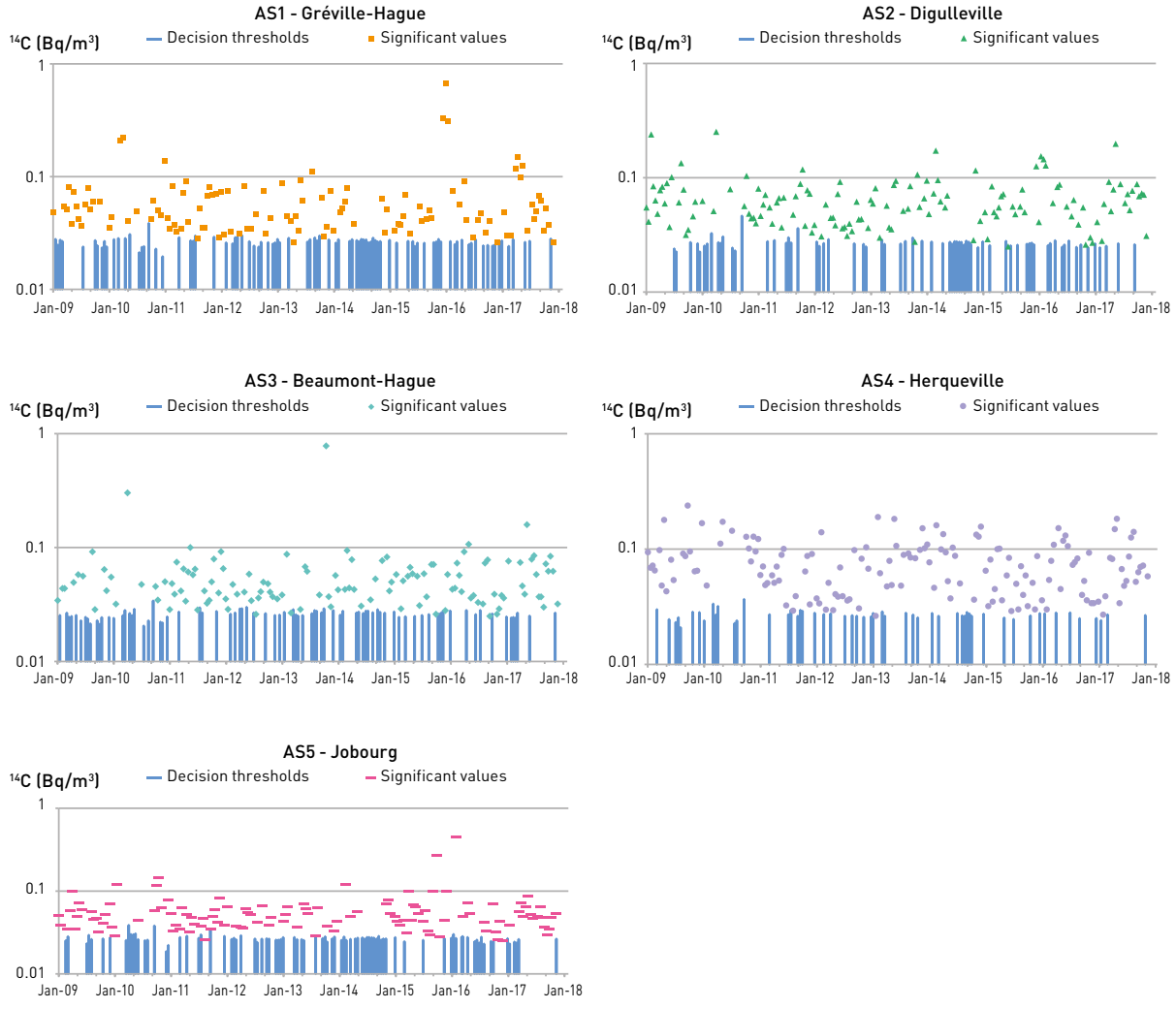
Carbon-14

The effects of liquid and gaseous effluents containing carbon-14 (CO_2) can be detected in most environmental components.

Ambient carbon-14 is regularly measured at the five village samplers located around the site (see figure 14). Ambient activity by volume measured on a bimonthly basis (for activity measured in the terrestrial food chain), fluctuates between less than 0.03 Bq/m³ (< DT) and 2.2 Bq/m³. Mean values calculated over the last three years (2015 - 2017) remain between the background level for this radionuclide (approx. 0.05 Bq/m³) at Digulleville and Beaumont-Hague, and 0.08 Bq/m³ at Jobourg.

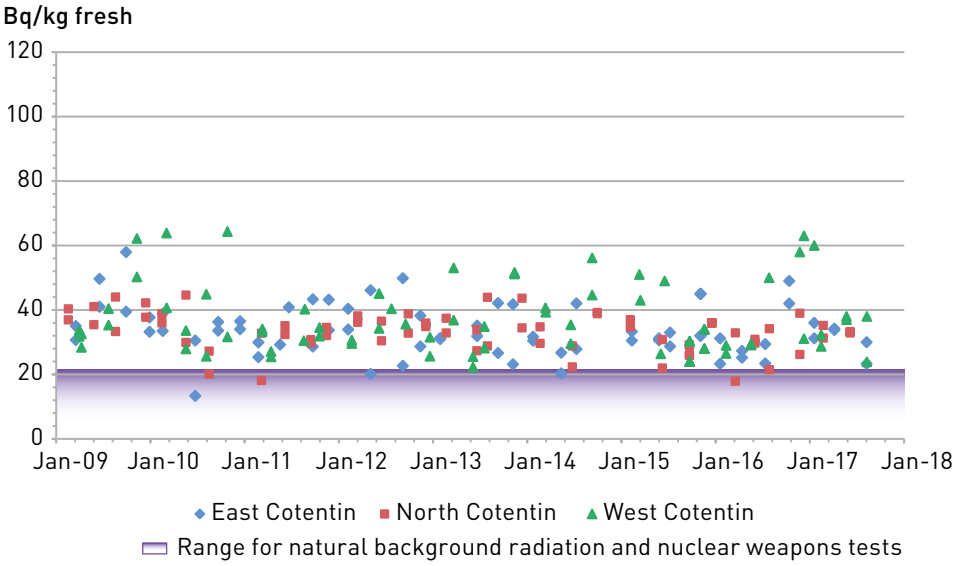
The dose absorbed by inhaling carbon-14 (as CO_2) by inhabitants of the municipality of Jobourg, where mean activity by volume is the highest, is very low (this dose peaks at 0.002 µSv/year).

FIGURE 14 / **AMBIENT CARBON-14 ACTIVITY BY VOLUME MEASURED AT THE FIVE VILLAGE SAMPLERS LOCATED NEAR TO THE LA HAGUE SITE (Bq/m³) SINCE JANUAR 2009**



The impact of carbon-14 discharges is easier to detect in food, particularly in sea food (fish, molluscs and shellfish) due to activity by mass measurements fluctuating between background radiation levels (approx. 20 Bq/kg fresh) and 3 to 4 times this value (see figures 15 to 17). Mean activity levels by mass calculated between 2015 and 2017 are between 33 Bq/kg fresh for fish and 53 Bq/kg fresh for shellfish. Due to variation in activity by mass, it is impossible to differentiate between sea food from the different sampling areas near to the site (west, north and east of the Cotentin peninsula). However, specific measurements taken on limpet samples collected on the Cotentin coast demonstrate that the impact of effluents discharged from La Hague is substantially higher near to the plant discharge points (near the discharge channel at Goury and Anse des Moulinets) than to the east, towards Cherbourg, or further south towards Barneville-Carteret. This impact is also detectable, to a smaller degree, along the entire French coast of the Channel up to Dunkirk (see. figure 18).

FIGURE 15 / **CARBON-14 ACTIVITY BY MASS IN FISH CAPTURED NEAR TO THE LA HAGUE SITE SINCE JANUARY 2009 (Bq/kg fresh)**



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Fish sampling (plaice)

FIGURE 16 / **CARBON-14 ACTIVITY BY MASS IN SHELLFISH CAPTURED NEAR TO THE LA HAGUE SITE SINCE JANUARY 2009 (Bq/kg fresh)**

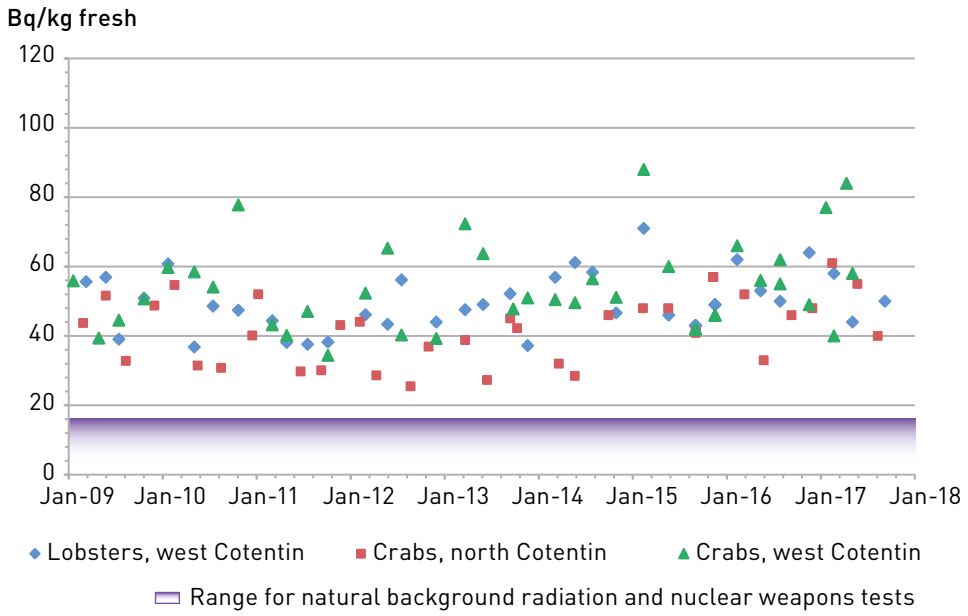
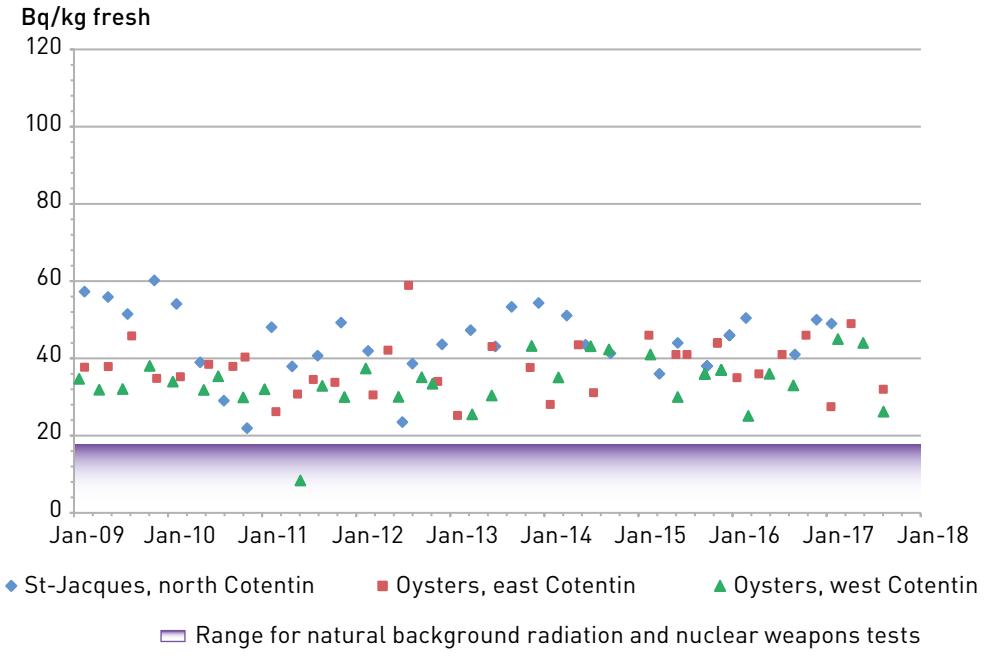
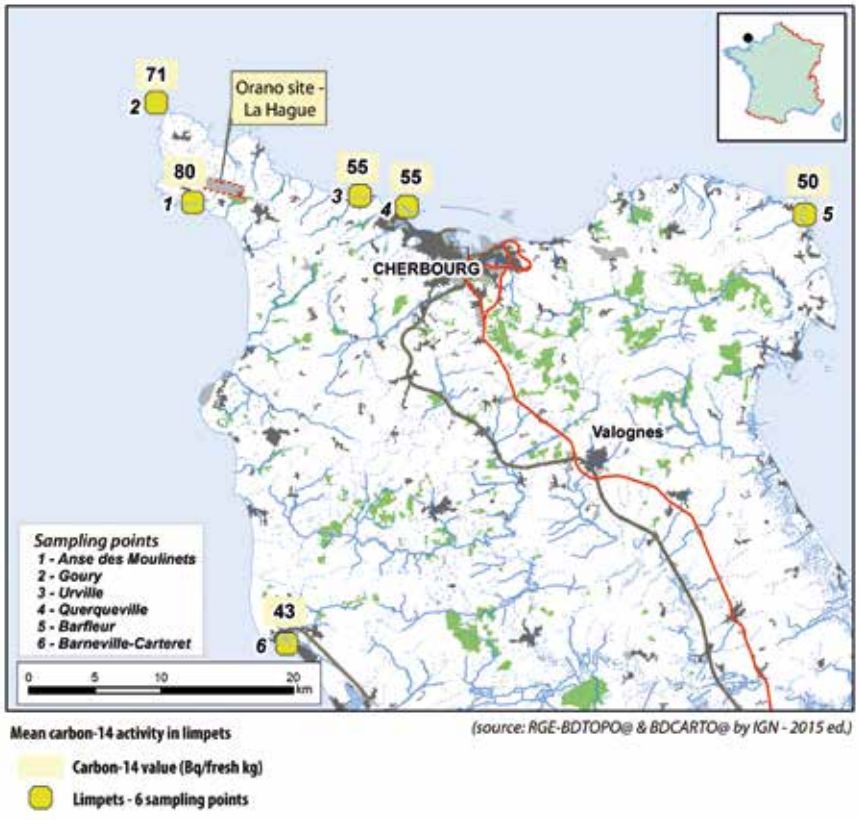


FIGURE 17 / **CARBON-14 ACTIVITY BY MASS IN MOLLUSCS CAPTURED NEAR TO THE LA HAGUE SITE SINCE JANUARY 2009 (Bq/kg fresh)**



Note: Orano has only taken oyster samples since 2014 due to a lack of mussels.

FIGURE 18 / **MEAN CARBON-14 ACTIVITY LEVELS IN LIMPETS CAPTURED NEAR TO THE LA HAGUE SITE BETWEEN 2015 AND 2017 (Bq/kg fresh)**



Carbon-14 activity in the terrestrial component around La Hague can also be differentiated from the "background radiation" for this radionuclide (see chapter 2), but to a lesser extent. Activity by volume measured in milk (see figure 19), rarely exceeds 40 Bq/L. Mean values calculated between 2015 et 2017 range from 19 Bq/L at Jobourg (Hameau Ricard) to 28 Bq/L at Herqueville (Hameau de l'église), where most activity is natural (approx. 15 Bq/L).

The geographic distribution of activity measured in grass samples (see figure 20) is fairly consistent with the expected configuration based on the prevailing winds (see figure 21) and with distance between the sampling site and the facility. The areas affected by atmospheric discharges from La Hague can be determined on this basis. The prevailing winds are west and south west.

FIGURE 19 / **CARBON-14 ACTIVITY BY VOLUME IN MILK SAMPLED NEAR TO THE LA HAGUE SITE SINCE JANUARY 2009 (Bq/L)**

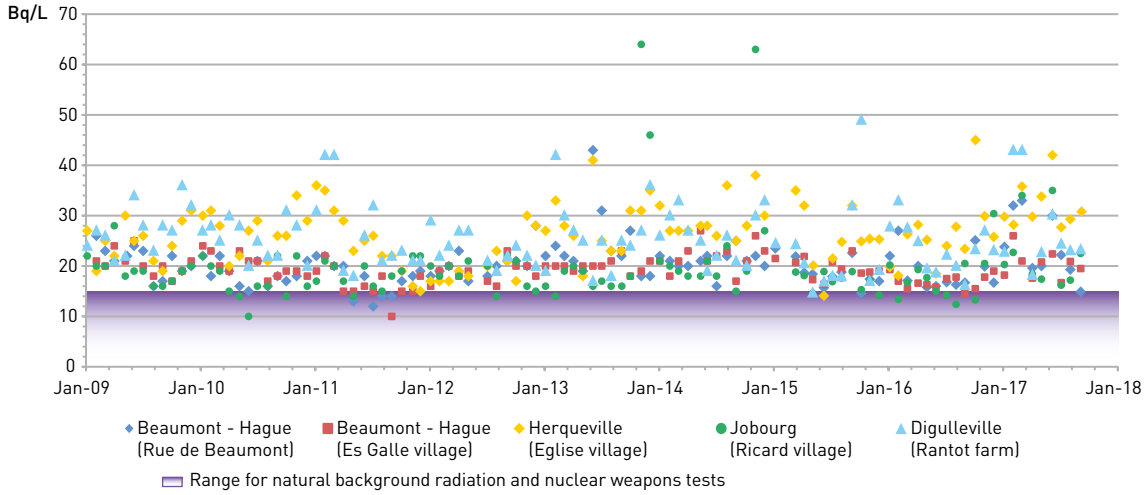
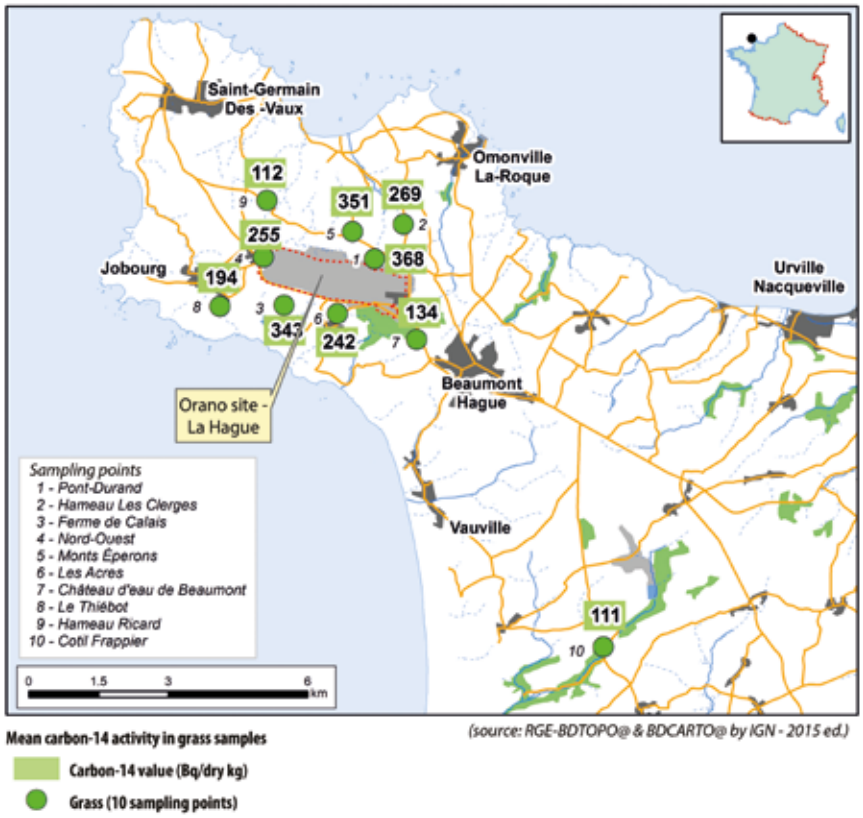


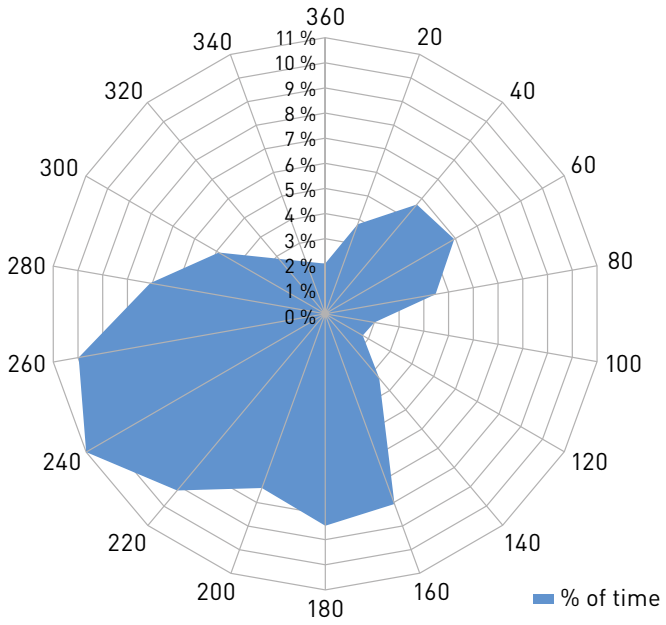
FIGURE 20 / **CARBON-14 ACTIVITY BY MASS IN GRASS SAMPLES TAKEN NEAR TO THE LA HAGUE (Bq/kg dry)**[3]

Mean values for the 2015-2017 period for ten samplers. The highest activity levels were recorded near to the site, under the prevailing winds east/north east of the site.



3. Since 2014, ASN has preferred for results relating to non-edible matrices to be given in Bq/kg dry to improve the harmonisation of data uploaded to the RNM database.

FIGURE 21 / **WIND DIRECTIONS (La Hague)**



Mean values measured in leaf vegetables and root vegetables between 2015 and 2017 (see figure 22) represent 17 and 27 Bq/kg fresh respectively, which is 2 to 3 times the value of background radiation (7 Bq/kg fresh for leaf vegetables and 10 Bq/kg fresh for root vegetables). Carbon-14 measurements during this period, in meat (poultry and sheep) and eggs (see figure 23) remain within the usual range in France and can mostly be attributed to natural sources (approx. 35 Bq/kg fresh for eggs, 55 Bq/kg fresh for poultry and 65 Bq/kg fresh for sheep). Only wild rabbits exceeded background radiation for this type of food on one occasion (approx. 50 Bq/kg fresh). Mean activity by mass calculated for this product represented 46 Bq/kg fresh between 2015 and 2017. Activity by mass measurements for fruit (blackberries) are similar to background radiation (14 Bq/kg fresh), and the mean value calculated over the study period reached 15 Bq/kg fresh.

The mean activity by mass of the two honey samples taken in 2015 and 2016 reached 73 Bq/kg fresh. This is also true for thyme, for which a mean activity by mass for the two samples represents 133 Bq/kg fresh. Both of these foods concentrate radioactivity.

The dose potentially absorbed by eating local food (milk, vegetables, fish, meat, honey, etc.) contaminated by carbon-14 due to effluents discharged from the La Hague site is estimated at 0.4 µSv/year for an adult eating items grown near to the La Hague site, on the basis of the mean activity levels measured in food during the study period (2015-2017). A diet (see table 5) corresponding to that of people living in the north of the Cotentin peninsula, with a fisherman at the head of the household, was assumed. Diet data and self-sufficiency rates were taken from the CREDOC survey carried out in the region in 1998.

FIGURE 22 / **CARBON-14 ACTIVITY BY MASS MEASURED FOR A FEW LEAF VEGETABLES SAMPLED NEAR TO THE LA HAGUE SITE SINCE JANUARY 2009 (Bq/kg fresh)**

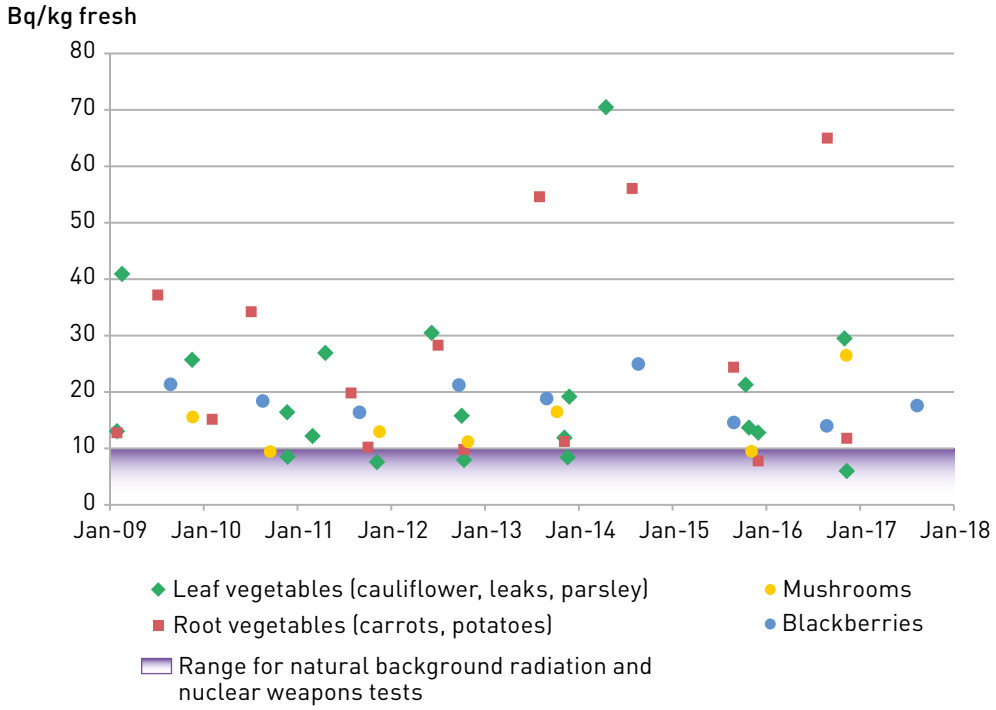
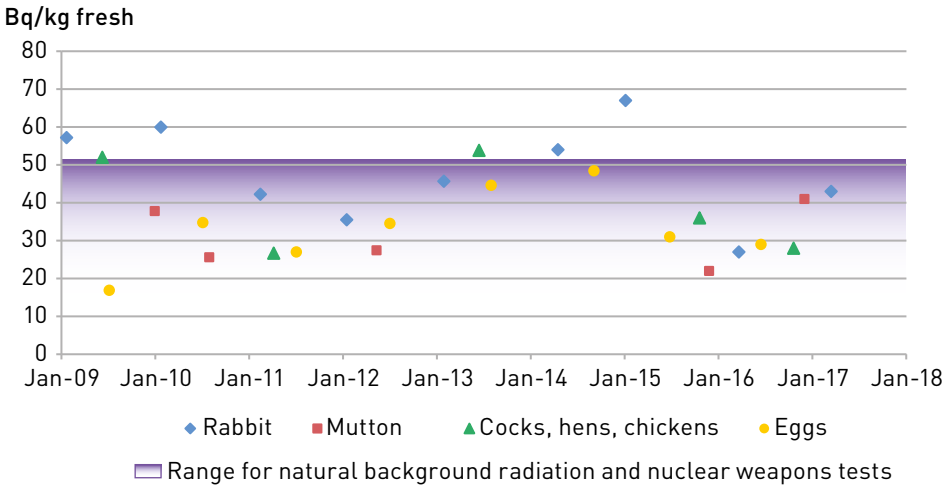


FIGURE 23 / **CARBON-14 ACTIVITY BY MASS MEASURED IN ANIMAL-BASED FOOD SAMPLES TAKEN NEAR TO THE LA HAGUE SITE SINCE JANUARY 2009 (Bq/kg fresh)**



Iodine-129

Iodine-129 is mainly discharged at sea after mixing with tritiated water.

Very little iodine-129 is discharged in gaseous form (6.1 MBq in 2016) as this radionuclide is absorbed by iodine filters installed on discharge stacks prior to discharge. For this reason and due to the decision thresholds used by Orano for routine monitoring (approx. 0.008 Bq/m^3), ambient iodine-129 is never measured at the five village samplers located in the municipalities around the site.

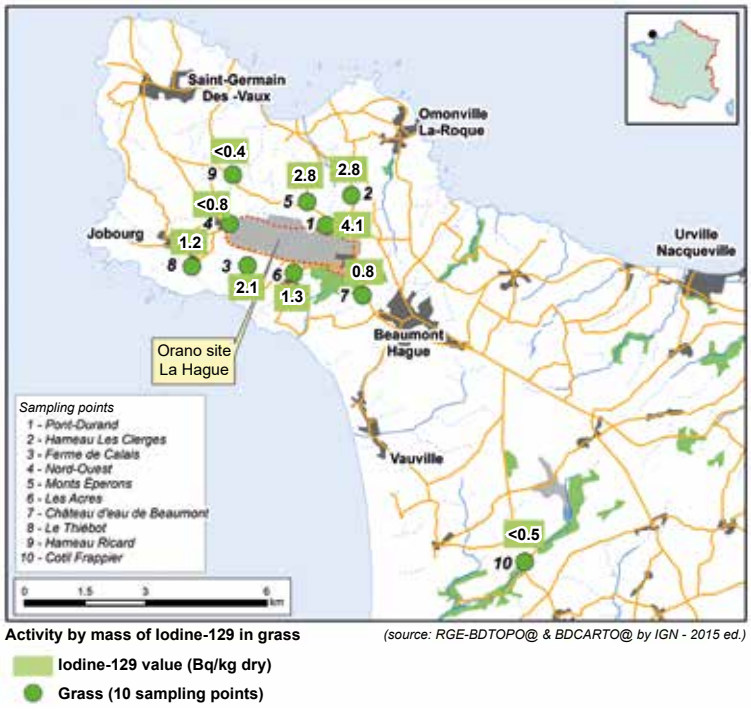
IRSN has run a new higher-flow aerosol sampler compared with the previous sampler fitted at Beaumont-Hague (80 m^3/h) at Omonville-la-Petite since 2015, to complement monitoring by Orano. Thanks to this system and the more advanced measuring systems used for expertise, ambient iodine-129 activity can be measured. Ambient activity levels by volume fluctuate between less than 0.5 µBq/m^3 (DT) and 27 µBq/m^3 for iodine-129 measured in particulate form and between 13 µBq/m^3 (DT) and 390 µBq/m^3 for iodine-129 measured in gaseous form. On this basis, iodine-129 is mainly discharged as a gas and the mean value calculated between 2015 and 2017 at Omonville-la-Petite represents 48 µBq/m^3.

Due to the very low ambient levels of iodine-129 at Omonville-la-Petite, the dose absorbed by local residents by inhaling is extremely low (estimated effective dose: 0.04 µSv/year). This dose is less than that calculated by Orano based on discharge data from 2016: 0.9 µSv/year per adult living in the Digulleville canton.

Mean activity levels by mass measured in grass samples[4] between 2015 and 2017 range between less than 0.4 and 4.4 Bq/kg dry (see figure 24). The geographic distribution of iodine-129 activity in grass samples is similar to that of carbon-14 or tritium.

FIGURE 24 / **MEAN IODINE-129 ACTIVITY BY MASS IN GRASS SAMPLES TAKEN NEAR TO THE LA HAGUE SITE (Bq/kg dry) BETWEEN 2015 AND 2017**

Mean values for the 2015-2017 period for ten samplers.



4. Since 2014, ASN has preferred for results relating to non-edible matrices to be given in Bq/kg dry to improve the harmonisation of data uploaded to the RNM database.

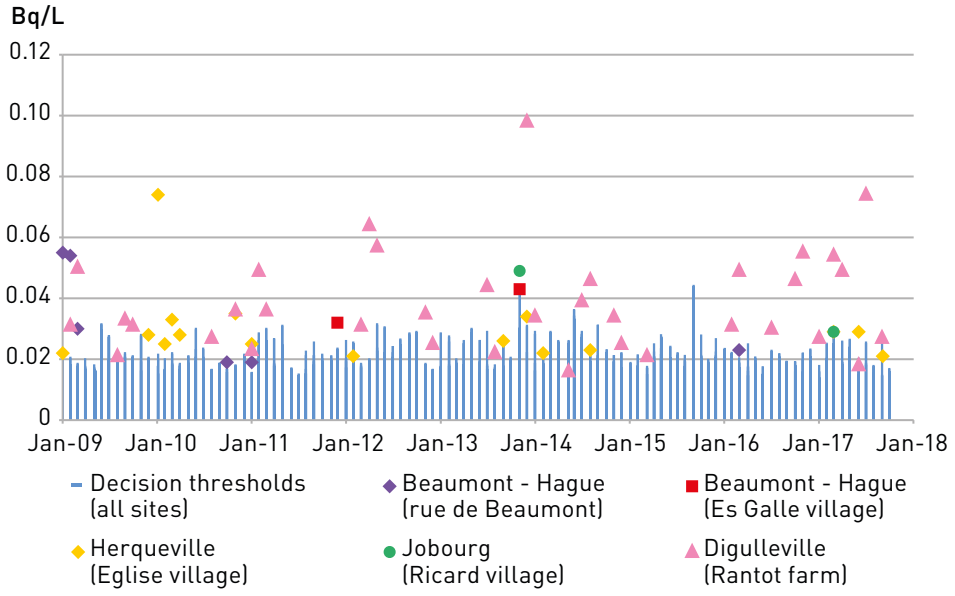
Iodine-129 is detected in less than 10% of milk samples taken at farms in the municipalities of Beaumont-Hague, Herqueville and Jobourg (for a decision threshold of approx. 0.02 Bq/L (see figure 25). The peak value measured in these municipalities reached 0.06 Bq/L. 34% of milk samples taken at the farm to the north east of the Digulleville site, where grass samples record the highest iodine-129 activity levels by mass, gave significant measurements[5] between 0.02 and 0.07 Bq/L. Activity levels generally corroborate those measured in grass samples, which would appear to indicate that some of the animal feed is grown locally.

Iodine-129 was not detected in any of the analyses conducted on cabbages, carrots, potatoes or leaks (DT < 0.1 Bq/kg fresh). On the other hand, iodine-129 was systematically detected in parsley, thyme and mushroom samples (with mean results of 0.4, 1.8 and 0.06 Bq/kg fresh respectively).

Activity could not be quantified in some meats (cock, rabbit and sheep), which could imply a more distant source of majority feed. However, a significant iodine-129 measurement was recorded for the two egg samples analysed between 2015 and 2017: 0.1 Bq/kg fresh); iodine is easily transferred to eggs

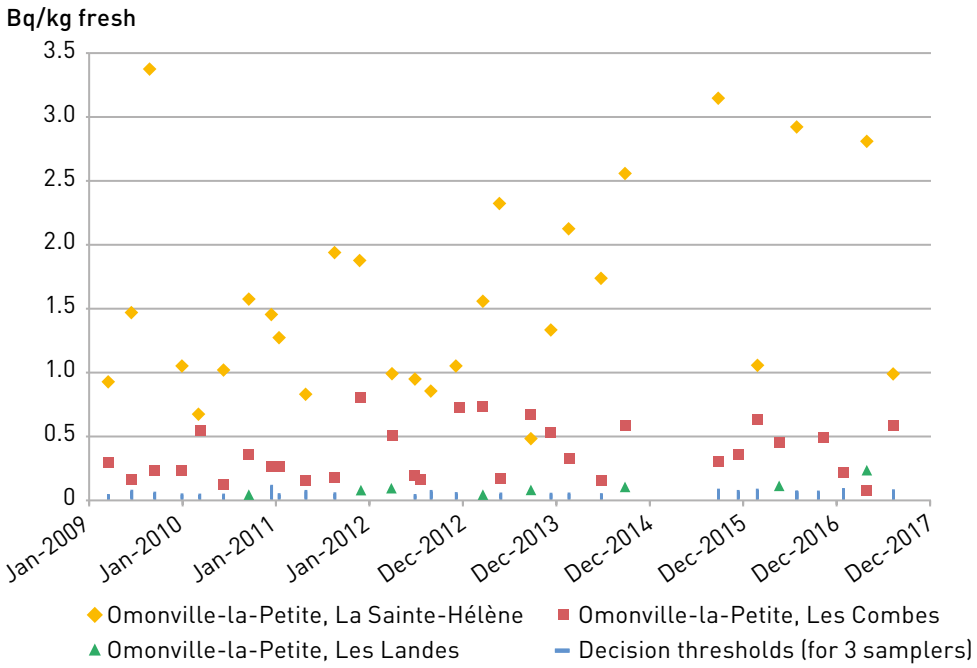
Iodine-129 has also been detected in aquatic plant samples taken from rivers to the north of the site: Landes, Combes and Sainte-Hélène (figure 26). However, no iodine-129 has been detected in water samples. Iodine-129 is occasionally detected in sediments (e.g. in samples taken near to the Moulinets dam), however the concentrations measured are near to the decision threshold in such circumstances (and less than 2 Bq/kg dry).

FIGURE 25 / **IODINE-129 ACTIVITY BY VOLUME MEASURED IN MILK SAMPLED NEAR TO THE LA HAGUE SITE SINCE JANUARY 2009 (Bq/L)**



5. In this document, a "significant value" is defined as a measurement which is above the decision threshold (DT).

FIGURE 26 / **IODINE-129 ACTIVITY BY MASS MEASURED IN AQUATIC PLANT SAMPLES TAKEN IN RIVERS NEAR TO THE LA HAGUE SITE (Bq/kg fresh)**



The highest iodine-129 activity levels in a marine environment are found in algae, which concentrate the radioelement. On this basis, algae can be used as a bio-indicator for the impact of iodine-129 effluents discharged from the La Hague plant, outside of the immediate environment of the site. Figure 27 shows changes in the geographic distribution of mean activity levels by mass measured between 2015 and 2017 in algae sampled along the Cotentin coast. These figures corroborate limpet data.

Seawater is only slightly contaminated by this radionuclide: over the 2015-2018 period, it was only detected four times (near to Goury port (Auderville) and Anse des Moulinets (Herqueville)) at concentrations of less than 10 mBq/L.

FIGURE 27 / **IODINE-129 ACTIVITY BY MASS MEASURED IN LIMPET (Bq/kg fresh) AND ALGAE (Bq/kg dry) SAMPLES TAKEN NEAR TO LA HAGUE - MEAN VALUES FOR THE 2015-2017 PERIOD FOR 12 SAMPLERS AND RECURRENT LIMPET VALUES SINCE 2009**

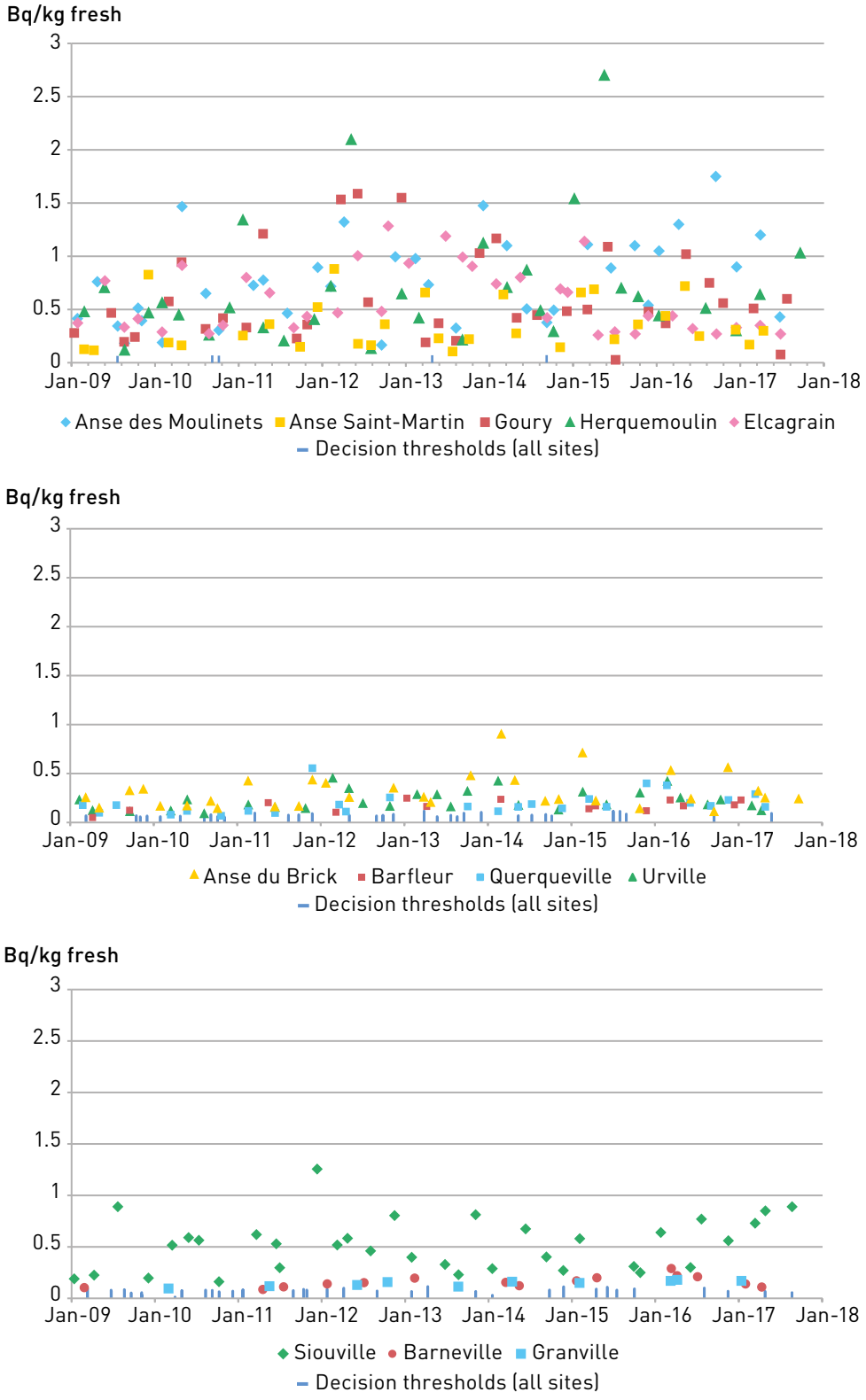
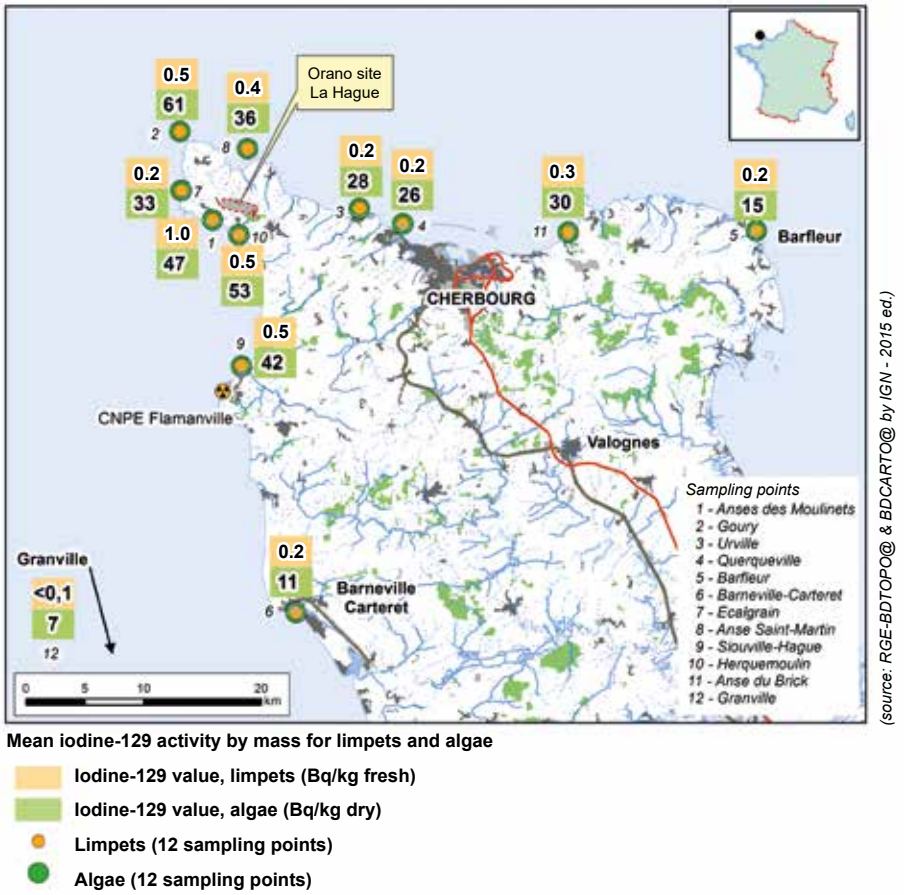


FIGURE 28 / **MEAN IODINE-129 ACTIVITY FOR LIMPETS AND ALGAE**



Iodine-129 contamination is higher in sea food than in terrestrial food produce. Contamination is more evenly spread in shellfish and molluscs than in fish (see figures 29 and 30). In fact, between 2015 and 2017, between 63% and 89% of the measurements recorded for fish were below the decision threshold Activities by mass measured range from 0.05 Bq/kg fresh on the east coast to 0.46 Bq/kg fresh on the west coast of the Channel. The highest iodine-129 activity levels by mass are recorded for lobsters captured on the west coast for shellfish (between 0.2 and 2.1 Bq/kg fresh). Crabs are also regularly contaminated, with activity levels by mass between 0.06 and 0.34 Bq/kg fresh. The highest levels were recorded in limpets captured near to the discharge channel for molluscs. Contamination levels drop progressively with distance. Mean activity levels by mass measured in limpet samples captured near to the discharge channel range between 0.4 and 1 Bq/kg fresh (see figure 27). Mean iodine-129 activity levels by mass calculated between 2015 and 2017 represent 0.4 Bq/kg fresh for shellfish and 0.5 Bq/kg fresh for molluscs.

The potential dose absorbed by eating local food contaminated by iodine-129 discharged by the La Hague plant is estimated at 0.2 µSv/year. This dose was assessed for an adult. Only the sea food components of the diet were considered (see table 5, for residents of north Cotentin peninsula, with a fisherman at the head of the household), given that most of the activity levels measured in almost all terrestrial food are insignificant therefore a mean value cannot be calculated.

FIGURE 29 / **IODINE-129 ACTIVITY BY MASS MEASURED IN FISH CAPTURED NEAR TO THE LA HAGUE SITE (Bq/kg fresh)**

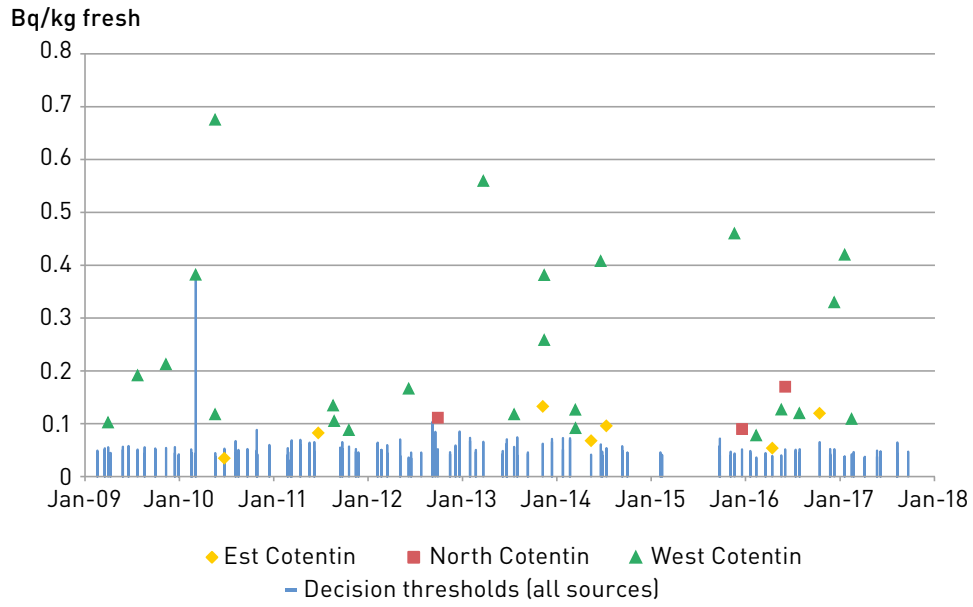
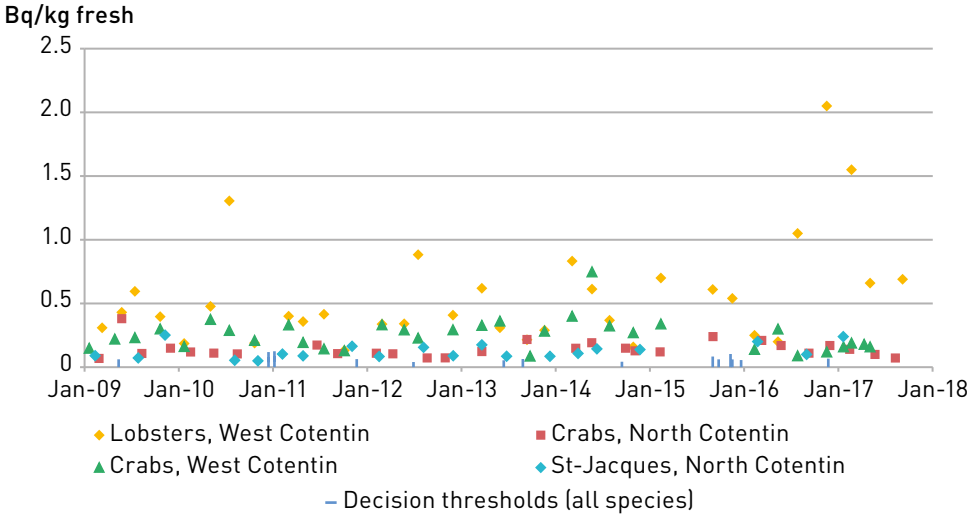


FIGURE 30 / **IODINE-129 ACTIVITY BY MASS MEASURED IN SHELLFISH AND MOLLUSC SAMPLES (excluding limpets) TAKEN NEAR TO THE LA HAGUE SITE (Bq/kg fresh)**



Plutonium 238, 239+240 and americium-241

Depending on the activity levels discharged, the impact of the actinides discharged by the La Hague site into the terrestrial environment cannot be differentiated from residual atmospheric fallout as plutonium and americium are mainly discharged in liquid effluents *via* the coastal discharge channel. In addition, discharges only affect the continental aquatic environment to a limited extent. Despite this, sediment samples taken from Sainte-Hélène steam and the Moulinets basin are contaminated due to old pollution from La Hague operations and the ANDRA storage facility. Liquid effluents from these two sites are not generally discharged *via* the Sainte-Hélène stream and Moulinets basin.

ANDRA collected two water samples from the Sainte-Hélène spring in June 2017, at monitoring points R6 and R6-10 (Hameau la Fosse). Analyses on these samples detected plutonium contamination. The activity by volume for the sample taken at point R6 represented 0.008 Bq/L for $^{239+240}$Pu and 0.0047 Bq/L for ^{238}Pu and 0.0011 Bq/L for $^{239+240}$Pu for the sample taken at point R6-10. Both of these samples were contaminated by ^{241}Am (0.00036 Bq/L for point R6 and 0.00042 Bq/L for point R6-10), but also by a rarer radionuclide: silver-108m. This radionuclide was probably released by the ANDRA site.

On the other hand, the impact of liquid discharges in the marine environment is far clearer. $^{239+240}$Pu and ^{238}Pu isotopes are regularly measured in molluscs, the most sensitive matrix (see figures 31 and 32). Significant activity levels by mass were recorded for all of the measurements taken on Saint-Jacques molluscs captured off the north coast of the Cotentin peninsula between 2015 and 2017, for ^{238}Pu and $^{239+240}$Pu. These measurements fell in the 0.007 - 0.03 Bq/kg fresh and 0.02 - 0.06 Bq/kg fresh brackets respectively.

For oysters collected on the east and west coasts of the Cotentin peninsula, 40% of values are below the decision threshold for the $^{239+240}$Pu (< 0.005 Bq/kg fresh) measurement. The maximum activity by mass measured reached 0.01 Bq/kg fresh. Only 20% of ^{238}Pu measurement results are significant for oysters, with a peak measurement of 0.01 Bq/kg fresh. Finally, between 60 and 80% of ^{238}Pu values are significant for limpets (except limpet samples taken at Urvillle: only 30% of measurements are significant). When measuring $^{239+240}$Pu, over 90% of results were significant for most monitoring points, except Urville where only 70% exceed the decision threshold. Figure 33 shows mean activity by mass calculated for the 2015-2017 period. The geographic distribution of actinide contamination in limpets is lower than iodine-129 contamination.

Shellfish (crabs and oysters) are not contaminated by these radionuclides.

All $^{239+240}$Pu measurements for fish samples between 2015 and 2017 are below the decision threshold (< 0.0025 Bq/kg fresh), except one sample taken on the east coast in 2016, where an activity by mass of 0.0003 Bq/kg fresh was measured.

Americium-241 was measured in a Saint-Jacques sample in 2017 (0.19 Bq/kg fresh) and in a limpet sample from Granville in 2016 (0.09 Bq/kg fresh).

The potential dose absorbed by eating local food contaminated by plutonium isotopes (239, 240 and 238) discharged by the La Hague plant is estimated at 0.02 µSv/year. This dose was assessed for an adult. Only mollusc type sea food components of the diet were considered (see table 5, for residents of north Cotentin peninsula, with a fisherman at the head of the household), given that only these products are regularly contaminated over time.

FIGURE 31 / **PLUTONIUM-239+240 ACTIVITY BY MASS MEASURED IN MOLLUSCS CAPTURED NEAR TO THE LA HAGUE SITE (Bq/kg fresh)**

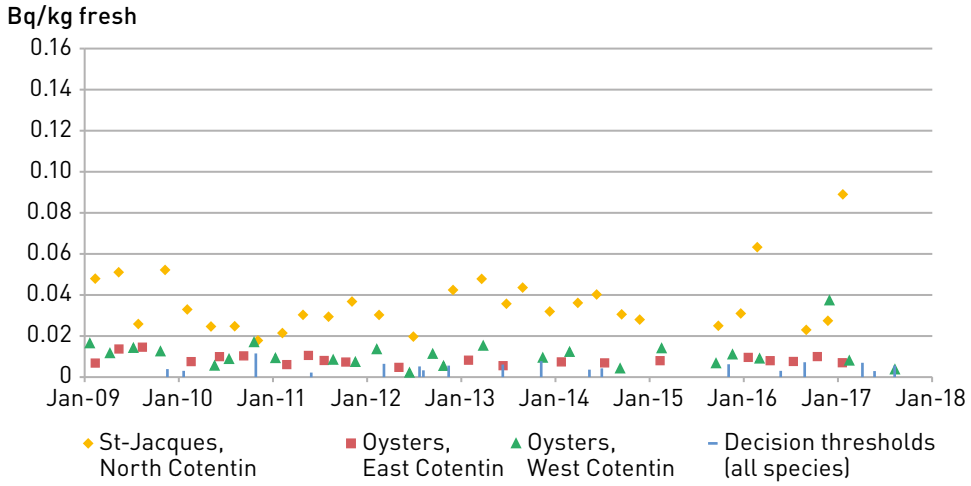


FIGURE 32 / **PLUTONIUM-238 ACTIVITY BY MASS MEASURED IN MOLLUSCS CAPTURED NEAR TO THE LA HAGUE SITE (Bq/kg fresh)**

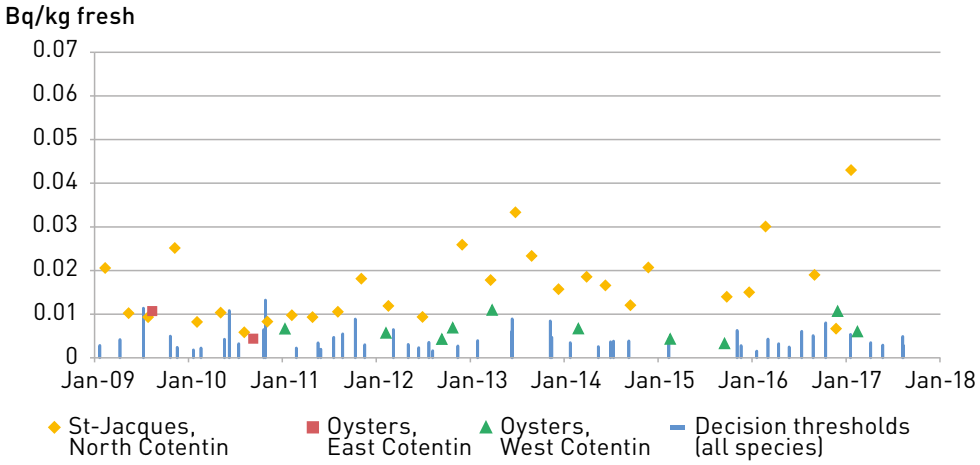
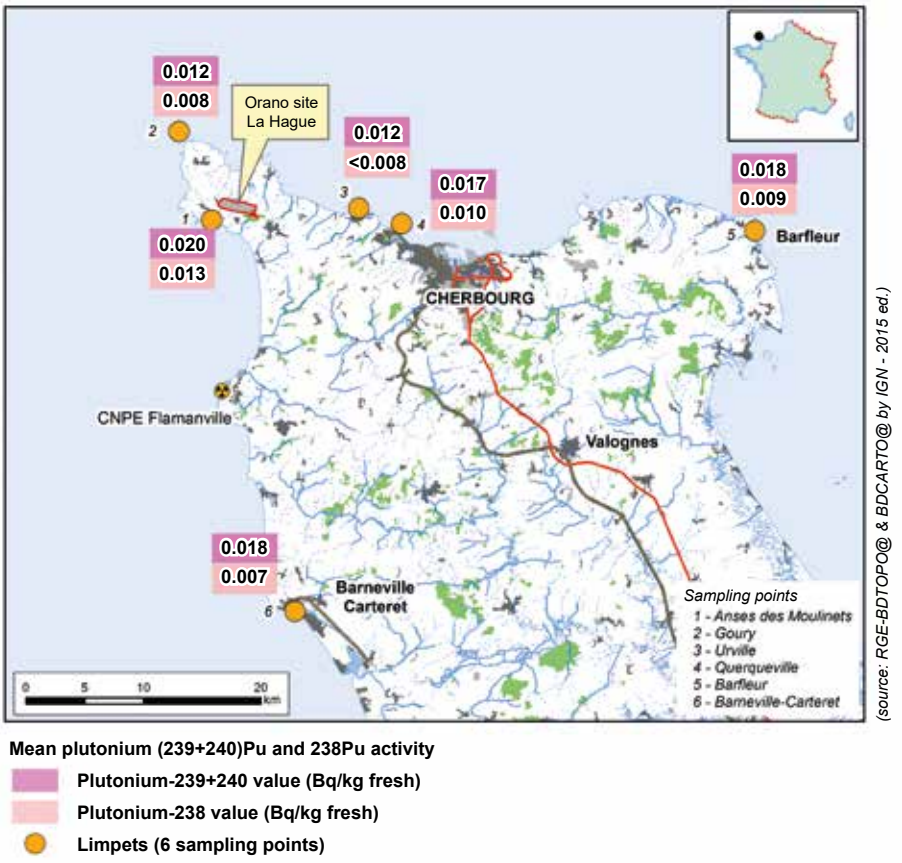


FIGURE 33 / **MEAN $^{239+240}$PU AND ^{238}PU ACTIVITY BY MASS MEASURED IN LIMPET SAMPLES TAKEN NEAR TO THE LA HAGUE SITE (Bq/kg fresh)**

Mean values for the 2015-2017 period for 6 samplers.



Finally, the impact of discharges from La Hague can also be detected in sediments and algae. Mean activity by mass in ocean sediments over this same period (see table 3), ranges from 0.31 Bq/kg dry at Barfleur to 1.1 Bq/kg dry in Cherbourg bay for $^{239+240}$Pu and from 0.15 to 0.46 Bq/kg dry for ^{238}Pu.

With the exception of Barfleur, ^{241}Am is systematically quantified in ocean sediments. The maximum mean activity by mass measured reached 2.9 Bq/kg dry in Cherbourg bay. ^{244}Cm is also occasionally measured in sediments (10% of results exceed the decision threshold). Significant measurements range from 0.14 Bq/kg dry in Cherbourg bay to 0.82 Bq/kg dry at Anse Saint-Martin. The highest values were recorded for samples from Cherbourg bay due to the finer sediments in the bay. The radionuclides can fix to these sediments more effectively. As was the case for sea food, the mean isotopic ratio between ^{238}Pu and $^{239+240}$Pu calculated based on activity levels for the different sediment samples is equal to 0.43, and provides proof of an industrial source.

Activity measured over the 2015-2017 period in algae ranges from 0.048 (< DT) to 0.49 Bq/kg dry for $^{239+240}$Pu and from 0.042 (< DT) to 0.3 Bq/kg dry for ^{238}Pu.

TABLE 3 / **MEAN ACTIVITIES BY MASS MEASURED IN OCEAN SEDIMENTS COLLECTED NEAR TO THE LA HAGUE SITE (Bq/kg dry)**

Sampling site	Mean activities by mass (Bq/kg dry)		
	^{238}Pu	$^{239+240}$Pu	^{241}Am
Anse des Moulinets	0.15	0.33	0.58
Elcagrain	0.21	0.51	0.92
Anse St-Martin	0.39	0.95	2.02
Grande Rade de Cherbourg	0.46	1.06	2.86
Sciotot	0.18	0.44	0.77
Anse du Brick (Cap Lévi D1)	0.39	1.01	1.97
Anse du Brick (Cap Lévi D2)	0.32	0.65	1.41
Barfleur	0.15	0.31	0.40

Ruthenium-106, cobalt-60, caesium-137 and strontium-90

Up until around 2005, ruthenium-106, cobalt-60 and even caesium-137 activity levels, mainly measured in algae, molluscs and shellfish, were affected by liquid discharges from the La Hague plant, not only in the marine environment (north coasts of the Cotentin peninsula), but along the entire French coast of the Channel[6].

Most of these radionuclides can no longer be detected as part of Orano's monitoring programme since liquid discharges containing specific radionuclides have been reduced (from 2007).

Ruthenium-106

^{106}Ru is no longer detected in sediments due to the decrease in quantities discharged and the relative short half life of this radionuclide. ^{106}Ru has only been detected in 20 to 40% of limpet samples captured in Elcagrain bay, Anse des Moulinets and Siouville since 2015. Despite this, the activity by mass measurements were all close to the decision threshold (and between 0.9 and 2.3 Bq/kg fresh). Ruthenium-106 was also detected in a sample of Saint-Jacques molluscs in 2017 (0.9 Bq/kg fresh).

Two grass samples taken at Pont Durand in March and April 2016 were contaminated with ^{106}Ru. Activity by mass measurements represented 14 and 6 Bq/kg dry).

Cobalt-60

Cobalt-60 is only occasionally detectable in sea food due to a progressive decrease in discharges containing this radionuclide. Cobalt-60 was only measured twice in 2015 in a spider crab sample and in a limpet sample from the Anse des Moulinets (activity by mass of 0.30 Bq/kg and 0.19 Bq/kg respectively) and once in 2017, in a Saint-Jacques sample (0.15 Bq/kg fresh) as part of the monitoring programme for the 2015-2017 period.

According to the studies conducted by IRSN, at the request of EDF, cobalt-60 is detected less frequently in sea food off the coast of Normandy (see table 4).

Cobalt-60 is still regularly detected in sediment samples taken from Cherbourg bay (1.9 Bq/kg dry) Levels decrease with distance (0.65 Bq/kg dry at Anse Saint-Martin and < DT towards the monitoring points located after the tip, heading along the coast towards the east (Elcalgrain and Anse des Moulinets). This decrease is also apparent on the east coast of the Cotentin peninsula, with a mean activity by mass of 0.6 Bq/kg dry at Anse du Brick (monitoring point SD16) and < DT at Barfleur.

Finally, the activity levels measured at the different sampling points range from 0.18 (< DT) to 1.39 Bq/kg dry in algae.

6. Ruthenium-106 activity levels are attributed to discharges from La Hague as the NPPs do not release this radionuclide; cobalt-60 and caesium-137 activities are mainly attributable to discharges from Hague, which are 1000 to 10,000 times higher than NPP discharges. This difference is currently smaller.

TABLEAU 4 / **COBALT-60 AND RUTHENIUM-106 ACTIVITY BY MASS MEASURED IN MOLLUSCS COLLECTED IN THE CHANNEL AND ANALYSED IN STUDIES ENTRUSTED TO IRSN BY EDF FOCUSING ON NPPS (Bq/kg fresh)**

The ratio indicates the number of times the radionuclide was measured over the number of measurements (all other results are below the decision threshold).

EDF NPP	Isotope	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Flamanville	^{60}Co	0.019-0.04 3/9	0.027 1/6	0.04-0.14 5/6	0.03-0.7 7/8	0.06-0.11 5/7	0.02-0.05 2/8	0.03-0.06 5/8	0.03-0.07 5/8	0.017-0.029 5/8	0.015-0.03 3/7	0.009-0.041 3/7
	^{106}Ru	0.2 2/9	0.023-0.03 2/6	0.27-0.60 2/6	0.6-0.8 3/8	0.3-0.4 3/7	0.25 1/8	0.18-0.27 2/8	0.12-0.16 3/8	0.15 1/8	0.11-0.23 3/7	0.19-0.28 2/7
Paluel	^{60}Co	0.03 2/5	0.04-0.08 2/7	0.03 1/7	0.02-0.06 4/5	0.02-0.03 2/6	-	0.03 1/6	0.02 1/6	0.023-0.071 3/6	0.043 1/6	0.042 1/6
	^{106}Ru	-	-	0.08 1/7	0.12 1/5	-	-	-	-	-	-	-
Penly	^{60}Co	0.023 1/7	0.03-0.15 5/6	0.03 1/7	0.11 1/5	0.02 1/7	0.01-0.03 2/7	0.03 1/6	-	0.012 1/6	0.013 1/6	0.021 1/6
	^{106}Ru	0.3 1/7	0.26-0.6 3/6	-	-	-	-	-	-	-	-	-
Gravelines	^{60}Co	0.04-0.05 3/5	0.04-0.05 3/4	0.02-0.06 3/5	0.02-0.03 5/6	0.02-0.03 2/4	0.05 1/2	0.02 1/3	0.01-0.04 4/6	0.033 1/4	-	0.012 1/2
	^{106}Ru	0.15 1/5	0.2-0.3 3/4	-	0.16 1/6	-	-	-	-	-	-	-

Caesium-137

In a terrestrial environment, it would appear that residual contamination can be detected in the area to the north west of the La Hague site. In fact, as shown by soil analyses near to the Landes stream in 2016 and 2017, (see chapter 5.4, focus article on the Landes stream) mean activities by mass measured in this area exceed background radiation levels for this radionuclide due to fallout from nuclear tests and the Chernobyl accident. This contamination was originally airborne and was released in past events, particularly the discharge incidents recorded from 1974. At this time, concrete blocks containing waste stored at off-site areas in the north west disseminated caesium-137 in the region.

This contamination can also be detected, to a lesser extent, at Orano's regular grass monitoring points to the north west of the site: mainly monitoring point A15 near to where the Landes stream comes out, and moving farther away from the site towards the north, at point A6 (Acres) and point B18 (Hameau Ricard). Activity levels by mass for the grass samples collected at these three points almost always, or regularly, exceed local background radiation levels for this type of matrix (< 0.4 Bq/kg dry at Flamanville). The same cannot be said for other monitoring points (see figure 34).

However, grass sample measurements are low enough to prevent a transfer of the radionuclides to cow's milk. In fact, all of the results for this type of matrix are below the decision threshold (< 0.04 Bq/L).

Mushrooms are the only terrestrial food with significant results, with a mean activity by mass measured between 2015 and 2017 of 0.2 Bq/kg fresh, which is equal to background radiation levels for this type of food.

Caesium-137 is also discharged by the La Hague plant in liquid effluents. The annual activity discharged (660 GBq/year for 2016) is progressively decreasing (see figure 35). In terms of sea food, caesium-137 activity by mass in fish captured along the Cotentin coast is relatively stable on the west and east coast and has been gradually decreasing on the north coast since 2015 (see figure 35). Activity levels measured between 2015 and 2017 range from 0.05 to 0.25 Bq/kg fresh, with a mean value of 0.09 Bq/kg fresh. Results for this radionuclide are similar to background radiation in sea fish (0.08 Bq/kg fresh).

The only food with activity by mass measurements which exceed background radiation is fish, based on caesium-137 measurements.

The dose absorbed by individuals who regularly eat this fish from La Hague is extremely low, depending on the selected scenario (less than 0.001 µSv/year).

FIGURE 34 / **CAESIUM-137 ACTIVITY BY MASS IN GRASS SAMPLES TAKEN NEAR TO THE LA HAGUE SITE (Bq/kg dry) BETWEEN 2015 AND 2017**

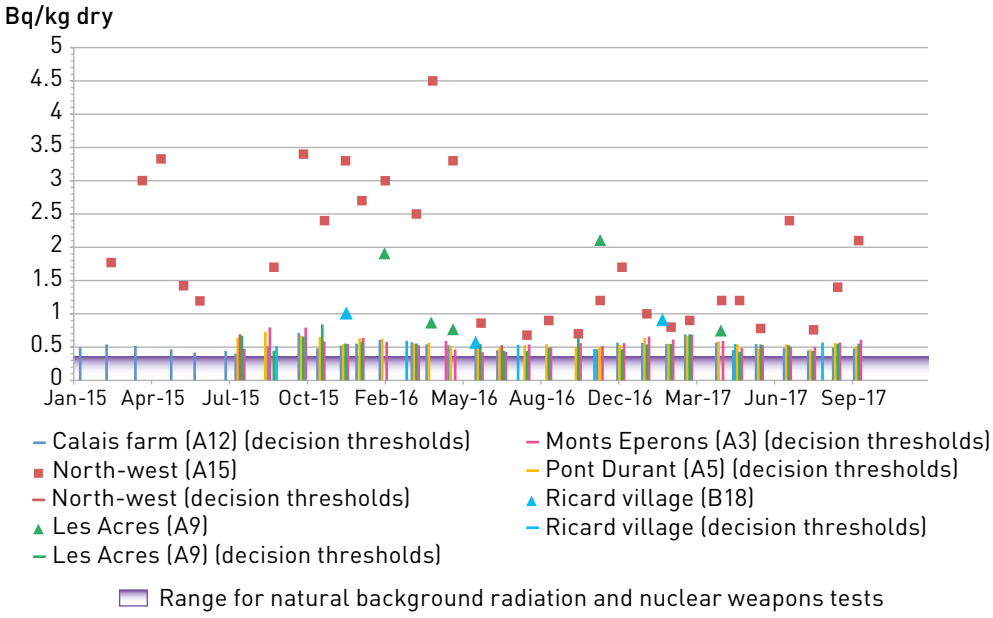
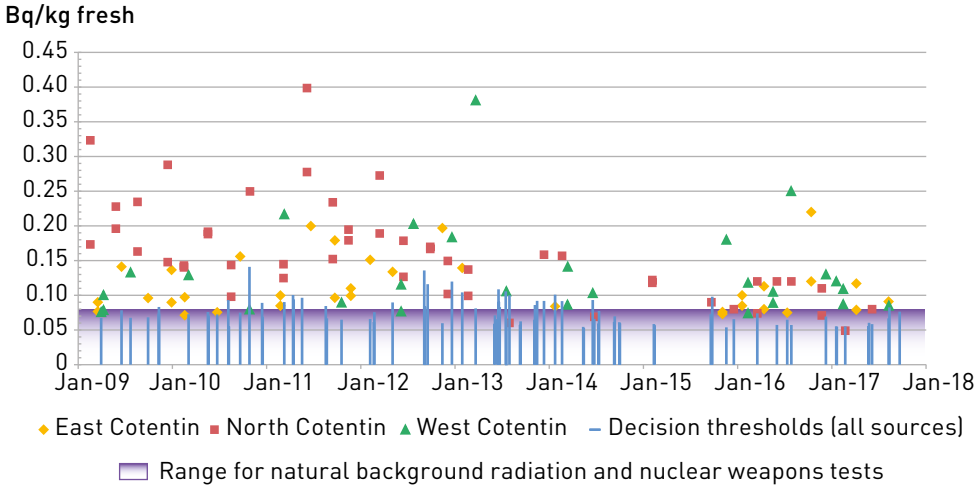


FIGURE 35 / **CAESIUM-137 ACTIVITY BY MASS MEASURED IN FISH CAPTURED IN THE CHANNEL NEAR TO THE LA HAGUE SITE (Bq/kg fresh) BETWEEN 2015 AND 2017**



Strontium-90

Strontium-90 is one of the main radionuclides remaining from fallout from atmospheric nuclear testing. This radionuclide can also be found in liquid effluent discharges from the La Hague plant and is part of the fission products discharged at sea.

In an aquatic continental environment, strontium-90 activity by volume in rivers near to the La Hague plant is approximately at background radiation levels due to the leaching of soils contaminated by atmospheric fallout from nuclear tests, that is < 10 mBq/L. Only the contamination of the Landes stream, which runs to the north west of the La Hague site, exceeds background radiation levels. Activity levels measured between 2015 and 2017 at the point where the Landes stream discharges range from 0.6 to 1.4 Bq/L. (see figure 36). These concentrations must be compared with the strontium-90 content of the ground water feeding this stream due to an incident in the 1980's when concrete pits used to store waste on the surface deteriorated and leaked content. The waste has since been recovered.

Over 97% of values are significant [7] for the cow's milk samples from the five farms located in the municipalities of Beaumont-Hague, Digulleville, Herqueville and Jobourg (see figure 37). The highest mean activity by volume recorded over the 2015 - 2017 period (0.07 Bq/L) was measured for the Beaumont-Hague farm. Strontium-90 levels at other farms are at local background levels (0.036 Bq/L); mean activity levels by volume range between 0.035 and 0.037 Bq/L.

Any one individual drinking cow's milk and dairy products from the municipality of Beaumont-Hague would absorb a dose of 0.05 µSv/year, depending on the selected scenario. The mean activity by volume for milk samples taken at the two farms located in the municipality of Beaumont-Hague was used for these calculations. This dose drops to 0.02 µSv/year if the mean activity by volume calculated using all of the milk samples from the farms located in the area around the site is assumed[8].

7. In this document, a "significant value" is defined as a measurement which is above the decision threshold (DT).

8. The annual ration of milk and dairy products consumed locally in the selected scenario represents 10.2 kg/year and 8 L/year of milk.

FIGURE 36 / **STRONTIUM-90 ACTIVITY BY VOLUME IN STREAM WATER SAMPLES TAKEN NEAR TO THE LA HAGUE SITE (Bq/L)(IRSN data)**

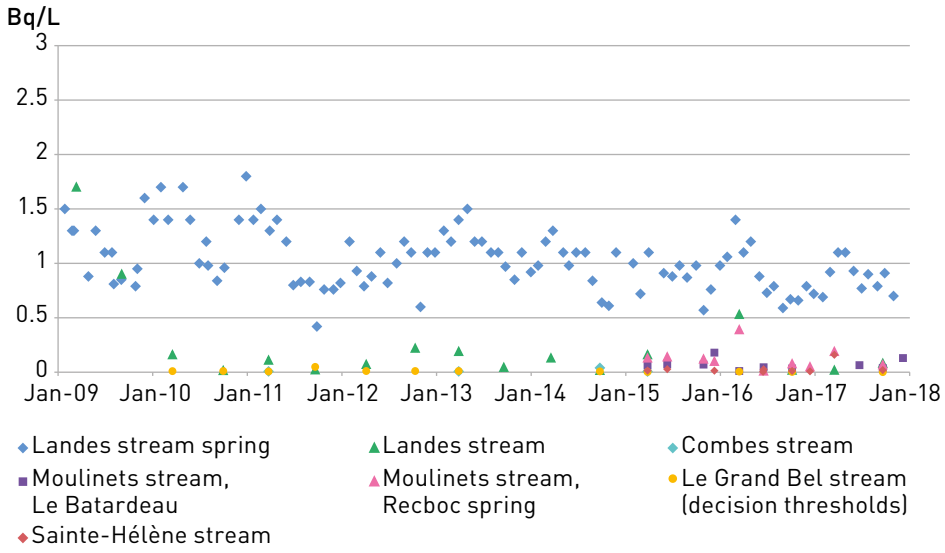
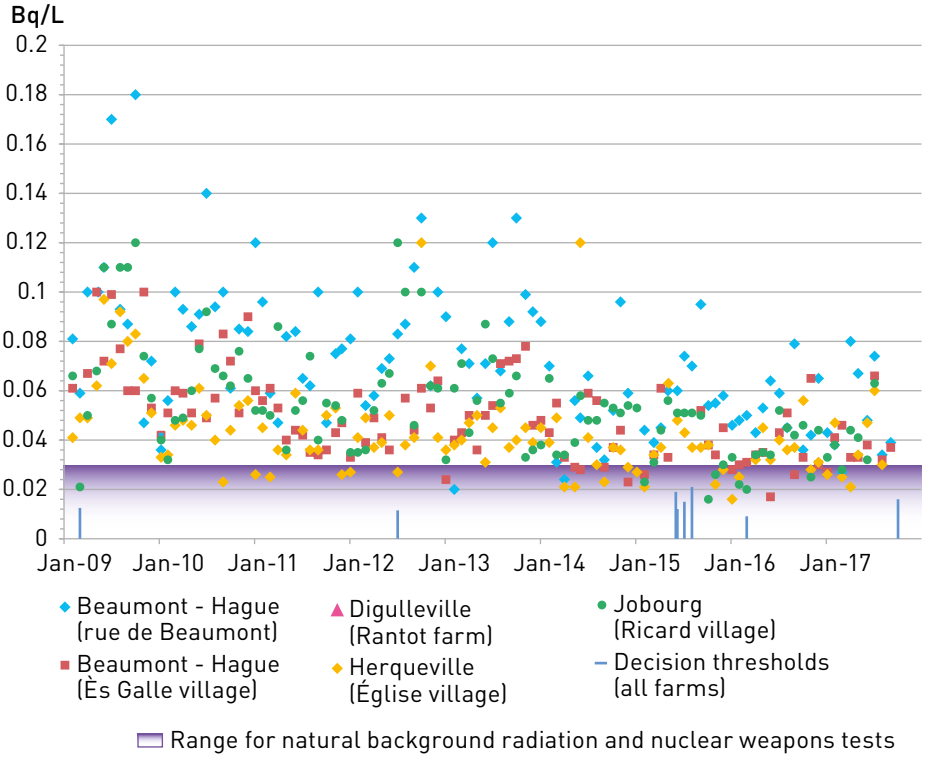


FIGURE 37 / **STRONTIUM-90 ACTIVITY BY VOLUME MEASURED IN MILK SAMPLED NEAR TO THE LA HAGUE SITE SINCE JANUARY 2009 (Bq/L)**

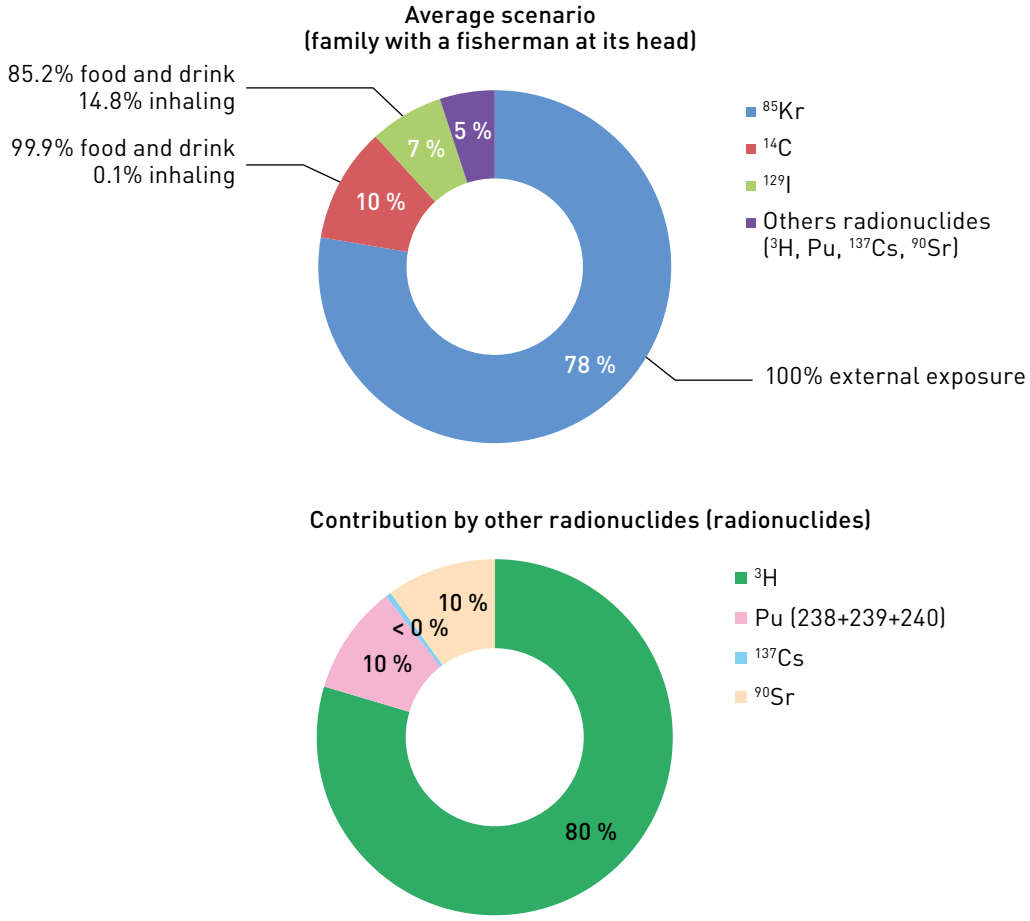


Summary of dose evaluations

Excluding tritium, since the dose absorbed by inhaling or ingestion is extremely low despite the large quantities discharged into the environment, krypton-85, carbon-14 and iodine-129 are the main three radionuclides discharged at the La Hague site in liquid or gaseous effluents, and represent the primary contributions to the dose reaching local residents.

If we consider a reference group, virtually spread around the site, breathing air containing a mean activity measurement by volume of each radionuclide as measured at various points around the site and eating local food[9] according to the selected mean scenario for an individual living in north Cotentin, with a fisherman at the head of the household, approx. 80% of the total effective dose is contributed by krypton-85 due to the inherent external exposure. On a subsidiary basis, carbon-14 contributes 10% of the dose, mainly due to residents eating local food, and iodine-129 contributes 7%, exclusively due to eating local food. The remaining 5% of the total dose is contributed by tritium, followed by strontium-90 and plutonium (238+239+240) on a 50/50 basis. Caesium-137 input is extremely low.

FIGURE 38 / **DISTRIBUTION OF THE DOSE BASED ON THE RADIONUCLIDE MEASURED IN THE ENVIRONMENT FOR A REFERENCE GROUP VIRTUALLY SPREAD AROUND THE AREA**



9. The mean activity of each radionuclide is calculated based on all food samples taken near to the site.

The scenario adopted when assessing the doses absorbed by the population as part of the radiological report for the 2015-2017 period tends to represent an average diet for people living in the north of the Cotentin peninsula. Two diets were proposed in 1999 as part of the study carried out by the GRNC (Groupe Radioécologie Nord Cotentin - North Cotentin peninsula radioecology group) in order to assess more worst-case dose scenarios. The first diet represents a fisherman living in the Huquets area at Jobourg and who regularly eats sea food, and the second diet represents a farmer living at Pont Durand near to Digulleville, eating a high percentage of roof vegetables and dairy products. Levels of self-sufficiency are identical for both diets. The quantities of local food eaten each year, based on this self-sufficiency ratio, are shown in table 5.

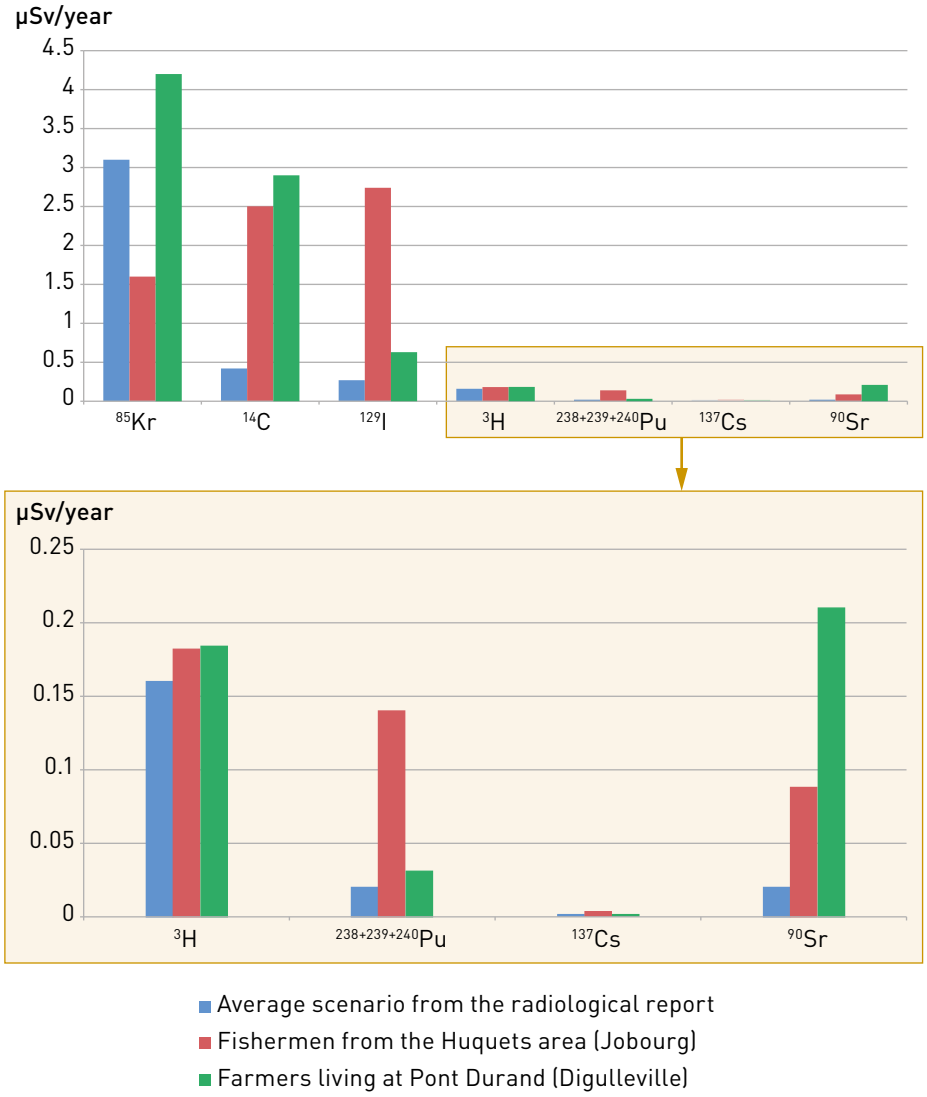
Large differences can arise for the quantity of some products eaten based on the selected diet. This is particularly true for sea food for fisherman and dairy products for farmers. The effective dose is then calculated based on the amount of local food eaten and will necessarily vary (see figure 39).

TABLE 5 / **QUANTITY OF LOCAL FOOD EATEN**

Food	Fisherman in the Huquets zone	Farmer living at Pont Durand	Average scenario in the radiological report: a person living in the north of the Cotentin peninsula with a fisherman at the head of the family
	Food ration (kg/year or l/year for milk and water)		
Shellfish	32.3	6.9	1.8
Molluscs	23.3	5.3	2.7
Fish	35.5	12.2	5.9
Milk	75.6	184.1	8.0
Dairy produce	9.9	23.4	10.2*
Lamb and mutton	1.1	1.1	0.6
Poultry	10.8	15.1	3.2
Rabbit	2.0	2.8	0.9
Eggs	9.6	20	3.9
Leaf vegetables	14.4	33	2.0
Root vegetables	78.6	159	21.2
Jams	3.4	8.4	0.5
Fruit			2.9
Honey			0.2
Water			720

** Including yoghurt and fresh cheese, cow's cheese and animal fat (butter).*

FIGURE 39 / **ASSESSMENT OF THE DOSES ABSORBED BY PEOPLE LIVING NEAR TO THE LA HAGUE SITE FOR EACH RADIONUCLIDE DETECTED IN THE ENVIRONMENT AS PER VARIOUS SCENARIOS**



The doses calculated based on these three scenarios are between 4 µSv/year for the mean scenario adopted for the radiological report and 8 µSv/year for the farmer at Digulleville.

These estimates are based on mean activity levels calculated based on the results of measurements obtained during environmental monitoring and are fully consistent with those obtained by Orano for the year 2016 on the basis of actual discharge data. In fact, Orano estimated the effective dose potentially absorbed by a fisherman at Goury at 5 µSv/year and the dose potentially absorbed by a farmer at Digulleville at 13 µSv/year.

Overview

The activities measured in the La Hague environment between 2015 and 2017 match those expected based on authorised discharge levels. These measurements also follow on from data from previous years. Krypton-85, carbon-14, iodine-129 and tritium are the radionuclides most regularly measured in the environment, as expected based on their dominant composition in effluents discharged.

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Water samples taken near to the La Hague site

Aube storage facility and Morvilliers storage facility

The Aube storage facility (CSA) is located in the municipalities of Soulaines-Dhuys, Ville-aux-Bois and Epothémont in the Aube department, and has been operated by ANDRA (INB no. 149) since January 1992. The CSA is the second surface storage facility in France for radioactive waste with weak and moderate activity and a short half life (WMA-SL). The CSA took over from the Channel storage facility. This storage facility is authorised for up to 1 million packages of radioactive waste. 33% of this authorised storage capacity had been reached by late 2017.

Most waste with a WMA-SL configuration is generated from small items of equipment contaminated during maintenance operations (gloves, clothing, tools, etc.) and the operation of French nuclear facilities (treating liquid and gaseous effluents). WMA-SL waste is also generated by research laboratories, hospitals, universities, etc. or by decommissioning or purification operations.

Waste is conditioned in concrete or metal packages (drums, caissons) before being stored at the CSA on the surface in reinforced concrete structures with open tops. Waste is stored under portable metal rail-fitted frames which protect from rain. Once full, the structures are sealed with a concrete slab and an impermeable coating is added.

A waste conditioning workshop is available at the CSA. This workshop comprises an injection unit used to block and contain specific large waste items supplied by the producers without a coating in mortar, and a compacting unit used to reduce the volume of compactable waste.

The Cires Industrial combination and storage facility (Centre industriel de regroupement, d'entreposage et de stockage) is located just a few kilometers from the CSA in the municipalities of Morvilliers and La Chaise. This facility is environmentally-classified (ICPE) and has been dedicated to storing very low activity (VLA) waste since 2003. This storage facility is authorised for up to 650,000 m^3 of radioactive waste. 54.2% of this maximum authorised capacity had been reached in 2017.

FIGURE 1 / **MAP SHOWING THE LOCATIONS OF THE AUBE AND CIRES STOCKAGE FACILITIES**

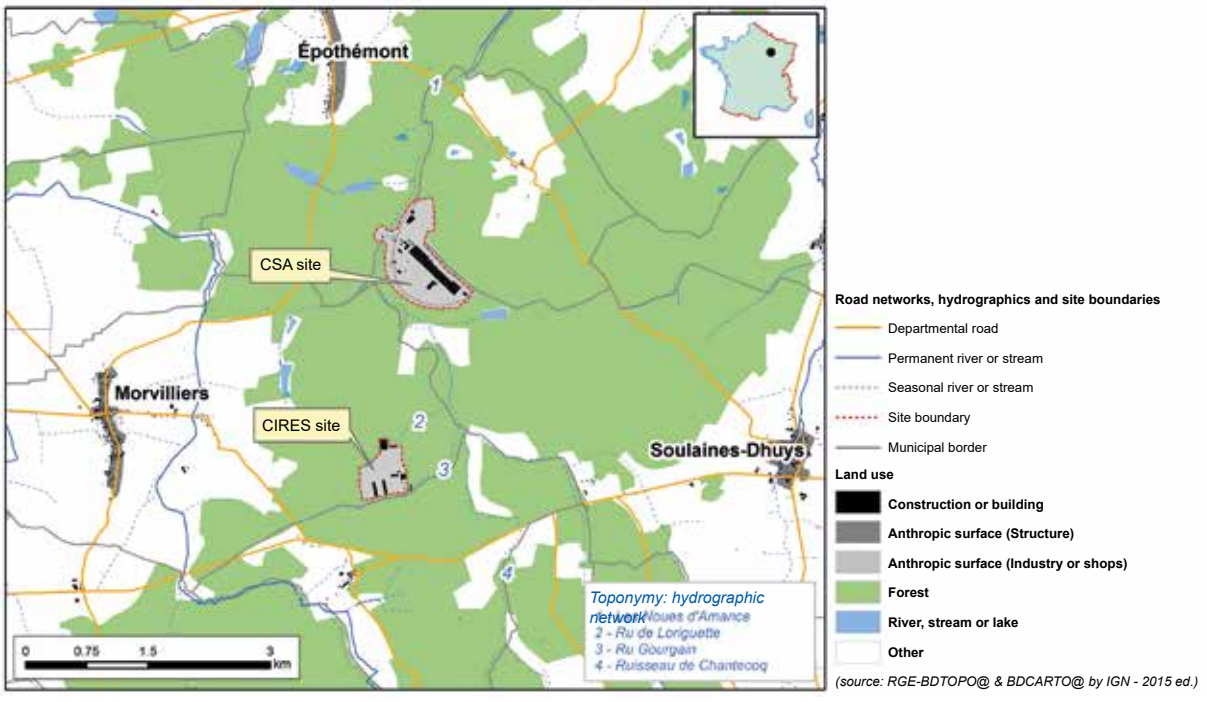


FIGURE 2 / **AUBE STORAGE FACILITY (CSA)**

FIGURE 3 / **THE INDUSTRIAL COMBINATION AND STORAGE FACILTY (Cires)**

VLA waste mainly comprises gravel, earth, scrap metal, etc. with very low contamination levels. This waste is generated when decommissioning or operating nuclear facilities or traditional industrial sites using materials which are naturally radioactive. This waste can also be generated when treating or renovating old sites contaminated by radioactivity.

Cires includes a VLA waste treatment building used to reduce the volume of compactable waste.

VLA waste is stored at Cires in cells in clay units. Once these cells are full, they are sealed with a coating, which mainly comprises a high density polyethylene membrane and an outer envelope of natural clays. These operations are carried out under portable roofs, which protect from rain.

Cires has also proposed combination and storage solutions for radioactive waste since 2012. The waste combined at the facility is collected from approximately 1,000 non-electronuclear producers spread throughout France (hospitals, pharmaceutical laboratories, individuals, etc.). A very wide range of types of waste is handled: gloves, plastics, solvents, blouses, lightning arresters, smoke detectors, etc. Most of this waste is VLA or WMA-SL and storage options are available. Some of this waste has a weak or moderate activity level and a long life; no storage solutions are currently available for such waste and it is stored at the site. Since 2016, Cires has also run a facility specifically dedicated to sorting and treating this waste from non-electronuclear activities and combined at the site.

Radioactive discharges

Radioactive discharges from the CSA

Waste conditioning operations lead to radioactive gaseous effluents, which are discharged *via* the stack in the waste conditioning workshop. These effluents are routed at source by nuclear ventilation systems. Very high efficiency (VHE) filters are fitted in ventilation ducts to purify any dust or aerosols in the effluents, as necessary. Tritium, radioactive iodine isotopes and carbon-14 are not filtered and are therefore likely to be discharged into the atmosphere.

Gaseous elements, dust and aerosols are monitored prior to discharge to the atmosphere. The aim of this process is to quantify the elements discharged to the environment; continuous samples are taken for this purpose, with subsequent laboratory measurements. The flow rate for the air discharged is also measured.

A representative portion of the air discharged is sampled in the ventilation duct and trapped using filters (dust - gross alpha/beta activities and alpha and beta-gamma emitters), activated carbon cartridges (used to trap iodines - ^{125}I, ^{129}I and ^{131}I) and bubblers (trapping ^{3}H and ^{14}C).

These sorted discharges are subject to maximum discharge levels as defined by order. Annual tritium discharges since 2006 have varied between 0.082 and 7.3 GBq (see figure 4). Tritium is the most frequently measured radionuclide in gaseous discharges from the CSA.

The liquid effluents produced in the facilities and likely to be contaminated are collected in several tanks at the site and then tested (tritium, carbon-14, alpha, beta and gamma emitters), before potential discharge into the storm retention basin *via* a specific network; the storm retention basin is the only discharge point for liquid effluents from CSA into the natural environment, specifically the Noues d'Amance stream. Annual discharges have varied between 0.2 and 5.3 MBq over the last decade for tritium, the most frequently measured radionuclide in liquid discharges from the CSA.

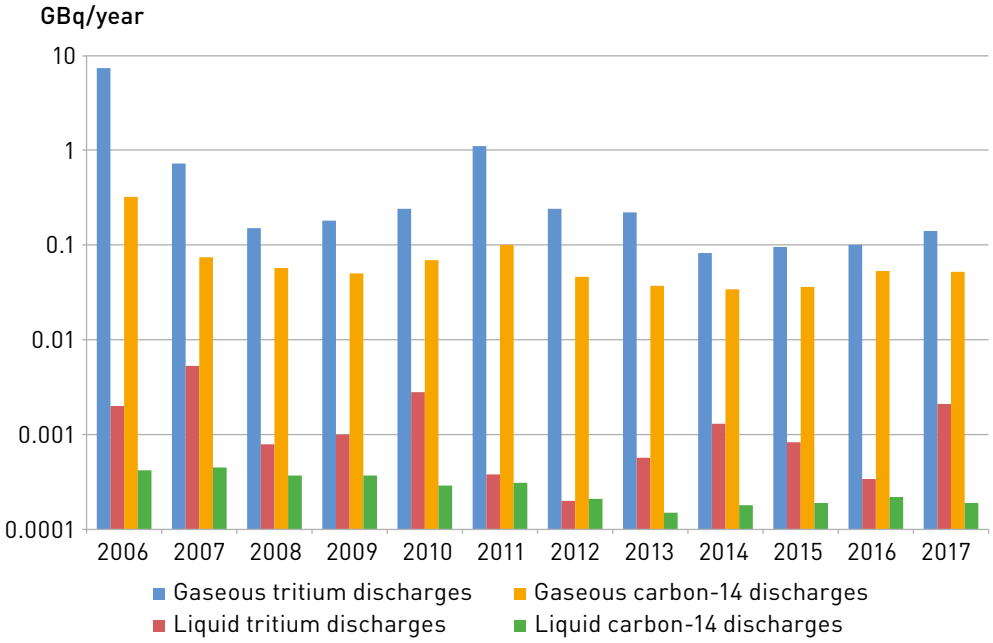
Radioactive waste from the Cires site

Gases are discharged from Cires due to VLA waste treatment operations (compacting) and the sorting and treatment of waste from non-electronuclear operations. A continuous air sampling system fitted at the discharge point for the ventilation/filtration system is used to test the air discharged (atmospheric tritium, iodines (^{125}I, ^{129}I and ^{131}I), carbon-14 and gross alpha and beta activity levels are measured) from each of the two discharge points.

These sorted discharges are subject to maximum discharge levels as defined by prefectoral order. Annual discharges have varied between 32 and 300 MBq over the last decade for tritium, the most frequently measured radionuclide in gaseous discharges from Cires.

Liquid effluents from Cires likely to contain radiological contamination are considered as liquid waste and collected + stored in tanks prior to recycling and elimination *via* an authorised external treatment unit. These effluents are not therefore discharged into the environment. Other liquid effluents (rainwater, household effluents, etc.) are collected, treated if necessary (settling, oil removal) and then routed to the Loriguette stream to the north of the site and to the Courgain stream to the south of the site *via* basins.

FIGURE 4 / **VARIATION IN LIQUID AND GASEOUS TRITIUM DISCHARGES FROM THE CSA BETWEEN 2006 AND 2017 (GBq/year)**



Radiological monitoring of the site environment

Monitoring the CSA

The operator monitors radioactivity in the atmosphere by measuring ambient gamma radiation directly, and with differed measurements based on daily atmospheric dust samples (gamma spectrometry, gross alpha and beta activity measurements), and periodic air (atmospheric carbon-14 and tritium measurements), halogen gas (iodine-125, 129 and 131 measurements) and rainwater (gross alpha and beta, carbon-14 and tritium activity measurements) samples collected *via* monitoring stations located as per the prevailing winds. Two monthly samples and one quarterly plant sample are taken in the terrestrial component, as well as two monthly milk samples. An annual sampling run is also organised for mushrooms, the main farming output and topsoil, particularly in areas under the prevailing winds. Gross alpha and beta activities are also generally measured in terrestrial water samples, and gamma spectrometry is performed. Carbon-14 measurements are also organised each quarter, and tritium measurements and alpha spectrometry are performed annually, particularly aiming to measure transuranic elements and complement the above analyses.

Occasional surface water and sediment samples (weekly, monthly and quarterly) are taken in the aquatic component, more specifically in the Noues d'Amance stream, upstream and downstream from the discharge point, and in the Voire river, downstream from the CSA discharge point. Tritium and gross alpha and beta activities are measured in water and sediment (in water) samples. Alpha and gamma spectrometry is also used to complement these results on a regular basis (downstream from the discharge point). Annual fish samples and 6-monthly aquatic plant samples are taken in Noues d'Amance. Analysis results for aquatic flora and fauna are similar to those for water and sediment samples.

Ground water under the CSA is tested on a monthly basis using 9 piezometers mainly installed inside the CSA, and at 13 other locations on a quarterly basis. Tritium and gross alpha and beta activities are measured using these samples.

Monitoring the Cires site

The Cires monitoring programme is defined in a prefectoral order on site activities. A continuous air sampling system is fitted in the administrative building and can be used to check the impact of discharges routed from the treatment building and discharges diffused by the facility (storage cells, etc.). The same measurements are taken at this sampler as those taken at the treatment building discharge point. Cires can also access ambient gamma radiation measuring systems (passive dosimeters).

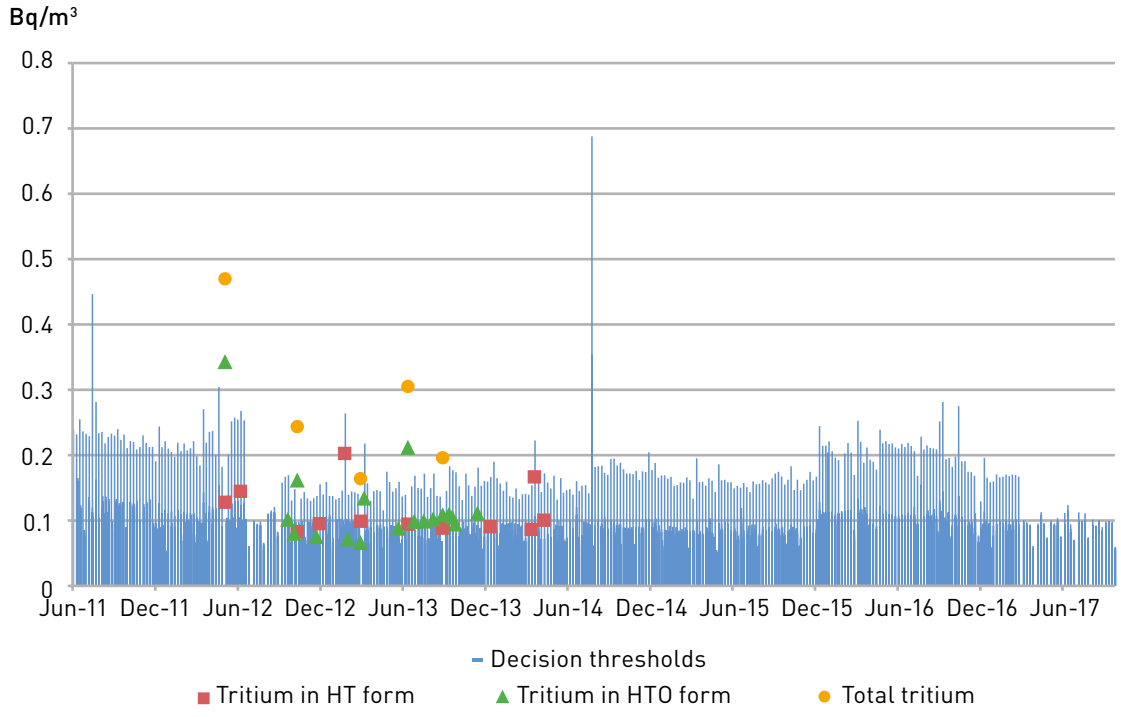
Water and sediment samples are taken from streams (Courgain and Loriguette steams). Gross alpha and gross beta and tritium activity is measured for water samples. alpha and gamma spectrometry is performed on sediments. Barrémien and Aptien ground water is monitored on a 6-monthly basis for radiological purposes.

The impact of the ANDRA Cires and CSA sites on their immediate environments

Atmospheric carbon-14 levels are monitored by a bubbler. The decision thresholds for the methods used are close to atmospheric background radiation levels. Gaseous iodine-125, 129 and 131 are monitored by taking air samples *via* a cartridge and by monitoring atmospheric aerosols. No radionuclides were detected in the immediate environment of the storage facilities run by ANDRA between 2015 and 2017. Tritium has been detected in the air as HT or HTO since May 2014 (see figure 5). Decision thresholds are between 10 and 20 times background radiation levels for atmospheric tritium, therefore these analyses do not decisively indicate if ANDRA discharges potentially affect the area. On the other hand, in terms of the rainwater samples collected between January 2015 and December 2017, which were all found to have activity levels below the decision threshold of approx. 2 Bq/L and therefore within the current background range, no visible contamination occurred during rainfall.

This lack of contamination by tritiated atmospheric discharges was confirmed by measuring results for this radionuclide in grass and soil samples taken during the 2015-2017 period. Bound tritium activity levels for these results are either below the decision threshold, or between 0.2 and 1.7 Bq/kg fresh, i.e. within the current background range. In addition, according to measurement results for grassland samples, carbon-14 activity varies extensively. Measurement uncertainty of up to 60% of results must also be considered. Contamination from ANDRA facilities cannot be concluded based on these uncertain results. All other measurements taken in the immediate environment of these two storage facilities are either natural radioactivity (^{40}K, ^{7}Be, etc.) or residual fallout from the Chernobyl accident or the testing of nuclear weapons (^{137}Cs).

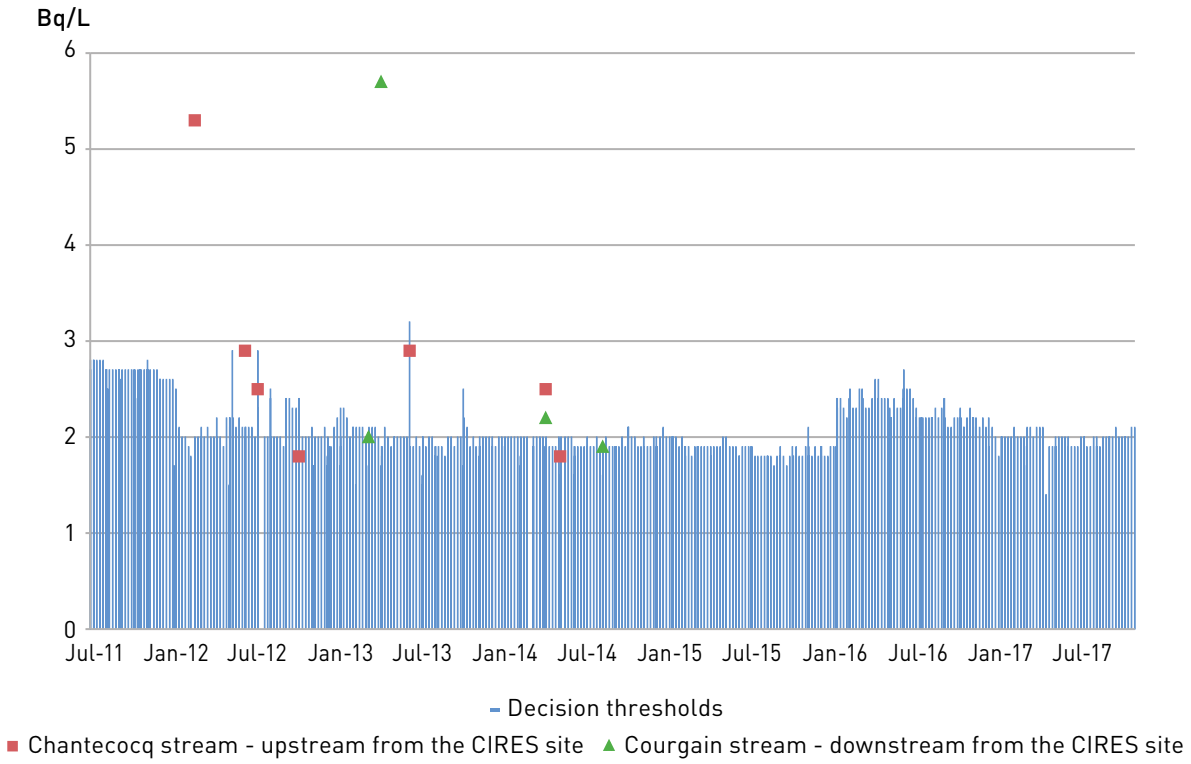
FIGURE 5 / **AMBIENT TRITIUM ACTIVITY BY VOLUME NEAR TO THE CSA AND CIRES FACILITIES BETWEEN JULY 2011 AND DECEMBER 2017 (Bq/m³)**



Tritium has not been detected as part of river monitoring (see figure 6) since August 2014 in measurements taken in stream water, upstream from Cires (Chantecocq stream), between Cires and the CSA (Courgain stream, Loriguette stream) and downstream from the CSA (Noues d'Amance in particular).

Measurements taken using sediment, fish and aquatic plant (ranunculus) samples failed to reveal any contamination of the aquatic environment by discharges from facilities operated by ANDRA.

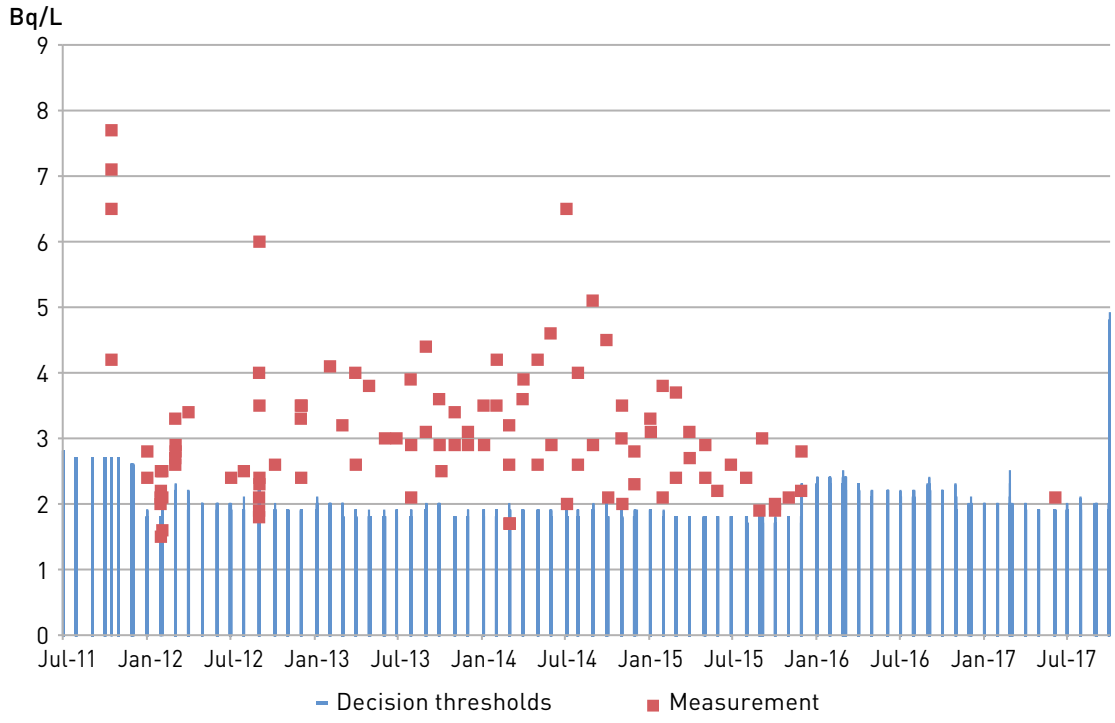
FIGURE 6 / **TRITIUM ACTIVITY BY VOLUME MEASURED IN SURFACE WATER SAMPLES TAKEN NEAR TO THE CSA AND ANDRA CIRES FACILITIES BETWEEN JULY 2011 AND DECEMBER AND 2017 (Bq/L)**



Ground water near to these two facilities is monitored for radiological purposes using two piezometers installed both on- and off-site. The tritium activities found in water samples taken at specific locations in 2015 were several times greater than background radiation, and peaked at 3.8 Bq/L (see figure 7).

Tritium was only detected once after January 2016 in ground water, with an activity level close to background radiation (2.1 Bq/L), using a piezometer located near to the storage facility. Measurements for beta and alpha emitters failed to reveal contamination by discharges from ANDRA facilities.

FIGURE 7 / **TRITIUM ACTIVITY BY VOLUME MEASURED IN GROUND WATER SAMPLES TAKEN USING PIEZOMETERS AT THE CSA AND ANDRA CIRES FACILITIES BETWEEN JULY 2011 AND DECEMBER 2017 FOR ALL PIEZOMETERS (Bq/L)**



3.4. RESEARCH SITES

Marcoule site

Discharges and monitoring plans

The Marcoule (Gard) site is home to around twenty facilities, including five basic nuclear facilities (INB):

- the Phénix reactor (INB 71) operated by CEA: a fast neutron reactor, shut down in 2009;
- the Atalante facility (INB 148) operated by CEA: this facility can be used for fundamental and radiochemical research on highly radioactive elements;
- the Melox facility (INB 151) operated by Orano Cycle: this facility was constructed to recycle plutonium from French PWR nuclear powerplants. Morax is currently the only French plant producing MOX fuel;
- the Centraco facility (INB 160) operated by Socodei: this facility was commissioned in 2000, and processes weakly radioactive effluents and waste aiming to reduce volumes before sending the former to ANDRA facilities for storage.
- the Gammatec facility (INB 170) operated by STERIS: this site houses gamma irradiators for the purposes of research and development.

The site is also home to a secret basic nuclear facility (INBS) operated by CEA. The main units at this INBS have been shut down and decommissioning is in progress:

- the Célestin 1 & 2 reactors were definitively shut down towards the end of 2009;
- The Tritium workshop at Marcoule (ATM) was definitively shut down in June 2012.

The radioactive liquid effluents produced at the site are transferred to the liquid effluent treatment station (STEL) operated by CEA. The CENTRACO INB is equipped with its own treatment unit for liquid effluents and subsequently discharges them. The details of discharges cannot be provided for each facility. Gaseous discharges are distributed between the different site facilities (Atalante, Phenix, Centraco and Melox) and each facility holds its own discharge authorisation. Table 1 provides details of liquid and gaseous discharges.

FIGURE 1 / **MAP SHOWING THE LOCATIONS OF CEA MONITORING POINTS (on the left) AND IRSN MONITORING POINTS (on the right) NEAR TO THE MARCOULE SITE**

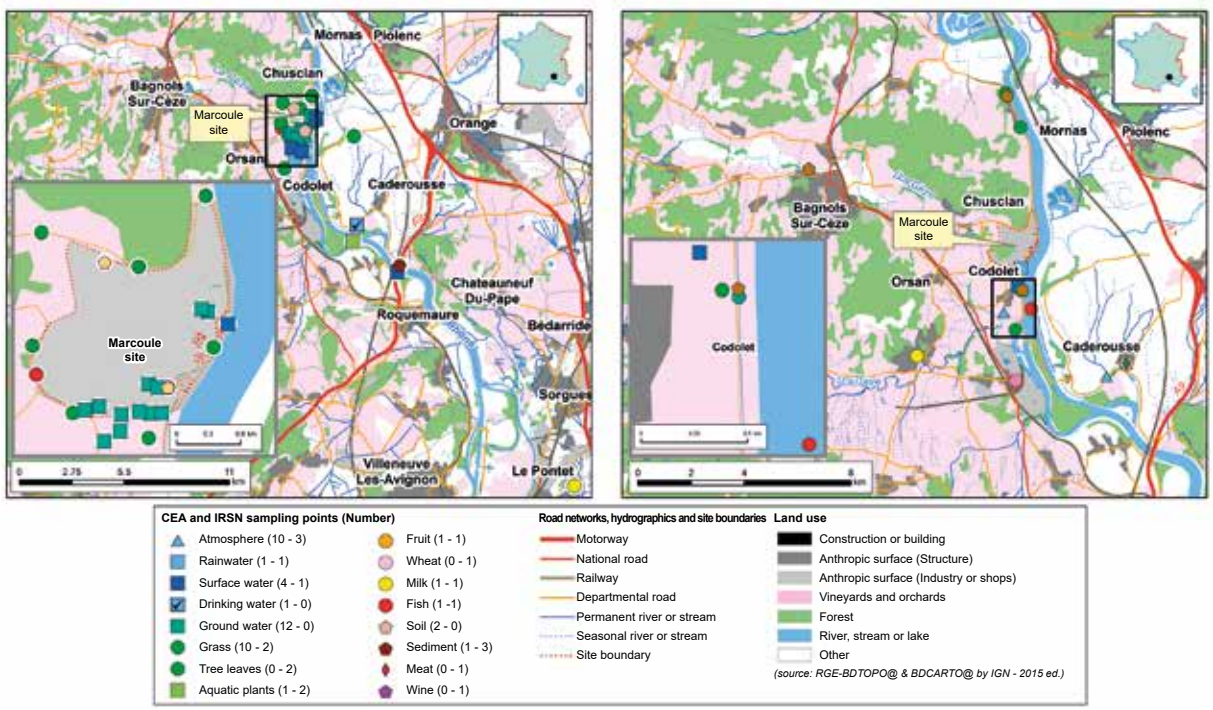


TABLE 1 / **DISTRIBUTION OF DISCHARGES FROM THE DIFFERENT FACILITIES IN 2016**

Gaseous effluents from CEA Marcoule INBs (PHENIX & ATALANTE)	2014	2015	2016
Gamma beta aerosols (MBq)	11.4	11	9.9
Alpha aerosols (MBq)	0.14	0.07	0.07
Tritium (MBq)	34.8	77.0	17.8
Halogens (MBq)	8.2	9.0	8.8
Gases excl. tritium (TBq)	46	54	52

Tritiated gaseous effluents discharged from INBs (TBq)	2014	2015	2016
	37	21	25

Liquid effluents (INBS)*	2014	2015	2016
Alpha emitters (GBq)	1.58	0.77	1.71
Carbon-14 (GBq)	6.29	2.77	4.64
Iodines (GBq)	0.46	0.26	0.12
Tritium (TBq)	22	20.2	38.2
Other gamma beta aerosols (GBq)	67.9	36.4	63.3

* Liquid effluents generated by facilities at the Marcoule site are processed at an INBS facilty (STEL), except for CENTRACO discharges.

CEA at Marcoule and IRSN have implemented monitoring plans for all environmental components since the site opened. CEA implements this plan on behalf of all Marcoule site operators. Table 2 and figure 1 provide details of the corresponding monitoring plans. When the Célestin reactors and the Tritium workshop were shut down in 2009, tritium discharges from the site dropped significantly, as shown in figure 2.

FIGURE 2/ **VARIATION IN TRITIATED ATMOSPHERIC DISCHARGES FROM THE SITE**

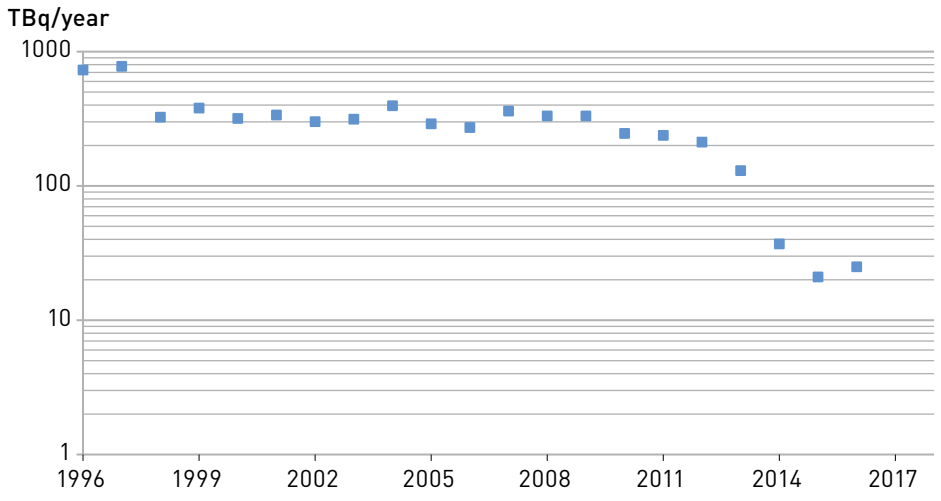


TABLE 2 / **CEA AND IRSN MONITORING PLANS FOR THE MARCOULE SITE (the CEA plan shown applied up to December 2016; the monitoring programme was amended on 1 January 2017 when adapting the new discharge authorisation)**

Environment monitored or type of testing	CEA	IRSN
Ambient gamma radiation	• **4 sensors in the immediate environment of the St-Étienne-des-Sorts, Bagnols-sur-Cèze, Codolet and Caderousse sites:** ambient γ dose rate • **10 passive dosimeters** at the site fence	• **2 sensors in the immediate environment of Bagnols-sur-Cèze and Orange sites:** ambient γ dose rate
Atmospheric aerosols	• **4 sampling points at the St-Étienne-des-Sorts, Bagnols-sur-Cèze, Codolet and Caderousse sites:** gross α and β activities (daily), γ spectrometry if gross α and β > 2 mBq/m^3	• **1 sampling point at Codolet:** γ spectrometry (weekly) isotopic uranium (monthly)
Ambient tritium, carbon-14 and iodine-129	• **2 sampling points at the St-Étienne-des-Sorts and Codolet sites:** ambient tritium (HTO - HT), ^{129}I and ^{14}C (every 1, 8, 15 and 22 of each month)	
Rainwater	• **1 sampling point at Codolet:** gross α and β activities, tritium (bimonthly) and gross α and β activities for TSS (monthly)	• **1 sampling point at Codolet:** tritium (monthly)
Ground water	• **10 sampling points on the site or at the site fence:** tritium, gross α and β activities, • **7 sampling points on the Codolet grasslands:** tritium, gross α and β activities	
Surface water	• **2 sampling points upstream and downstream from the site:** gross α and β activities with a filtrate, gross β activity for filtration residue, tritium (weekly), γ spectrometry at the downstream point (monthly) • **1 sampling point at Codolet lake:** tritium, gross α and β activities, γ spectrometry (monthly)	• **1 sampling point at Codolet lake:** tritium (6-monthly)
Sediments	• **1 sampling point downstream from the site:** gross α and β activities, γ spectrometry, ^{90}Sr (monthly) and γ spectrometry (annual)	• **2 sampling points upstream and downstream from the site:** γ and α spectrometry, ^{90}Sr (6-monthly)
Fish	• **1 sampling point downstream from the site:** gross β activity, γ spectrometry, ^{90}Sr (monthly), ^{14}C and ^{3}H (annual)	• **1 sampling point downstream from the site:** γ and α spectrometry, ^{90}Sr (annual)
Aquatic plants	• **1 sampling point downstream from the site:** gross β activity, γ spectrometry, ^{90}Sr (monthly), ^{14}C and ^{3}H (annual)	• **2 sampling points upstream and downstream from the site:** γ spectrometry, organically-bound tritium, α spectrometry (6-monthly)
Soils	• **2 sampling points to the north and south of the site:** γ spectrometry (annual)	
Grass	• **10 sampling points around the site:** gross β activity, γ spectrometry (monthly) free tritium, α spectrometry (rotate between 3 to 4 points each month), ^{14}C (quarterly rotation between 2 points)	• **2 sampling points at St-Etienne-des-Sorts and Codolet:** γ spectrometry, free tritium, α spectrometry, ^{90}Sr (annual)
Tree leaves		• **3 sampling points at St-Etienne-des-Sorts, Codolet and Caderousse:** free and organically-bound tritium (annual)
Fruit and vegetables	• **Annual sampling runs for the main farming outputs, particularly to the north south of the site:** gross β activity, γ spectrometry, ^{90}Sr, ^{14}C and HTO (annual)	• **1 leaf vegetable sampling point to the south-west of the site:** γ spectrometry, free and organically-bound tritium (annual) • **1 root vegetable sampling point to the south east of the site:** γ and α spectrometry (annual) • **1 sampling point to the south-east of the site:** γ spectrometry, free and organically-bound tritium (annual)
Wheat		• **1 sampling point to the south of the site:** γ spectrometry, organically-bound tritium, α spectrometry, ^{90}Sr (annual)
Meat		• **1 sampling point to the south of the site:** γ spectrometry, organically-bound tritium (annual)
Wine		• **1 sampling point to the south of the site:** γ spectrometry, free tritium (annual)
Milk	• **1 sampling point at Le Pontet:** gross β activity, γ spectrometry, HTO (monthly)	• **2 sampling points to the south and south-west of the site:** γ spectrometry, free tritium, ^{129}I (quarterly)
Drinking water	• **4 sampling points at the Caderousse, Codolet, St-Étienne-des-Sorts and Bagnols-sur-Cèze sites:** gross β activity, tritium (monthly), and α spectrometry (6-monthly)	

The impact of the Marcoule facility on its immediate environment

Tritium

Tritium is the dominant radionuclide in atmospheric and liquid discharges from Marcoule, and is also the most frequently measured and most abundant isotope in the different environmental components around the site.

Tritium can be found in two forms in the air: tritiated water vapour (HTO) and gas (HT and other tritiated gaseous organic compounds). Ambient activity levels for these 2 forms are measured using bubblers on a weekly basis at 2 sampling stations: Saint-Étienne-des-Sorts to the north and Codolet to the south of the site. Figure 3 shows the results for both sampling stations.

Tritiated water vapour is the dominant form. Despite this, 78% of the HTO measurements acquired at the two samplers are below the decision threshold. At the Codolet site, activity levels measured over the 2015-2017 period vary from less than 0.09 Bq/m^3 to 0.42 Bq/m^3 for vapour tritium (HTO) and from 0.12 Bq/m^3 to 0.16 Bq/m^3 for gas tritium (HT). Similar values were recorded at Saint-Étienne-des-Sorts: from 0.08 Bq/m^3 to 0.40 Bq/m^3 for vapour tritium (HTO) and from 0.16 Bq/m^3 to 0.27 Bq/m^3 for gas tritium (HT). In general, the range of activity is smaller than that recorded over the previous period (2011-2014). This is due to the progressive decrease in discharges since the Tritium workshop was shut down in 2012. This decrease can also be considered as part of a dominant trend since the Célestin reactors were shut down in 2009.

FIGURE 3 / **AMBIENT TRITIUM ACTIVITY LEVELS IN THE FORM OF WATER VAPOUR (HTO) AND AS A GAS (HT and other tritiated gaseous organic compounds) MEASURED IN THE IMMEDIATE ENVIRONMENT OF THE MARCOULE SITE ON A WEEKLY BASIS**

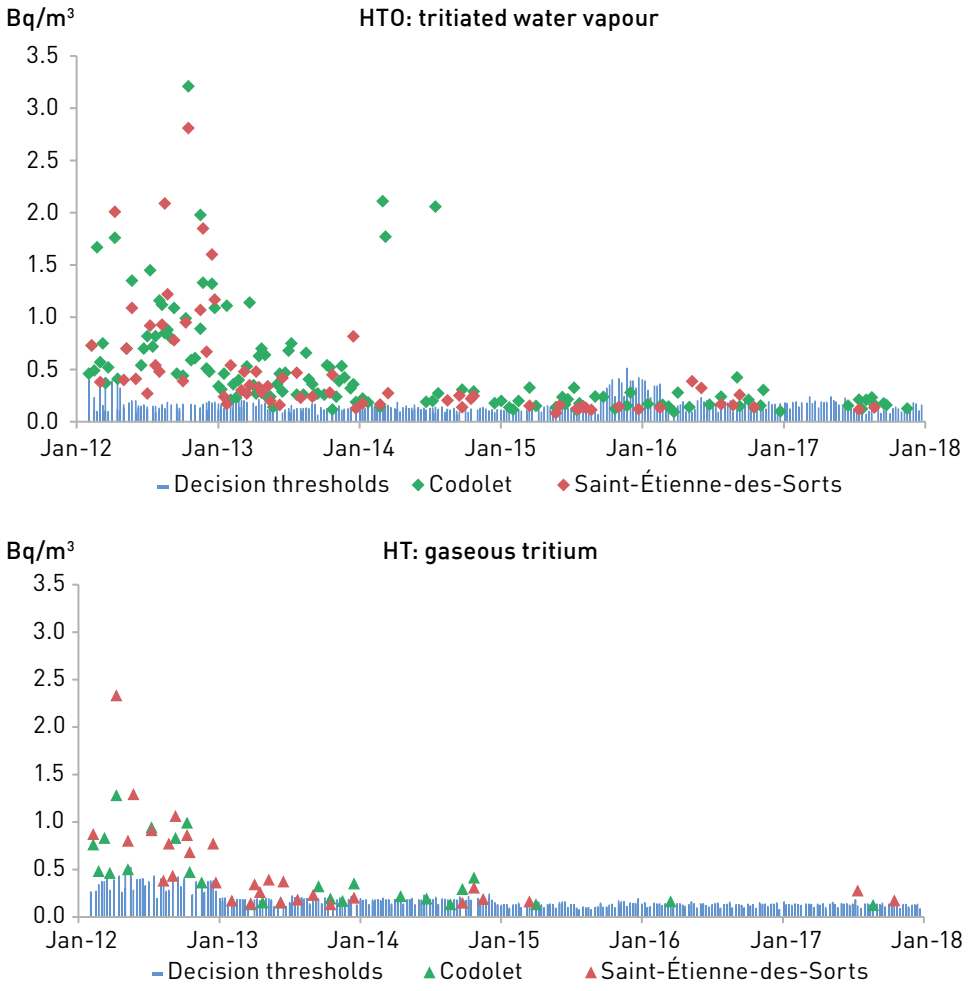
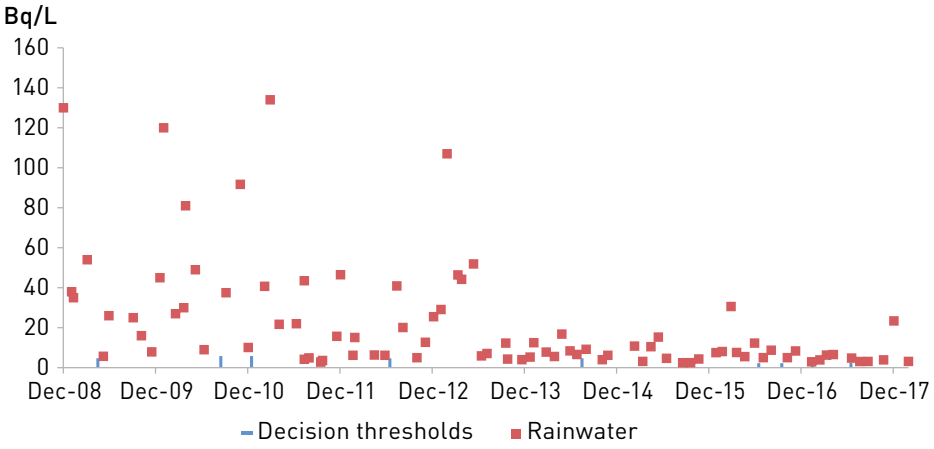


FIGURE 4 /TRITIUM **ACTIVITY MEASURED IN RAINWATER (Bq/L)**

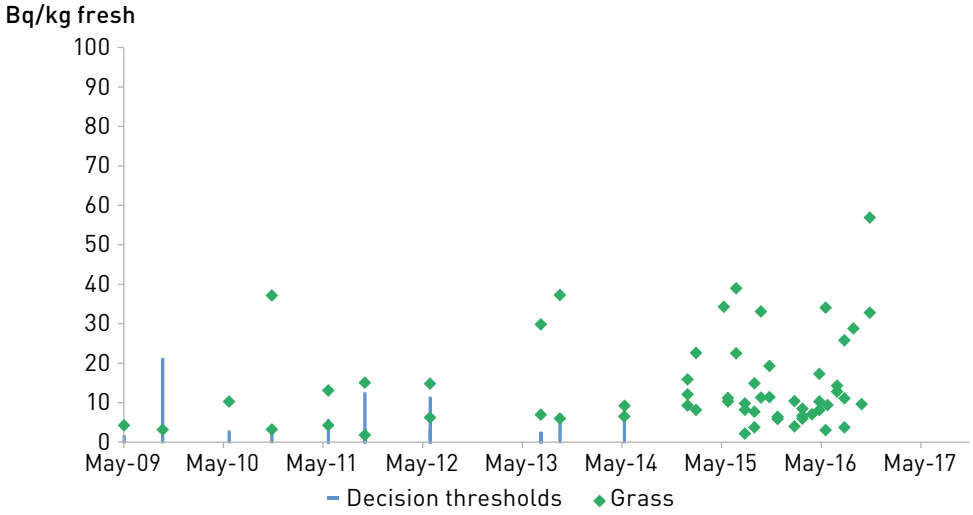


However, significant ambient tritium activity levels detected in the area around the Marcoule site remain well above background radiation levels for this radionuclide (approx. 0.01 Bq/m^3 for HTO).

The range of activity levels measured for tritium in rainwater samples at Codolet is also decreasing, in line with ambient tritium activity levels and reduced discharges. The range runs from 2.5 Bq/L measured in June 2015 to a peak of 30.6 Bq/L measured in December 2015 (see figure 4). These figures an be compared with current background radiation levels, which are between less than 1 and 3 Bq/L of rainwater.

Grass measurements for samples taken near to the site are based on the atmospheric activity data provided above. Indeed, tritium in free water in grass (HTO) reflects the ambient tritium concentration a few hours prior to taking the sample. Concentration measurements vary between 2.2 Bq/kg fresh and 56.9 Bq/kg fresh (see figure 5) for the period in question. On the other hand, according to figure 6, tritium activity in milk is lower (ranging from less than 2.6 to 3.4 Bq/L over the 2015-2017 period), and remains within the background radiation range. This is due to the fact that the milk samples were taken at Pontet at a distance from the site and out of the prevailing winds, and that local feed is not therefore strongly contaminated.

FIGURE 5 / **FREE TRITIUM ACTIVITY MEASURED IN GRASS SAMPLES (Bq / kg fresh of HTO) NEAR TO THE CEA SITE AT MARCOULE**



Note: over the previous period (2011-2014), free tritium activity levels in milk were mostly above background radiation levels. This variation was once again due to the reduction in discharge levels in recent years. Activity levels measured in fruit, which range from 2.9 to 9.2 Bq/kg fresh (see figure 7), and wine (8 Bq/L), reflect the limited tritium contamination of these food items.

Finally, organically bound tritium activity in tree leaves collected in the municipalities of Caderousse and Codolet varies extensively (5.2 - 55.4 Bq/kg dry) to match the measurements for the grass samples, atmospheric water vapour and rainwater.

The impact of tritium discharges from the site can also be detected in ground water. In general, tritium activity in ground water samples decreased for all piezometers installed at the site (see figure 8).

Over the 2015-2017 period, the highest measurement was recorded in February 2015 at piezometer F215 and reached 68 Bq/L.

FIGURE 6 / **FREE TRITIUM ACTIVITY MEASURED IN MILK (Bq/L) NEAR TO THE CEA SITE AT MARCOULE**

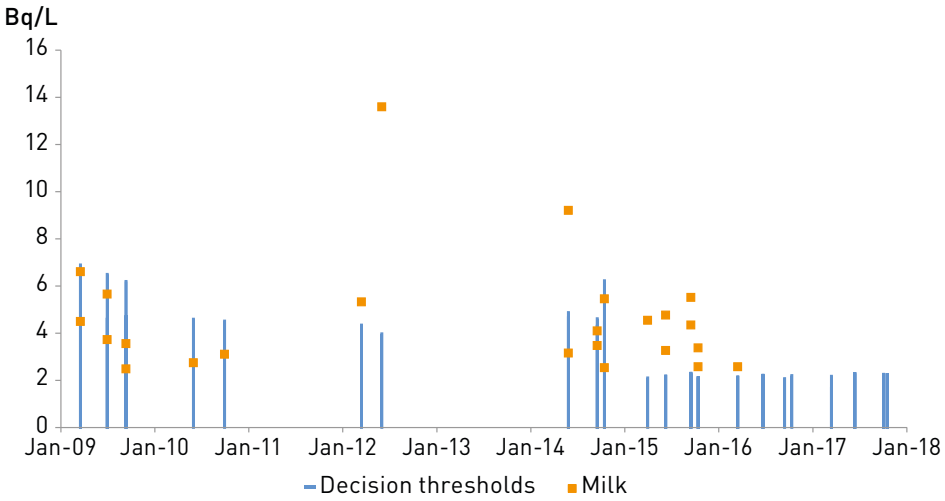


FIGURE 7 / **FREE TRITIUM ACTIVITY MEASURED IN FRUIT TAKEN FROM TREES NEAR TO THE CEA SITE AT MARCOULE (Bq of tritium/kg fresh)**

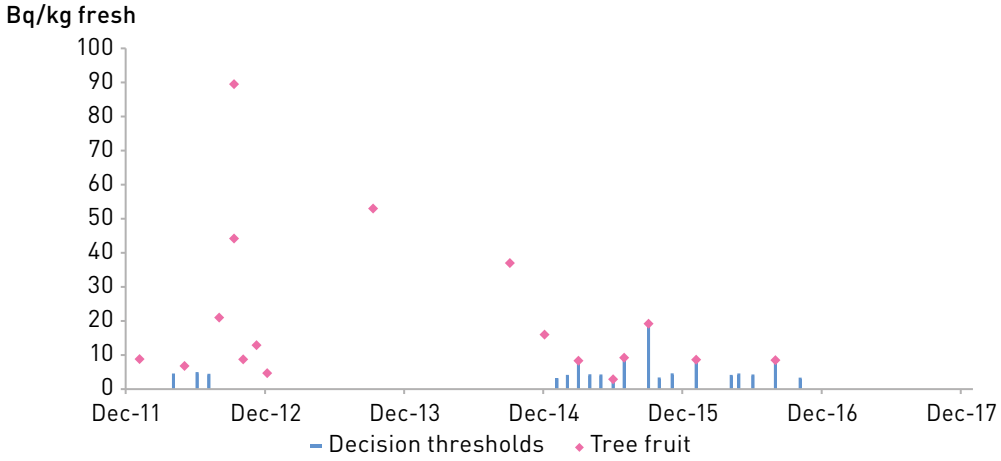
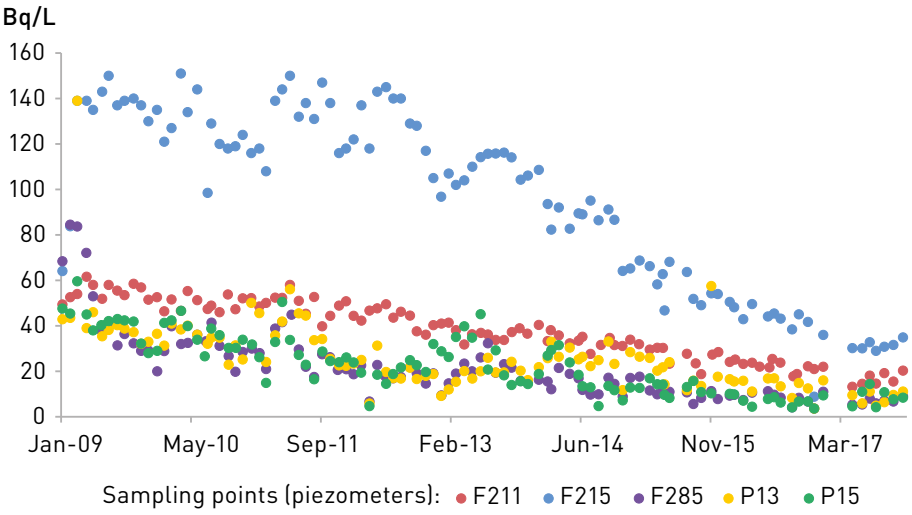
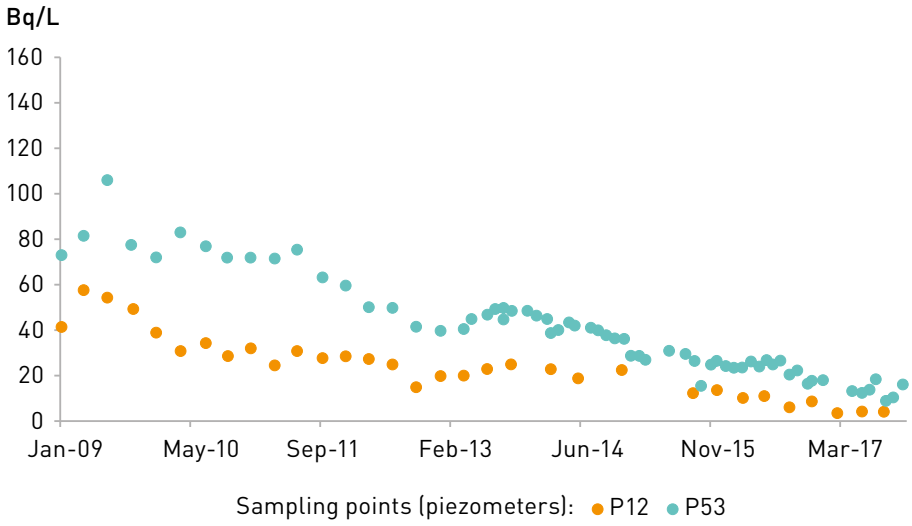


FIGURE 8 / **ACTIVITY LEVELS IN GROUND WATER SAMPLES (Bq/L) COLLECTED AT THE SITE (top graphic) AND TO THE SOUTH OF THE SITE (bottom graphic)**



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Aerial view of the Marcoule site

Tritium contamination was also detected *via* the radiological monitoring of surface water, particularly at the Codolet lake to the south of the site. Variation in tritium activity at Codelet lake, as shown in figure 9, matches variation in ground water measurements (see figure 8). Mean tritium activity for the lake dropped from 67.5 Bq/L for the 2011-2014 period, to 24.6 Bq/L for the 2015-2017 period.

According to regular analyses, low activity was detected in Rhône river water, mainly due to the other nuclear facilities in the Rhône valley (NPP discharges represent a total of approx. 95% of tritium discharges) (see figure 10). Tritium activity downstream from the site represents 6.3 Bq/L on average over the 2015-2017 period, but ranges between 3.1 Bq/L and 11.1 Bq/L.

FIGURE 9 /TRITIUM **ACTIVITY MEASURED IN WATER SAMPLES TAKEN FROM CODOLET LAKE TO THE SOUTH OF THE CEA SITE AT MARCOULE (Bq/L)**

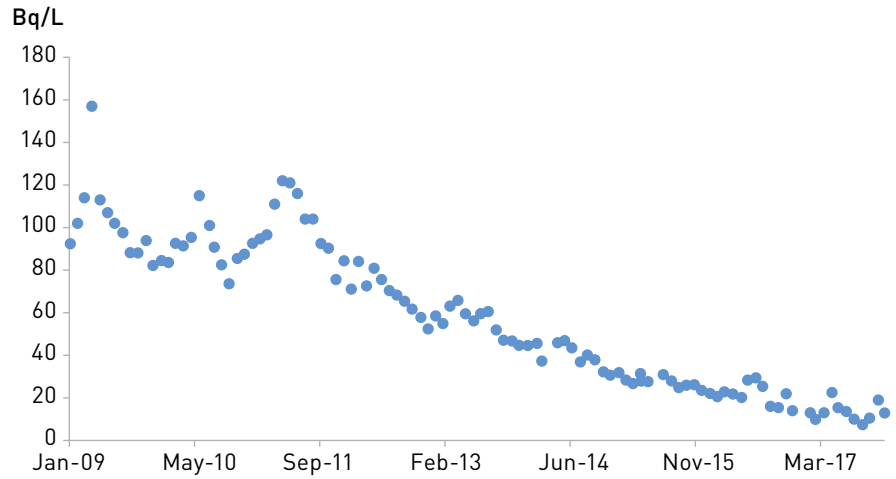
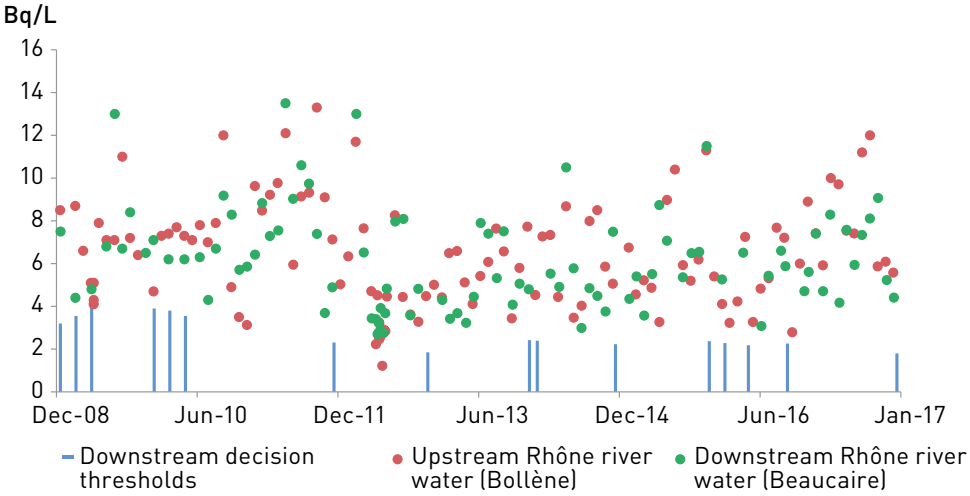


FIGURE 10 / **TRITIUM ACTIVITY FOR RHÔNE WATER SAMPLES TAKEN UPSTREAM (Bollène municipality) AND DOWNSTREAM (Beaucaire municipality) FROM THE MARCOULE SITE**



Tritium is the only radionuclide detected in drinking water supply for the municipality of Caderousse. Most measurements are below the detection threshold, with a peak value of 5.8 Bq/L reached in 2016.

Carbon-14

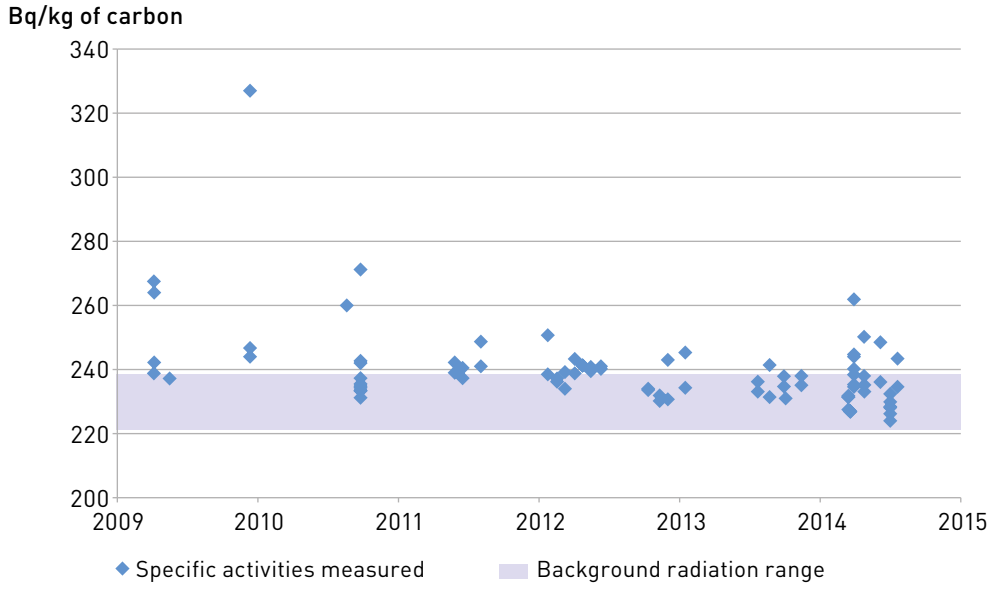
Although atmospheric carbon discharges released by the facilities at Marcoule are very minor, activity levels in the environment due to these discharges can be differentiated from background radiation levels if the specific activity is measured as Bq/kg of carbon. Figure 11 shows specific carbon-14 activity levels, as measured by IRSN since 2009 in various plants, and tree leaves in particular. Most of these activity measurements exceed the background radiation range (current mean background radiation: 227 Bq/kg of C). Due to the decrease in specific carbon-14 activity throughout the northern hemisphere, this mean value for background radiation represented approx. 240 Bq/kg of C in 2009 (see chapter 2). The mean measurement acquired by IRSN over the 2015-2017 period reflects an average increase of + 8 Bq/kg of C, which is + 3.5% versus current background radiation levels, due to site discharges. In terms of food, this additional specific activity corresponds to an additional activity by mass of around 0.2 Bq/kg fresh for a lettuce or 0.5 Bq/kg fresh for fruit or 0.5 Bq/L for milk. These additional activity levels by mass cannot be differentiated from background radiation, in theory. On this basis, significantly higher measurements acquired by CEA as part of its monitoring programme, particularly for fruit, could be due to technical measuring uncertainties.

Carbon-14 activity measured in the aquatic environment, particularly for fish in the Rhône river downstream from the Marcoule site, is mainly attributable to discharges from NPPs on the Rhône river (see chapter on NPPs).

Other radionuclides

In the terrestrial environment, only caesium-137 from fallout from the Chernobyl accident and nuclear tests can be measured at similar levels to those detected in areas unaffected by a nuclear facility, and can therefore be attributed to background radiation (see chapter 3.1 pp. 90-91).

FIGURE 11 / **SPECIFIC CARBON-14 ACTIVITY MEASURED BY IRSN IN THE TERRESTRIAL ENVIRONMENT OF THE CEA SITE AT MARCOULE**



Caesium-137 activity levels in sediment samples taken downstream from the site are higher than levels for sediment samples taken upstream: 15.3 Bq/kg dry compared with 1.2 Bq/kg dry (figure 12). Sediment contamination is slightly higher at Codolet. Despite this, activity measurements correspond to background radiation levels (see chapter 2: fallout from atmospheric testing). In addition, several artificial radionuclides can also be measured downstream: cobalt-60, strontium-90, americium-241 and plutonium-239+240, to varying degrees.

Aquatic plant and fish samples are taken in the Rhône upstream and downstream from the site. A few traces of artificial radionuclides are occasionally measured in aquatic plants: particularly caesium-137, cobalt-60, strontium-90, americium-241 and plutonium-239+240. Table 3 can be used to compare activity levels upstream and downstream from the site, and demonstrates that these measurements do not indicate any site impact at the current time. With caesium-137, activity levels may indeed be higher downstream, but remain within the range of variation in background radiation from residual fallout.

In terms of fish, with the exception of one single sample containing quantifiable traces of caesium-137, no artificial radionuclide was detected between 2015 and 2017.

FIGURE 12 / **ACTIVITY BY MASS FOR THE MAIN RADIONUCLIDES OF INTEREST IN THE SEDIMENT SAMPLES TAKEN IN THE RHÔNE RIVER UPSTREAM AND DOWNSTREAM FROM THE CEA SITE AT MARCOULE**

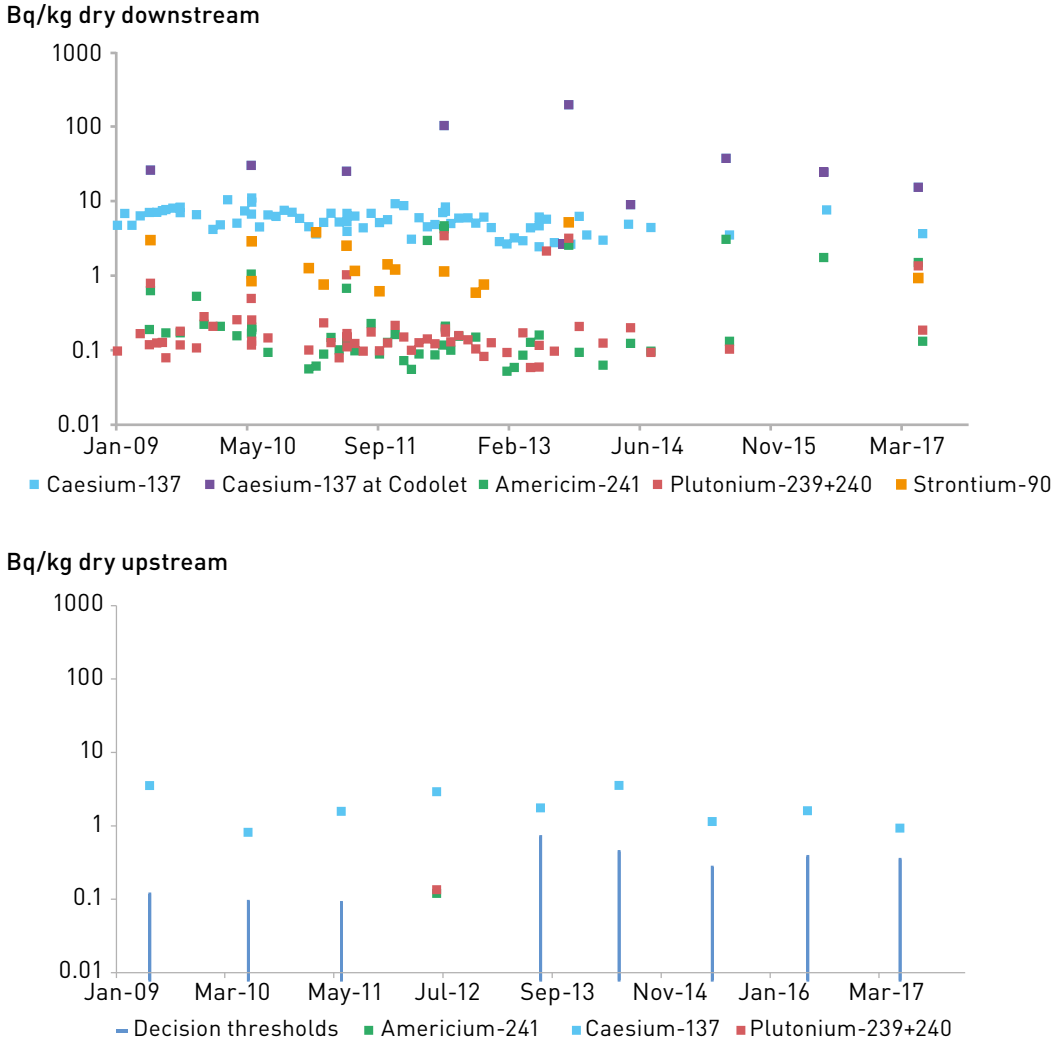


TABLE 3 / **ACTIVITY MEASURED IN AQUATIC PLANT SAMPLES TAKEN UPSTREAM AND DOWNSTREAM OF THE CEA SITE AT MARCOULE (Bq/kg fresh)**

Radionuclide	Min. and max. value upstream from Saint-Étienne-des-Sorts	Min. and max. value downstream from Codolet
^{3}H	0.34 – 0.65	0.38 – 3.43
^{137}Cs	0.32 – 0.35	0.17 – 0.22
^{60}Co	< DT	0.08
^{90}Sr	0.54	0.15 – 0.30
^{241}Am	0.007	0.009 – 0.018
^{238}Pu	< DT	< DT
$^{239+240}$Pu	0.006 – 0.008	0.010 – 0.065

Conclusions

In general, tritium activity levels have decreased in all environmental components near to the Marcoule site, due to the substantial reduction in discharges as the Célestin reactors and the Tritium workshop have been shut down, and this feature characterises the radiological changes recorded in the immediate environment of the site over recent years. Due to this decrease, over the 2015-2017 period, the number of significant measurements (results above the decision threshold) is far lower than in previous periods (22% for ambient HTO measurements) and mean values[1] which could be used to estimate the doses potentially reaching local residents cannot be determined. In the previous *Radiological report for the 2011-2014 period*, the dose inherent to tritiated discharges from the facility had been estimated at 0.28 µSv/year; the current value would be far lower.

According to the specific carbon-14 activity measured by IRSN around the site and the exposure scenarios described in chapter 8 of the appendices, the dose absorbed due to carbon-14 is approx. 0.07 µSv/year.

Discharge levels for other radionuclides are too low for the inherent activity in the environment to be detectable. However, in an aquatic environment, and particularly in sediments, residual activity from past site discharges is still detectable.

1. Mean values are only calculated if at least 50% of measurements are significant (> DT) (see chapter 8 of the appendices).

Valduc site

Discharges and monitoring plans

The Valduc facility is dedicated to technological research and development for the nuclear materials required to ensure a dissuasive French nuclear force. The fast neutron reactor, Rachel, was particularly installed at Valduc in 1957, and led to the first ever criticality studies in France. Since this time, specialists at the site also maintain and decommission nuclear units. The site is located in a rural area, surrounded by forests and farming land in the municipality of Salives, 45 km to the north west of Dijon in the Côte-d'Or department (figure 1). Site facilities mainly discharge gaseous tritium into the atmosphere. Discharges have decreased considerably since the 1970's and have reached stable levels since the early years of the 21st century, at around 300 TBq/year (figure 2). CEA and IRSN have implemented a monitoring plan since the site opened, focusing on this radionuclide (table 1), to test and estimate the impact of site discharges on the population and the environment.

FIGURE 1 / **MAP SHOWING THE LOCATIONS OF MONITORING POINTS NEAR TO THE VALDUC SITE**

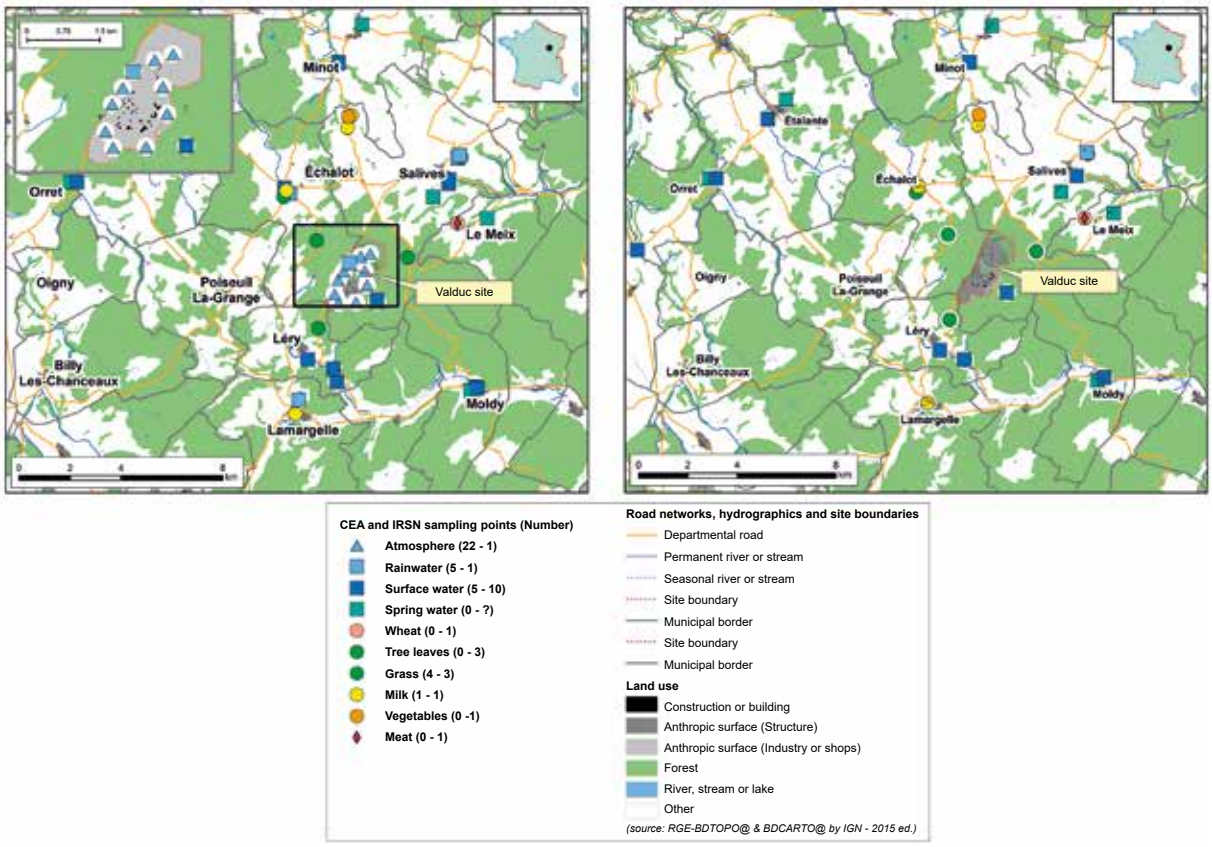
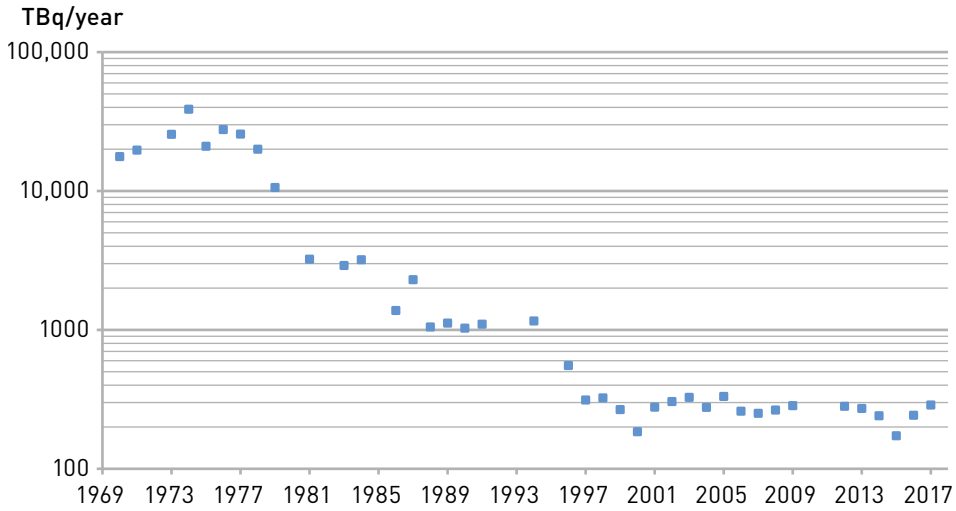


FIGURE 2 / **GASEOUS EFFLUENTS CONTAINING TRITIUM DISCHARGED INTO THE ATMOSPHERE FROM THE CEA SITE AT VALDUC (TBq/year)**



The impact of the Valduc facility on its immediate environment

Tritium discharges into the immediate environment around the Valduc site can be detected in all environment components, up to a few dozen kilometres around the site. Ambient tritium is sampled on a weekly basis using bubblers at 4 sampling stations located in the 4 municipalities in the area around the site. Ambient tritium can be found in two forms: tritiated water vapour (HTO) and gas (HT and other tritiated gaseous organic compounds), however water vapour is the dominant form. Figure 3 shows measurement results, with mean and maximum values for each sampler given in Table 2. Mean tritiated water vapour activity measured over the 2015-2017 period for the samplers at Échalot and Salives represents 0.6 Bq/m^3. The highest values are measured to the north of the site, particularly in the municipality of Échalot, where a maximum value of 4.5 Bq/m^3 of tritiated water vapour (HTO) was reached in July 2017 and 0.9 Bq/m^3 of gaseous tritium (HT) was measured in December 2016.

According to figure 3, while activity levels vary substantially, the ranges are fairly constant over time, with similar mean values, matching variation in discharge levels over the last 20 years. These ambient tritium levels are well above the current background radiation levels for atmospheric tritium in areas unaffected by a nuclear facility, i.e. approx. 0.01 Bq/m^3 of air for tritiated water vapour.

Tritium activity in rainwater can be tracked in the same municipalities using collectors. The annual mean figure over the period for the 4 samplers represents 21.8 Bq/L. Note: just like ambient activity levels (HTO and HT), the highest activity levels are recorded at samplers to the north of the site (table 2). The peak activity reached in rainwater represented 151 Bq/L at the Échalot sampler on 30 January 2017 (see figure 3). These rainwater measurements match the above ambient data.

TABLE 1 / **MONITORING PLANS FOR THE VALDUC SITE**

Environment monitored or type of testing	CEA	IRSN
Ambient gamma radiation	• 10 passive dosimeters at the edge of the site or on-site: ambient γ dose rate • 4 passive dosimeters in the immediate environment of Échalot, Léry, Moloy and Salives: ambient γ dose rate	
Atmospheric aerosols	• 3 sampling points at Échalot, Moloy and Léry gross α and β activities (weekly) • 1 sampling point at Salives: gross α and β activities (daily)	
Ambient tritium	• 4 sampling points at Echalot, Moloy, Léry and Salives: ambient tritium (HTO - HT) (weekly)	• 1 sampling point at Salives: ambient tritium (HTO - HT) (weekly)
Rainwater	• 4 sampling points at Échalot, Moloy, Léry and Salives: tritium (weekly) • 1 sampling point at the CEA site: gross α and β activities (monthly)	• 1 sampling point at Salives: tritium (weekly)
Milk	• 1 sampling point at Salives (Larçon): tritium, γ spectrometry (monthly)	• 1 sampling point at Salives (Larçon): free and organically-bound tritium (6-monthly) • 2 sampling points to the north-west and south-west of the site: free tritium (quarterly)
Grass	• 4 sampling points at Échalot, Moloy, Léry and Salives: tritium (monthly), γ spectrometry (monthly rotation between the 4 points)	• 3 sampling points at Échalot, Léry and Salives: free and organically-bound tritium (annual)
Tree leaves		• 5 sampling points at Échalot, Léry, Salives, Avot and Vernois les Vesvres: free and organically-bound tritium (annual)
Vegetables		• 1 sampling point at Salives (Larçon): free and organically-bound tritium (annual)
Meat		• 1 sampling point to the north-west or south-west of the site: organically-bound tritium (annual)
Wheat		• 1 sample of a departmental mixture: organically-bound tritium, γ spectrometry (annual)
Surface water	• 5 sampling points at Échalot, Moloy, Salives, Léry and Grand Étang at the CEA site: gross α and β activities, tritium, γ spectrometry	• 9 sampling points at Étalante (2 points), Léry (2 points), Minot, Moitron, Moloy, Orret and Salives: gross β activity, potassium, tritium (6-monthly) • 1 sampling point at Grand Etang at the CEA site: gross α and β activities, potassium, γ spectrometry (6-monthly)
Spring water or outlet		• 8 sampling points at Étalante (2 points), Le Meix, Minot, Moitron, Moloy, Poiseul-la-ville-et-Laperrière and Salives: gross β activity, potassium, tritium (6-monthly)

TABLE 2 / **MEAN AND MAXIMUM TRITIUM ACTIVITY LEVELS IN THE FORM OF WATER VAPOUR (HTO) ESTABLISHED ON THE BASIS OF SIGNIFICANT AMBIENT MEASUREMENTS OBTAINED ON A WEEKLY BASIS IN THE IMMEDIATE ENVIRONMENT OF THE CEA SITE AT VALDUC**

	HTO (Bq/m³)	
	Mean value	Maximum value
Moloy	-*	1.0
Échalot	0.7	4.5
Léry	-*	0.8
Salives	0.5	2.1

* Mean values are only calculated in this radiological report if at least 50% of measurements are significant (above the decision threshold), which is not the case for ambient tritium activity measurements at the Lery and Moloy samplers (see chapter 8 in the appendices).

FIGURE 3 / **AMBIENT TRITIUM ACTIVITY LEVELS IN THE FORM OF WATER VAPOUR (HTO) AND AS A GAS (HT and other tritiated gaseous organic compounds) MEASURED IN THE IMMEDIATE ENVIRONMENT OF THE CEA SITE AT VALDUC ON A WEEKLY BASIS (Bq/m³)**

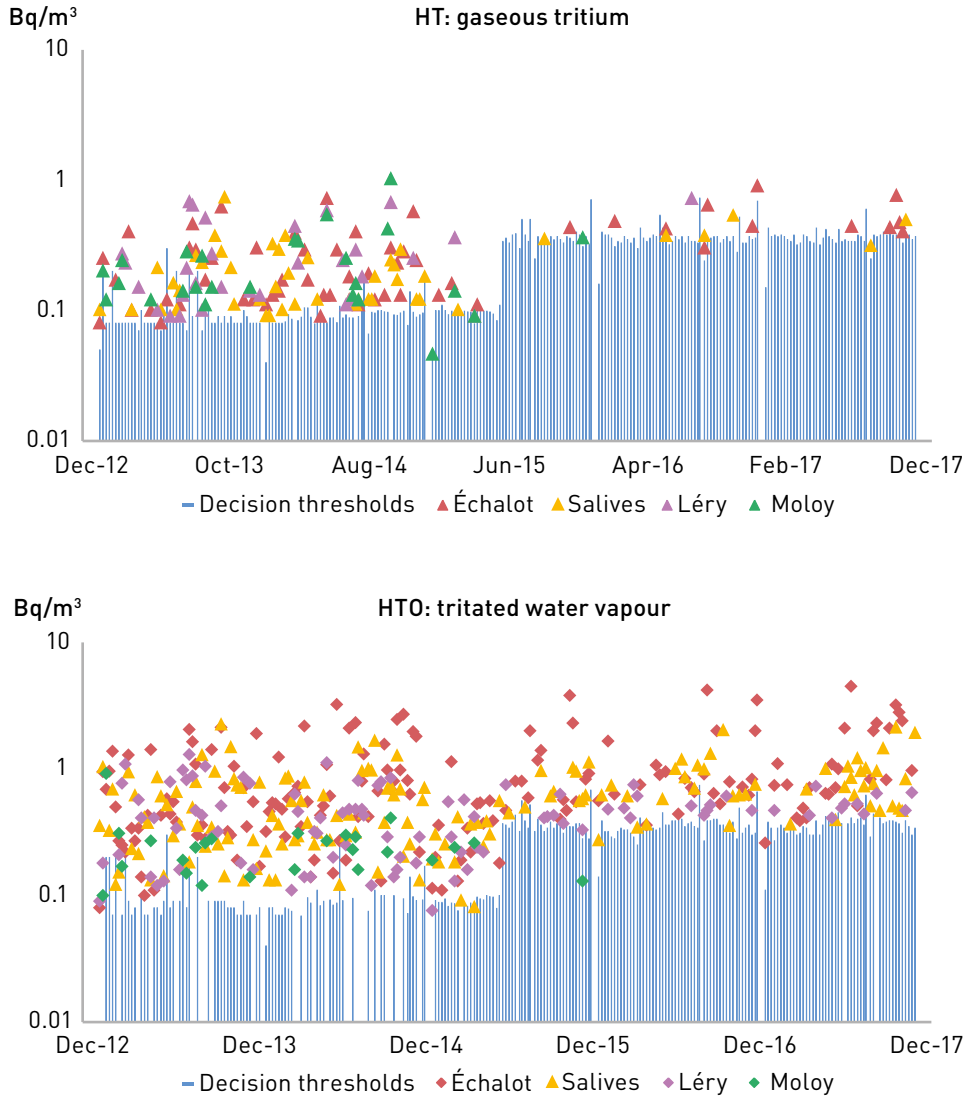
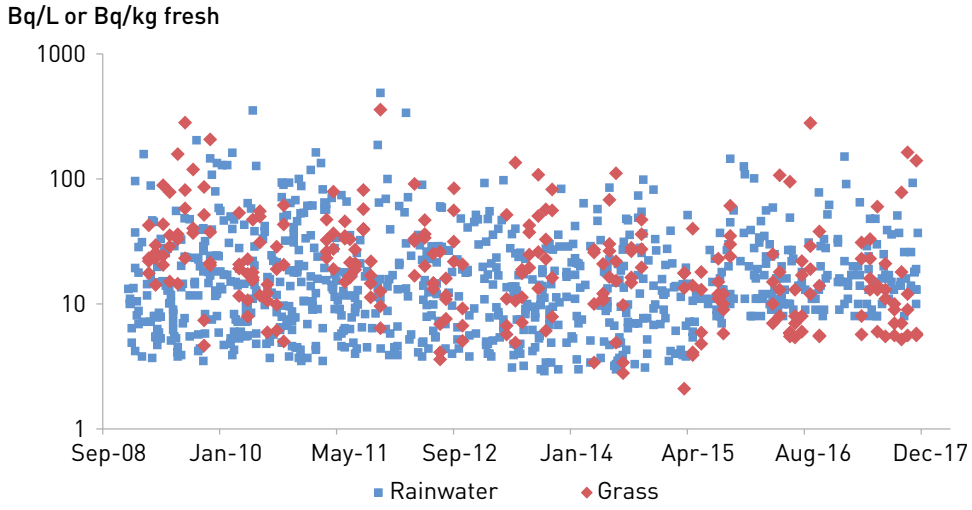


TABLE 3 /**TRITIUM ACTIVITY IN RAINWATER (Bq/L)**

Municipality		Mean value (Bq/L)	Maximum value (Bq/L)
Salives	**North**	24.9	126.0
Échalot		28.2	151.0
Léry	**South**	14.7	45.0
Moloy		14.2	56.0

Free tritium measurements (free water HTO in plants) are taken from grass samples around the Valduc site on a monthly basis. Figure 4 highlights the parallels between activity levels measured in rainwater and those in plants. In fact, HTO activity levels in plants are representative of tritium activity levels in the atmosphere over the period preceding the sample. Variation in these activity levels is also similar to that recorded for rainwater and air. The mean value for the 4 samplers over the 2015-2017 period is also very similar to the mean measurement for rainwater: 23.7 Bq/kg of fresh grass. The peak value during the study period was measured in the municipality of Échalot: 280 Bq/kg of fresh grass.

FIGURE 4 / **TRITIUM ACTIVITY MEASURED IN RAINWATER (Bq/L) AND IN GRASS SAMPLES (Bq of free tritium/kg fresh) NEAR TO THE CEA SITE AT VALDUC**



Free tritium activity levels (HTO), based on the analysis of cow's milk samples taken around the site, vary significantly, in the same way as rainwater and grass samples. Figure 5 shows the parallels between activity levels measured in grass and those in milk. Mean tritium activity for milk over the period in question is equal to 11.7 Bq/L, with a peak value of 27.2 Bq/L in a sample taken in the municipality of Salives in September 2015. Activity in milk is very naturally lower (2 to 3 times lower on average), than activity in grass samples.

This is due to the fact that tritium is primarily transferred to livestock by eating food and drinking water, as well as by inhaling and transcutaneously. The tritium contamination of some cattle food components (feed or water) can be less than that of local grass. Figure 6 also confirms that activity levels are higher to the north of the site. These tritium activity levels in milk samples collected in the area around the Valduc site are well above local background radiation levels, which currently range between less than 1 Bq/L and 3 Bq/L.

FIGURE 5 / **FREE TRITIUM ACTIVITY MEASURED IN MILK (Bq/L) AND GRASS SAMPLES (Bq of free tritium/kg fresh) NEAR TO THE CEA SITE AT VALDUC**

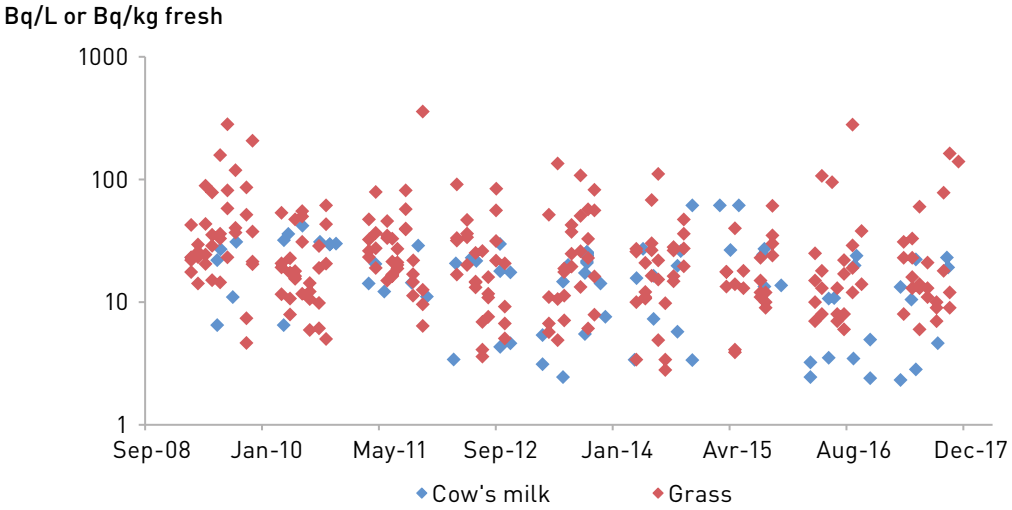
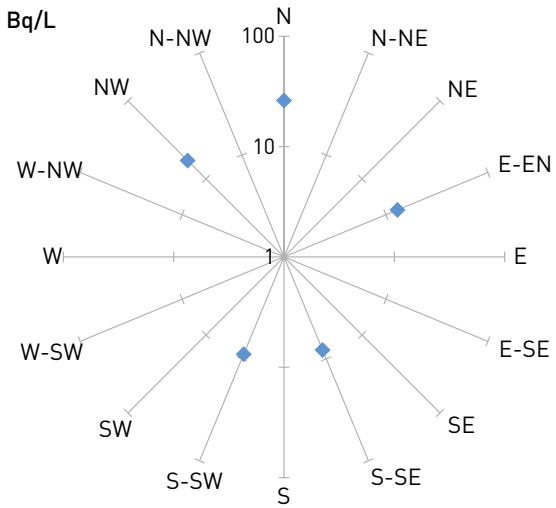


FIGURE 6 / **GEOGRAPHIC DISTRIBUTION OF MEAN TRITIUM ACTIVITY IN MILK (Bq/L) IN THE IMMEDIATE ENVIRONMENT OF THE CEA SITE AT VALDUC**



According to analyses of annual beef samples taken in the municipalities around the facility, activity ranges from 1.1 to 9.3 Bq/kg dry of meat in OBT. This activity must be divided by 3 to 4 to obtain the activity in Bq/kg fresh. This activity range in wheat falls between 2.2 and 8.7 Bq/kg dry of wheat. Finally, according to analyses of honey samples, tritium activity ranges between 4.2 and 11.6 Bq/kg fresh. These activity levels must be compared with background radiation levels for tritium, which are currently between less than 1 and 3 Bq/kg fresh.

Figure 7 shows the results of the analysis of tree leaves collected at increasing distances between the Valduc site facility and the municipality of Vernois Les Vesvres. According to these results, at approximately 20 km from the site, tritium activity levels can still exceed over 3 times background radiation for this radionuclide, confirming that tritium discharges from the Valduc facility affect the terrestrial environment around the site over several tens of kilometres.

Ground water is monitored by taking samples at the points where the Coquille, Galopine, Prélard, and Prégelan springs emerge and public supply points: a public fountain at Minot and at Moloy, and the washing point at Le Meix (figure 8). Tritium activities measured range from 2.2 to 67.7 Bq/L of water. The highest activity levels were measured in samples taken at the Prégelan spring at Salives and in the municipality of Le Meix with mean values of 53.9 Bq/L and 24.7 Bq/L of water respectively. Tritium contamination of other water sources oscillates between the decision threshold (< 5 Bq/L) and 9.3 Bq/L.

FIGURE 7 / **ORGANICALLY-BOUND TRITIUM ACTIVITY MEASURED IN TREE LEAF SAMPLES (Bq/kg dry of leaves) BETWEEN 2012 AND 2017**

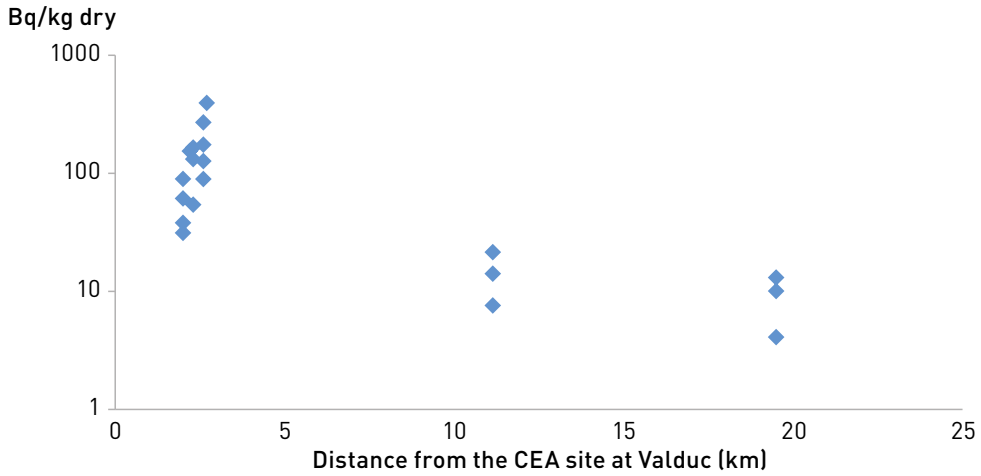
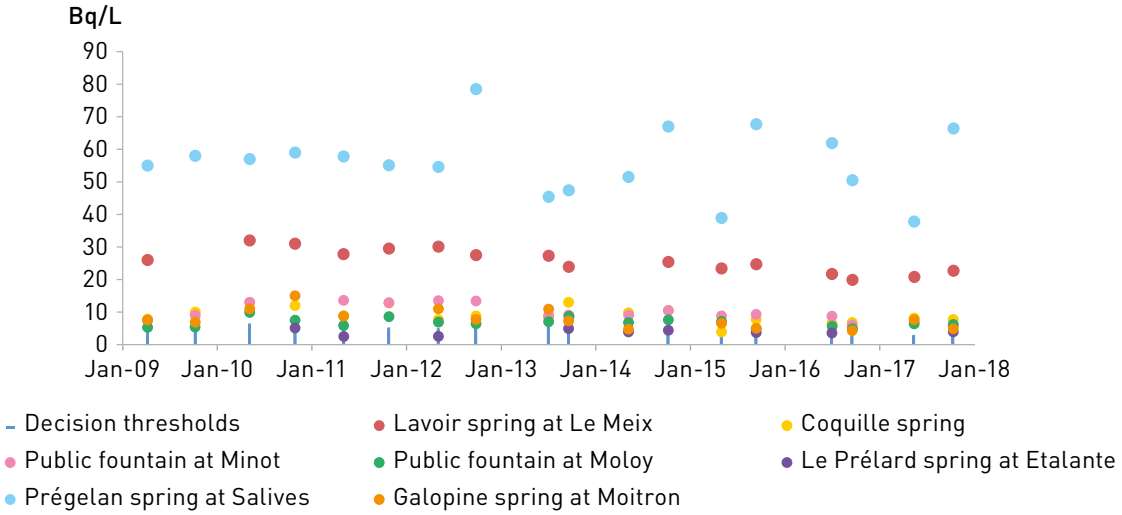


FIGURE 8 / **TRITIUM ACTIVITY MEASURED IN GROUND WATER SAMPLES TAKEN FROM NEAR TO THE CEA SITE AT MARCOULE (Bq/L)**



Two aquifers flow under the Valduc site and feed several rivers. To the north and west, water is part of the Seine drainage area; to the south and east, water is part of the Saône drainage area (see figure 9). According to monitoring results, tritium activity in the rivers draining the Valduc butte fell substantially during the 1990's and the first decade of this century, although the decrease slowed in recent years. This overall trend matches variation in atmospheric discharges (see figures 10 and 11).

Mean activity levels at Grand Étang represent 152.3 Bq/L of water. This lake feeds the Noirvau stream, which then joins the Douix river, as shown in figure 9. Douix river water is therefore less contaminated as Noirvau activity is diluted (see figure 10). On this basis, the maximum activity levels measured in the Douix and Noirvau rivers reached 25.8 Bq/L and 138.0 Bq/L respectively.

The Noirvau and Douix rivers join the Ignon to the south of the site. Mean activity levels measured in these rivers: 116.1 Bq/L, 23.3 Bq/L and 17.4 Bq/L respectively. The La Tille river flows to the east, with peak tritium activity of 33.5 Bq/L and mean activity of 28.6 Bq/L of water. On this basis, according to monitoring results for rivers in the area around the site, tritium contamination is a general feature, with the exception of the Seine river (to the west of the site) for which all measurements were below the decision threshold

FIGURE 9 / **MAP OF RIVERS IN THE IMMEDIATE ENVIRONMENT OF THE CEA SITE AT VALDUC AND THE SURFACE WATER MONITORED**

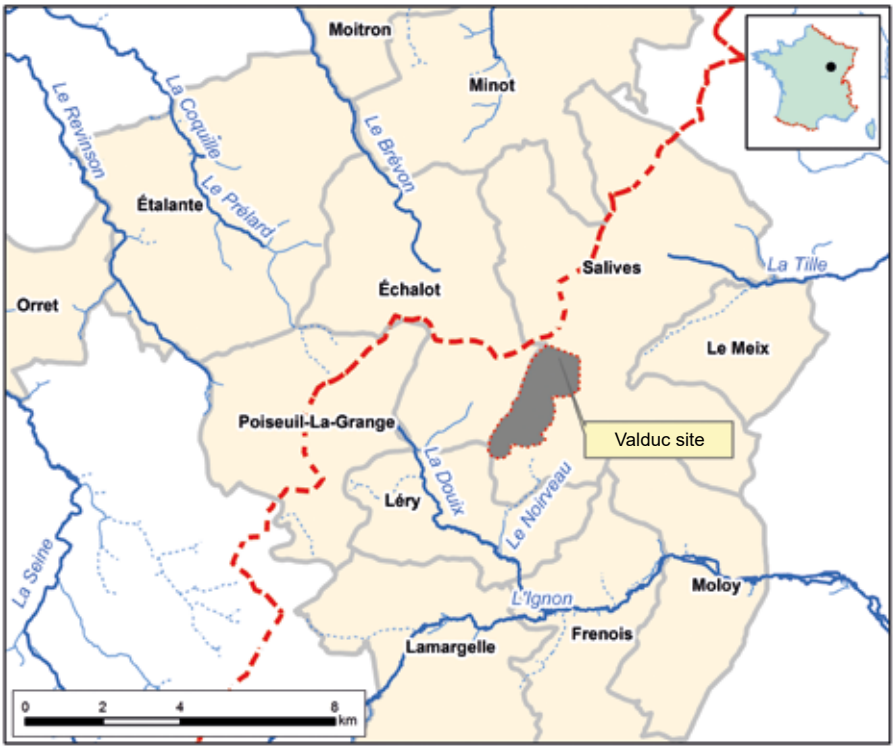


FIGURE 10 / **TRITIUM ACTIVITY MEASURED IN SURFACE WATER SAMPLES TAKEN FROM NEAR TO THE CEA SITE AT VALDUC (Bq/L) IN THE SEINE DRAINAGE AREA**

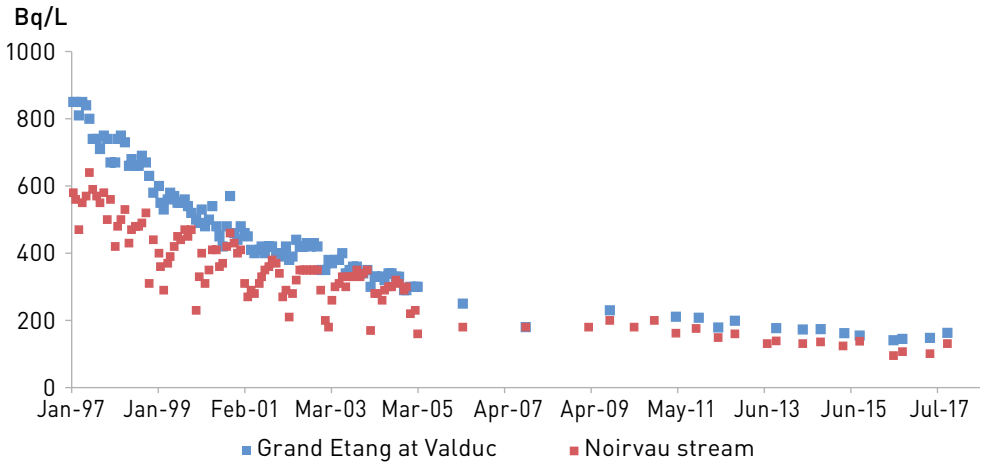
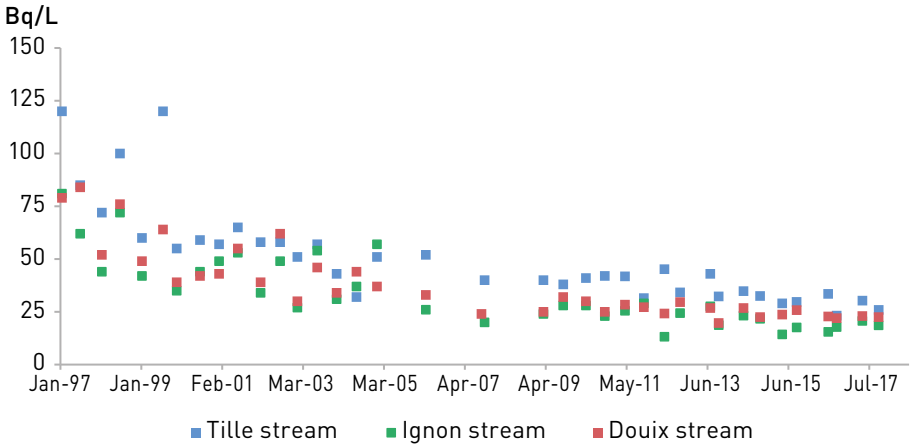


FIGURE 11 / **TRITIUM ACTIVITY MEASURED IN SURFACE WATER SAMPLES TAKEN FROM NEAR TO THE CEA SITE AT VALDUC (Bq/L) IN THE SAÔNE DRAINAGE AREA**



Assessing mean doses based on environmental measurements

The following types of exposure are considered when calculating the dose: eating food and drinking water, inhaling and transcutaneous transfer. Mean tritium contamination was calculated for all types of exposure considered. No other radionuclides were taken into consideration as the impact of the CEA site at Valduc cannot be detected in analyses for these radionuclides.

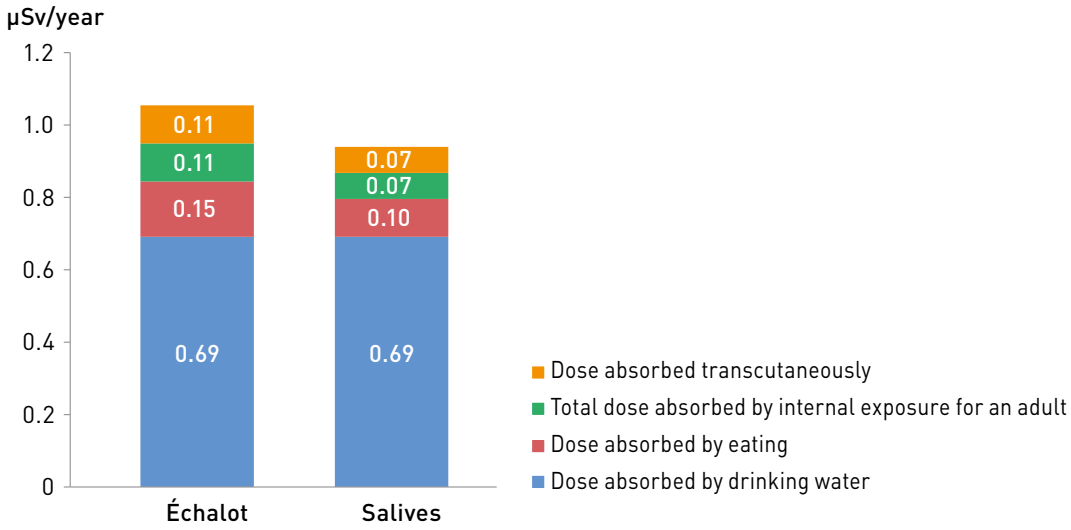
When calculating exposure by inhaling and transcutaneous transfer, the individual is assumed to spend all of their time in an atmosphere with the mean activity level indicated in table 2 for tritiated water vapour (HTO) and gaseous tritium (HT and other tritiated gaseous organic compounds); this applies for the two municipalities to the north of the site. The inherent dose is estimated at 0.22 µSv/year at Échalot and 0.14 µSv/year at Salives.

In the same way as a worst-case assumption is used when calculating the dose absorbed by inhaling or transcutaneous transfer, the impact of the presence of radionuclides in drinking water is calculated based on the presence of tritium in rivers and ground water. The use of spring water with activity of 53.9 Bq/L was assumed for the municipalities of Salives and Échalot. The inherent dose is calculated as approx. 0.7 µSv/year for the municipalities of Échalot and Salives.

A basic standard diet was assumed for France as a whole in rural areas for calculations on eating food grown locally. A dose of approx. 0.15 µSv/year was obtained for Échalot and 0.10 µSv/year for residents living in Salives.

The mean total dose for tritiated discharges from the site for these municipalities is therefore around 1 µSv/year (see figure 12 for contributions per type of exposure).

FIGURE 12 / **ESTIMATED DOSES FOR TRITIUM DISCHARGED INTO THE ATMOSPHERE FROM THE CEA SITE AT VALDUC: CONTRIBUTION TO THE TOTAL EFFECTIVE DOSE**



Conclusions

According to the results of the measurements taken in all environmental components in the immediate environment around the facility, only tritium contaminates this area up to a distance of several tens of 10 km. The activity measured for other radionuclides is insufficient to detect any contribution from CEA discharges. Tritium levels in the different environmental components are stable and generally 10 to 100 times above background radiation. The potential effective dose inherent to CEA discharges from Valduc represents 1.0 µSv/year on average for an adult living in the immediate environment of the site for one full year, and eating local food. This estimate is 1,000 times less than the exposure limit defined for the public (1 mSv/year).

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Taking water samples at the Coquille spring at Étalante

Cadarache site

The CEA facility at Cadarache (see figure 1) was created on 14 October 1959. This facility was constructed in the municipality of Saint-Paul-Lez-Durance in the Bouches-du-Rhône area at the point where three other administrative departments join up (Alpes-de-Haute-Provence, Var and Vaucluse). This facility is home to a research centre, experimental fuel design and production laboratories and development units for the associated nuclear technologies.

Cadarache site operated in 2017:

- 21 basic nuclear facilities (INB);
- 24 environmentally-classified facilities (ICPE) excluding INB, including 14 "nuclear" ICPE;
- 12 facilities using radioactive substances subject to authorisation under the French public health code; 3 of these facilities are also non-nuclear ICPE.

Radioactive discharges

In addition to the noble gases (krypton, etc.) discharged by some INB at the facility (Cabri, Leca-Star, Phébus, etc.), tritium is the main radionuclide discharged into the atmosphere by the Cadarache nuclear facility (figure 2).

Since 2014, after conducting radiological tests for each facility, liquid radioactive effluents from the site have been transferred to the Advanced effluent treatment and management workshop (AGATE). This workshop can be used to reduce the volume of waste while concentrating radioactivity. The concentrates are then routed to the Marcoule site for final treatment and preparation as waste packages.

If the liquid effluents comply with transfer standards, they will then join the industrial effluent network prior to treatment at the purification station (STEP-EI). These effluents are treated and then discharged into the Durance river (table 1). Tritium is the main radionuclide discharged in liquid effluents.

Radiological monitoring of the site environment

The operator monitors radioactivity in the atmosphere using continuous measurements (ambient gamma radiation) or deferred measurements (atmospheric dust, tritium, carbon-14, rainwater) *via* five samplers spread both inside and outside of the site: Grande Bastide, Verrerie, Cabri, Ginasservis and Saint-Paul-Lez-Durance.

Monthly milk and plant samples are taken in the terrestrial component, under the prevailing winds. An annual sampling run is also organised for the main farming output and topsoil. Gross alpha and beta activities are also generally measured in terrestrial samples, and gamma spectrometry is performed. Alpha spectrometry, and tritium, carbon-14 and strontium-90 measurements are performed annually, particularly aiming to measure transuranic elements, and complement the above analyses.

Continuous and occasional surface water samples are taken in the aquatic component, more specifically in the Durance river, upstream (facility pumping station) and downstream (Pont Mirabeau sampler) from the Cadarache facility. Samples are also taken from the discharge pipe outlet and the village of Saint-Eucher. Tritium and gross alpha and beta activities are measured in water samples. Alpha and gamma spectrometry and strontium-90 measurements are occasionally used to complement these results (particularly downstream from the discharge point). Sediment, aquatic plant and fish samples are taken in the Durance river on an annual basis or more often.

Ground water under the facility is tested on a monthly basis using samples collected *via* 48 piezometers. Tritium and gross alpha and beta activities are determined using these samples. Strontium-90 and actinide activity (alpha spectrometry) is also determined every 6 months at some locations.

FIGURE 1 / **CADARACHE SITE**

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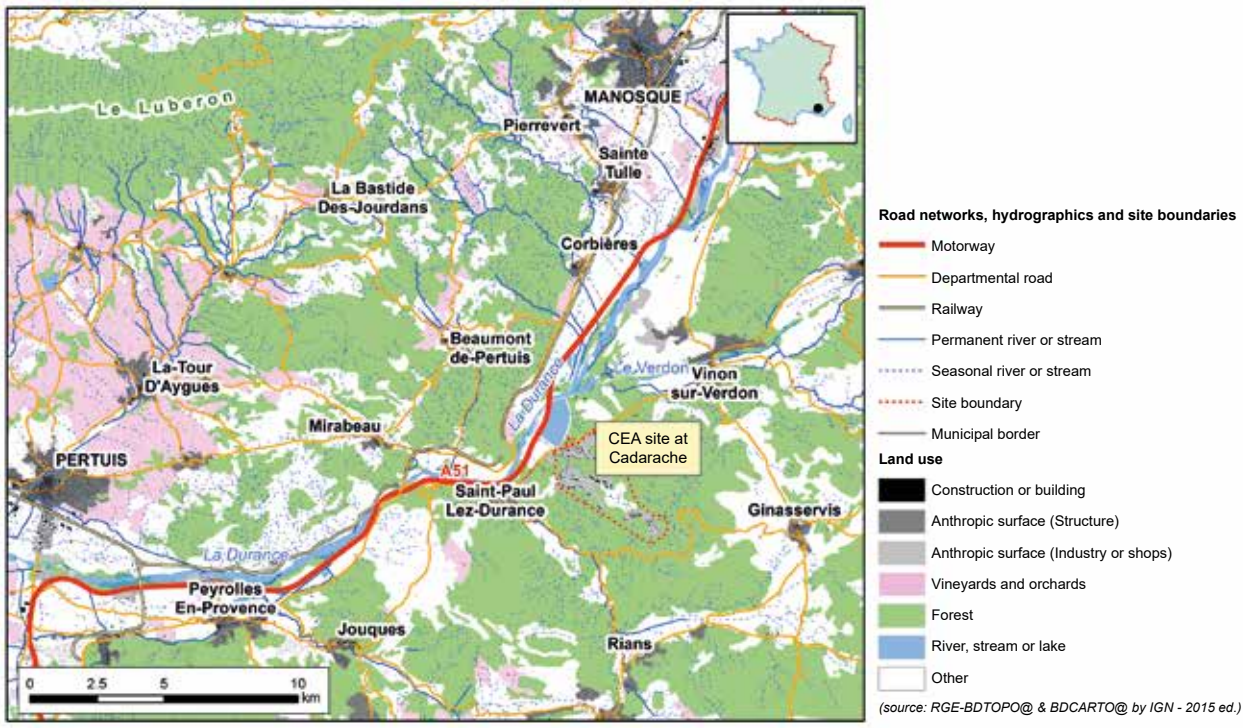


The corresponding measurements for the sub-surface of the site are not uploaded to the RNM or used in this report, which exclusively describes and comments on off-site data.

Punctual analyses carried out at the request of ASN as part of inspections with environmental sampling can be added to this monitoring plan.

FIGURE 2 / **VARIATION IN LIQUID AND GASEOUS TRITIUM DISCHARGES FROM THE CEA SITE AT CADARACHE SINCE 2004 (GBq/year)**

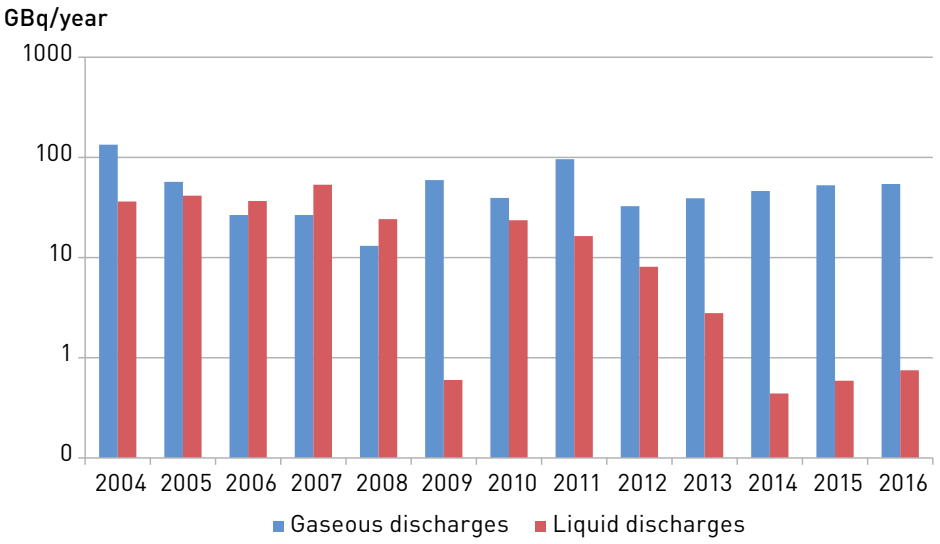


TABLE 1 / **OVERVIEW OF LIQUID RADIOACTIVE EFFLUENTS DISCHARGED INTO THE DURANCE RIVER BETWEEN 2009 AND 2016 (GBq/year)**

Source: CEA

Parameters	Tritium	Carbon-14	Gross beta measurement	Gross alpha measurement
Activity discharged in 2009	0.6	0.006	0.26	0.000202
Activity discharged in 2010	23.64	0.008	0.18	0.000208
Activity discharged in 2011	16.4	0.0103	0.201	0.000446
Activity discharged in 2012	8.1	0.00458	0.28	0.000185
Activity discharged in 2013	2.79	0.00219	0.29	0.000195
Activity discharged in 2014	0.44	0.0019	0.32	0.00018
Activity discharged in 2015	0.59	0.0019	0.23	0.00012
Activity discharged in 2016	0.75	0.002	0.23	0.0002

The impact of the Cadarache site on its immediate environment

Tritium

Although atmospheric tritium is dominant in gaseous discharges, as a gas (HT) and as water vapour (HTO), it was only measured on one occasion between 2014 and 2017 (as HT). The measurement (0.14 Bq/m^3) exceeds background radiation for this radionuclide and reflects the temporary impact of discharges from the Cadarache site.

Tritium is also very occasionally (5 times between 2014 and 2017) measured in rainwater collected near to the site. Measurements vary from 2.4 to 5 Bq/L, and are similar to or slightly above background radiation, which ranges from less than 1 to 3 Bq/L).

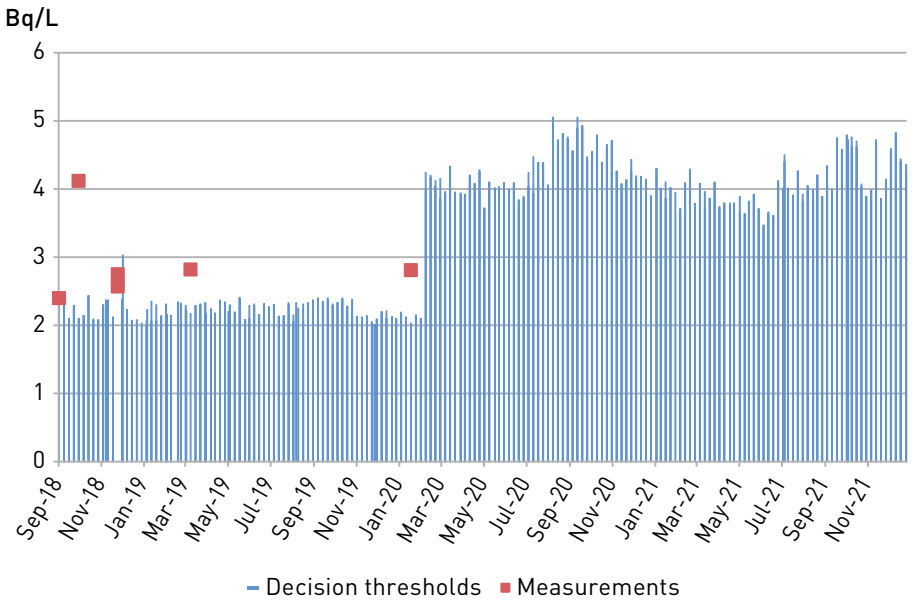
Tritium activity levels above the decision threshold were only recorded for 6 out of the 350 water samples taken between 2014 and 2017 in the Durance river downstream from the Cadarache site and in the canal upstream from the site (figure 3).

An activity of approx. 4 Bq/L for one single sample, taken downstream from the site in 2014, revealed transient and minor contamination from discharges from the Cadarache site. Note: tritium was not detected at any time after the decision threshold was increased from approx. 2.2 to 4 Bq/L early in 2016, in line with the regulatory decision thresholds established in ASN decision no. 2013-DC-0360 of 16/07/13.

Tritium measurements only exceeded the decision threshold for 18 of the 787 ground water samples taken using 14 piezometers located around the Cadarache site. The values obtained vary from 2.2 to 34 Bq/L, which is approximately equal to background radiation levels for this radionuclide (ranging from less than 1 to 3 Bq/L). Tritium was most recently detected in January 2016, before the decision threshold was increased from approx. 2.2 to 4 Bq/L.

Finally, tritium results in vegetables and milk do not indicate any contamination by discharges from the Cadarache site.

FIGURE 3 / **DECISION THRESHOLDS AND TRITIUM ACTIVITY BY VOLUME MEASURED IN DURANCE RIVER WATER (upstream and downstream samples combined) BETWEEN SEPTEMBER 2014 AND DECEMBER 2017 (Bq/L)**



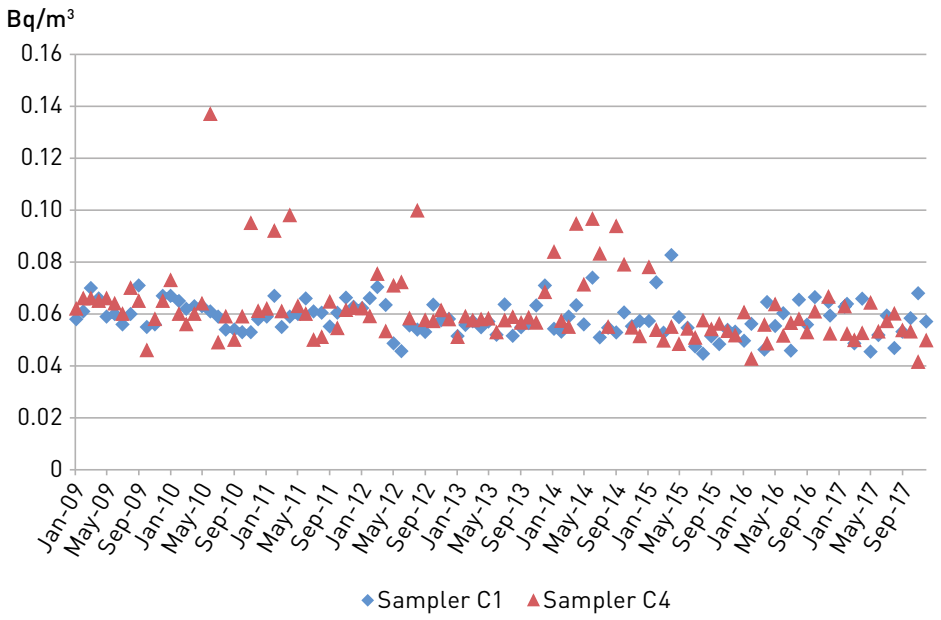
Carbon-14

Carbon-14 samples are taken using bubblers, just as for atmospheric tritium. The results obtained vary from 0.042 to 0.094 Bq/m^3, with a mean value of approx. 0.06 Bq/m^3. All of the data obtained using these samplers are slightly above background radiation in France (approx. 0.05 Bq/m^3), indicating the very low influence of carbon-14 discharges from the Cadarache site (figure 4).

Carbon-14 activity is also measured in fish from Durance river, with a mean activity level of 26 Bq/kg fresh for the 2 samples analysed, which is similar to background radiation levels for these indicators (around 24 Bq/kg fresh; see chapter 2). The same applies for aquatic plants, activity levels cannot be differentiated from background radiation measured at a distance from nuclear facilities.

The carbon-14 activity levels measured in milk samples are typical of residual atmospheric fallout from nuclear weapons tests. Carbon-14 activity levels measured in 2016 in vegetable samples taken at Saint-Paul-lez-Durance and Ginasservis are above background radiation for this radionuclide. However, no details are available as to the matrix sampled and considering the variation in carbon content of "vegetables and fine herbs" (class used in the RNM database), no conclusion can be reached as to whether this difference from background radiation (6 and 16 Bq/kg fresh respectively) is due to CEA discharges from the Cadarache site. In fact, NPPs discharge far higher quantities of this radionuclide comparatively speaking and contaminate the immediate environment (5 km radius) with approx. 0.3 - 0.7 Bq/kg fresh in fruit and vegetables (see the corresponding paragraph).

FIGURE 4 / **AMBIENT CARBON-14 ACTIVITY BY VOLUME NEAR TO THE CADARACHE SITE BETWEEN JANUARY 2009 AND NOVEMBER 2017 - BUBBLERS AT THE ATMOSPHERIC SAMPLERS AT GINASSERVIS (C1) AND SAINT-PAUL-LEZ-DURANCE (C4) (Bq/m^3)**



Other radionuclides

Traces of ^{90}Sr and $^{239+240}Pu$ from residual fallout from older atmospheric contamination are detected in a Durance river water sample taken by IRSN downstream from the Cadarache site.

If ^{137}Cs is detected in soils, vegetables or milk, activity levels are low, and represent residual activity from old atmospheric fallout. The same applies for $^{239+240}Pu$ detected in soils and vegetables.

Traces of ^{134}Cs (0.13 Bq/kg) were detected in a thyme sample in August 2014, at levels below the decision threshold generally reached (approx. 0.5 Bq/Kg in 2014). ^{134}Cs had already been measured at this sampler in April 2011, after the Fukushima Daichi accident. On this basis, these traces of ^{134}Cs could represent residual contamination from this event, although they could also partially come from Cadarache discharges. It is important to consider the high level of uncertainty inherent to this measurement (76%).

Sediment samples were taken in 2010, 2012 and 2013 both at and off the Cadarache site, as part of inspections carried out by IRSN at the request of ASN. Alpha emitters (^{238}Pu, $^{239+240}Pu$ and ^{241}Am) were detected in sediment samples collected in the Bête ravine, both on- and off-site. The activity levels measured were 5 to 10 times higher than mean levels for sediments in France. Isotopic ratios ($^{238}Pu/^{239+240}Pu$ and $^{241}Am/^{239+240}Pu$) confirm that this contamination differs from residual atmospheric fallout. ICP-MS measurements taken to quantify uranium isotopes failed to reveal any anomalous values for activities or ^{235}U and ^{238}U mass ratios. On the other hand, traces of artificial ^{236}U were detected, which most probably indicates that discharges from the Cadarache site are affecting its immediate environment. The measurements acquired for Durance river water samples collected further downstream (at Pertuis bridge) do not indicate any contamination from the site at this distance.

The annual sediment samples collected by CEA contain traces of ^{137}Cs and $^{239+240}Pu$, at activity levels similar to those recorded at a distance from any facility.

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Taking a ground water sample

Grenoble sites

The CEA and ILL (Institut Laue-Langevin) research facilities are right next to each other and within the urban sprawl of Grenoble (Isère; see figure 1). These sites are at the entrance to the Isère valley between the Vercors massif to the south and the Chartreuse to the north.

Institut Laue-Langevin (ILL) is an international research body in neutron science & technology and was founded in 1967 by France and Germany (and later joined by the United Kingdom in 1973).

The facility runs a highly intense source of neutrons, the high-flux nuclear reactor, INB no. 67. It also operates 40 high-technology spectrometers able to provide information on the structure and dynamics of materials (solids, liquids, gases, etc.) in many research fields: particle physics, nuclear physics, chemistry, biosciences, materials sciences, etc.

The decommissioning works for the CEA facilities in Grenoble are now complete. The order authorising the ASN decision on the decommissioning of INB 61 (LAMA) was published on 13 October 2017.

FIGURE 1 / **THE ILL SITE AT GRENOBLE**

© DR

Radioactive discharges

Gaseous discharges from the ILL site are monitored at 2 outlets, downstream from the effluent filtration systems. Gaseous discharges are assigned to 5 radionuclide categories (noble gases, tritium, carbon-14, iodines and aerosols). Gaseous discharges are quantified by measuring gases in real time and by taking representative samples on a weekly basis. These samples are subjected to laboratory measurements to determine the spectrum of the gaseous radionuclides.

Tritium is the most frequently detected radionuclide in gaseous discharges from ILL (see figure 2), followed by noble gases (mainly argon 41) and carbon-14, for which the activity levels discharged are 10 times lower. In terms of halogenated discharges and aerosols, the activity levels discharged are rarely above the decision thresholds (approx. a few thousandths of the total authorised discharge). The CEA facility in Grenoble ceased discharging gases in July 2013 with the definitive shutdown of the ventilation system following completion of the purification process for INB 61 (LAMA).

Liquid effluents from ILL are discharged and tested at the outlet in the Isère river, 1 km upstream from its confluence with the Drac river. The end of this pipe is in the bed of the Isère river. Liquid effluents are stored in tanks at the facility before being discharged into the pipe leading to the outlet. Discharges are characterised in this tank on the basis of representative samples taken after mixing the contents. Tritium is the most frequently detected radionuclide in liquid discharges, with activity levels approximately 1,000 times higher than carbon-14 in 2013 and 2,000 times higher than that attributed to beta/gamma emitter discharges (see table 2).

No radioactive liquid effluents have been discharged from the INBs at the CEA facility in Grenoble since February 2009.

FIGURE 2 / **VARIATION IN GASEOUS DISCHARGES (NOBLE GASES, TRITIUM AND CARBON-14) FROM THE ILL SITE SINCE 2008**

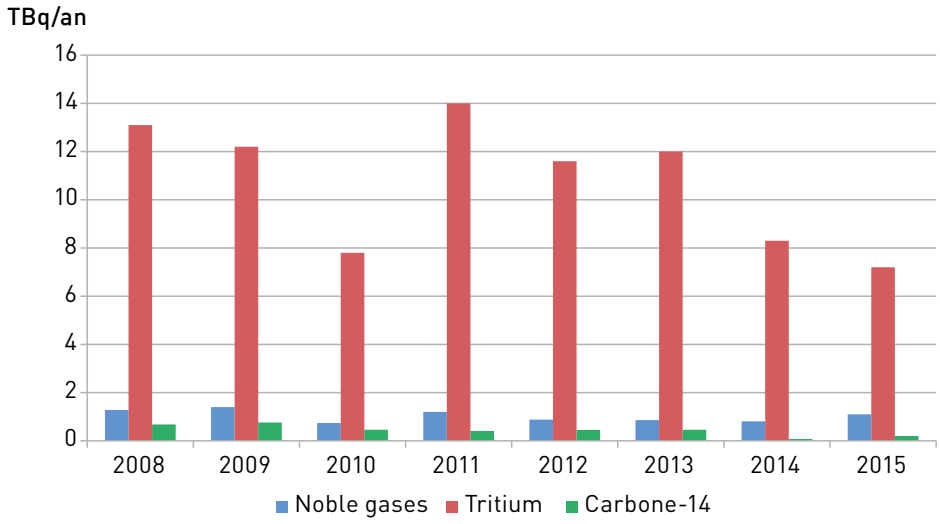


TABLE 1 / **VARIATION IN GASEOUS DISCHARGES (NOBLE GASES, TRITIUM, CARBON-14) FROM THE ILL SITE SINCE 2008 (TBq)**

Year	Noble gas	Tritium	Carbon-14
2008	1.28	13.1	0.68
2009	1.4	12.2	0.76
2010	0.74	7.7	0.46
2011	1.2	13.7	0.41
2012	0.88	11.6	0.45
2013	0.86	12	0.46
2014	0.81	8.3	0.076
2015	1.1	7.2	0.2

TABLE 2 / **VARIATION IN LIQUID DISCHARGES (TRITIUM, CARBON-14 AND BETA/GAMMA EMITTERS) FOR THE ILL SINCE 2008 (GBq/year)**

Year	Tritium	Carbon-14	Beta/gamma emitters
2008	220	0.23	0.0975
2009	32	0.11	0.094
2010	240	0.21	0.096
2011	170	0.27	0.13
2012	370	0.27	0.11
2013	240	0.25	0.11
2014	180	0.22	0.051
2015	430	0.1	0.033

Radiological monitoring of the site environment

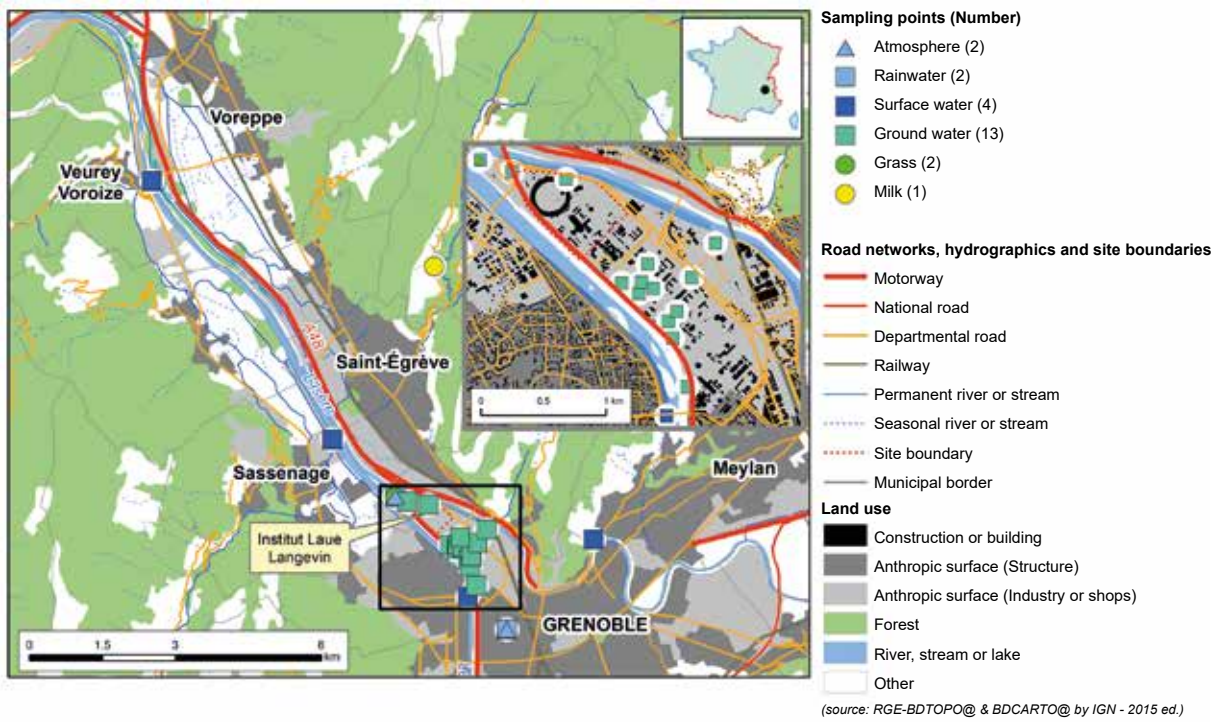
The INBs at the CEA facility in Grenoble ceased all potential effect on the environment in July 2013. Only the ILL research reactor now contributes substantial nuclear activity at the scientific site. With this in mind, Institut Laue Langevin has been responsible for monitoring the shared immediate environment of the two sites since 4 January 2010.

Two types of monitoring programmes are run by ILL:

- continuous monitoring, using sampling stations located at various points in the urban area. Two to the north, at the foot of the weather station at the tip of the peninsula, and farther to the north west, at Rollandière, and two to the south, on the roof of the Chorier-Berriat pool and at Mûrier, above Saint-Martin-d'Hères;
- deferred monitoring, based on regular sampling, followed by laboratory analysis. These samples are taken at the intervals defined in regulations.

ILL takes approximately 2,000 samples each year (aerosols, gases, rainwater, ground water, river water (Drac & Isère), food and terrestrial bio-indicators (milk, grass, farming output) and aquatic bio-indicators (fish, reeds), soils and sediments) (see figure 3). 5,000 analyses are performed on these samples each year. The aim is to ensure that the Grenoble environment and the food chain are not affected radiologically.

FIGURE 3 / **MAP SHOWING THE LOCATION OF THE MAIN SAMPLING POINTS AROUND THE ILL SITE**



(source: RGE-BDTOPO@ & BDCARTO@ by IGN - 2015 ed.)

The impact of discharges from the site (ILL only) on its immediate environment

Tritiated discharges are by far the key factors to be considered when reporting on the impact of the ILL research reactor on the environment.

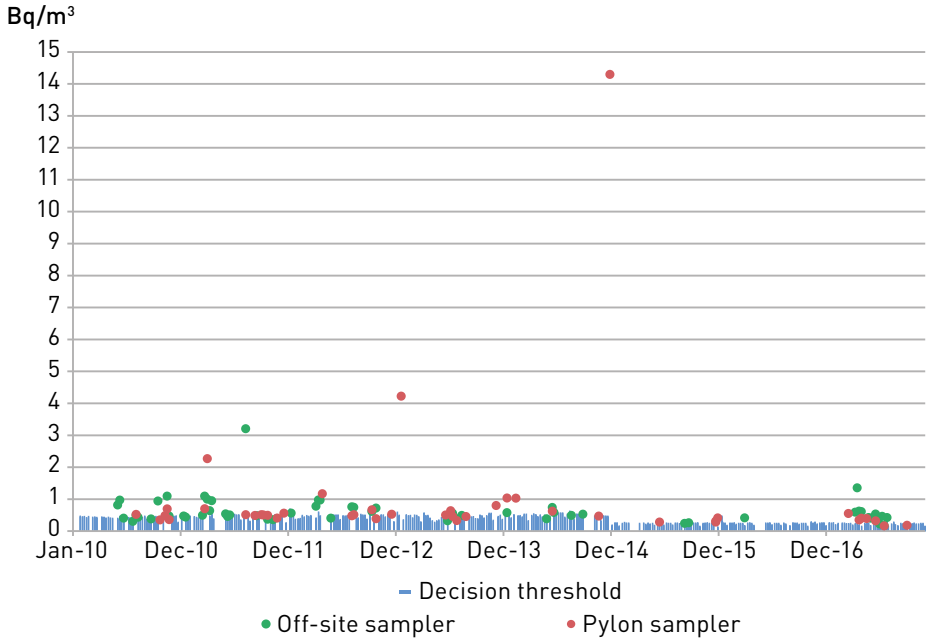
Weekly ambient tritium monitoring is organised using bubblers set up under the prevailing winds; to the south-east of the site ("off-site" samplers) and to the north-west of the site ("pylon" sampler located at the confluence between the Drac and Isère rivers). Measurements are generally below the decision threshold (see figure 4). However, tritium can occasionally be detected at between 0.5 and 1 Bq/m^3. A peak value of 14.3 Bq/m^3 was reached in December 2014, but was never equalled during the 2015-2017 period, during which the maximum value was 1.3 Bq/m^3. During the winter, poor weather conditions limit the dispersal of atmospheric pollutants and concentrations are likely to increase. The ambient tritium activity levels are well above background radiation levels (approx. 0.01 Bq/m^3) and indicate that ILL operations have a clear impact.

The results acquired by IRSN since 2014 confirm the operator's measurements, particularly the peak value (14.3 Bq/m^3) obtained 22 - 29 December 2014. According to the details of the breakdown between HT gas and tritiated water vapour (HTO) obtained by IRSN, this peak is mainly caused by tritiated gas (HT) discharges. Most of the ambient HTO tritium activity measurements obtained by IRSN in 2017 were above the decision threshold, with a mean value of 0.18 Bq/m^3. This mean figure is below those calculated on the basis of measurements for the 2011-2014 period. This decrease is due to the approx. 40% decrease in tritium discharges from ILL.

Tritium can also be detected in rainwater samples taken from near to the ILL site (see figure 5). Tritium was detected slightly more frequently in rainwater samples during the 2015-2017 period, (approx. 50% of the time), with a mean activity level at the north-west sampler significantly higher than the value for the south-east sampler. The significantly higher levels recorded at the north-west sampler are caused by the fact that this sampler is nearer to the discharge point and under the prevailing

FIGURE 4 / **AMBIENT TRITIUM ACTIVITY BY VOLUME NEAR TO THE ILL FACILITY BETWEEN JANUARY 2010 AND DECEMBER 2017 (Bq/m³)**

ILL and IRSN sites



SSW winds in the ILL area. Over the 2015-2017 period, the maximum activity is approx. 30 Bq/L in rainwater and mean activity is close to 4.4 Bq/L. This mean activity is approximately 3 times higher than background radiation levels (approx. 1.3 Bq/L over the same period) and similar to ambient activity measurements.

In terms of river water samples, tritium has only been detected on a very exceptional basis since 2015, (twice in January 2015) in the Isère river, and only downstream from and immediately next to the ILL site (see figure 6). The activity levels measured (3.3 and 3.4 Bq/L) are similar to those found in ground water samples collected using the piezometers installed at the ILL site (see figure 7). These activity levels are similar to the background radiation range (from less than 1 to 3 Bq/L).

FIGURE 5 / **TRITIUM ACTIVITY BY VOLUME IN RAINWATER NEAR TO THE ILL FACILITY BETWEEN JANUARY 2010 AND DECEMBER 2017 (Bq/L)**

ILL and IRSN sites

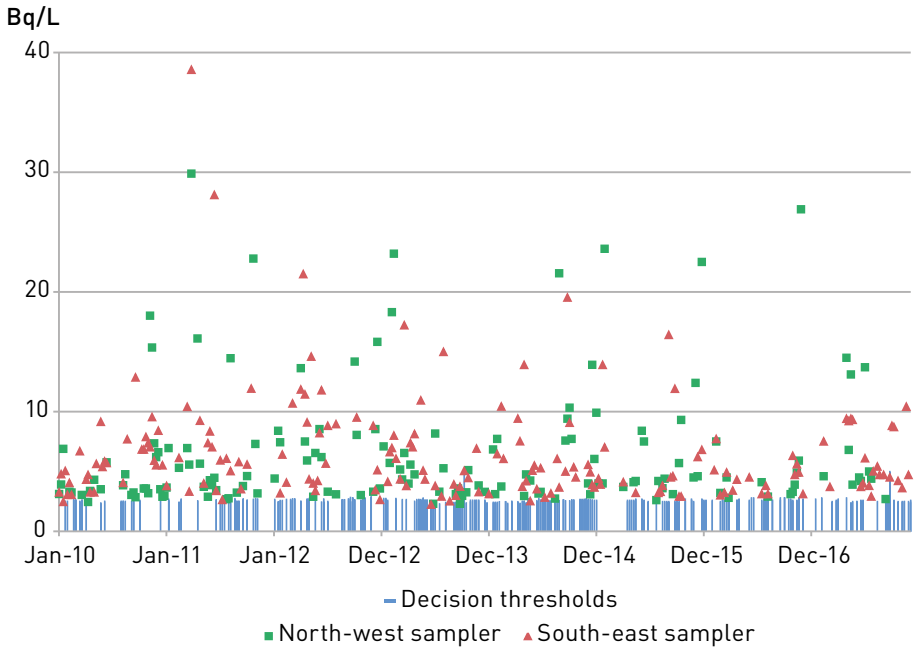


FIGURE 6 / **TRITIUM ACTIVITY BY VOLUME IN THE ISÈRE AND DRAC RIVERS UPSTREAM FROM THE ILL SITE BETWEEN JANUARY 2010 AND DECEMBER 2017 (Bq/L)**

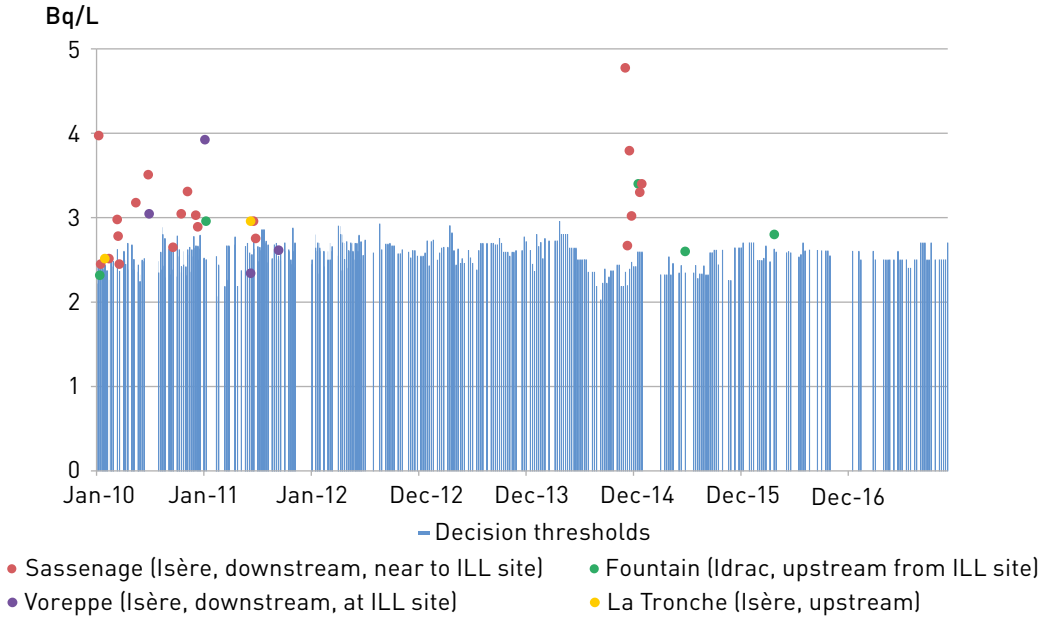
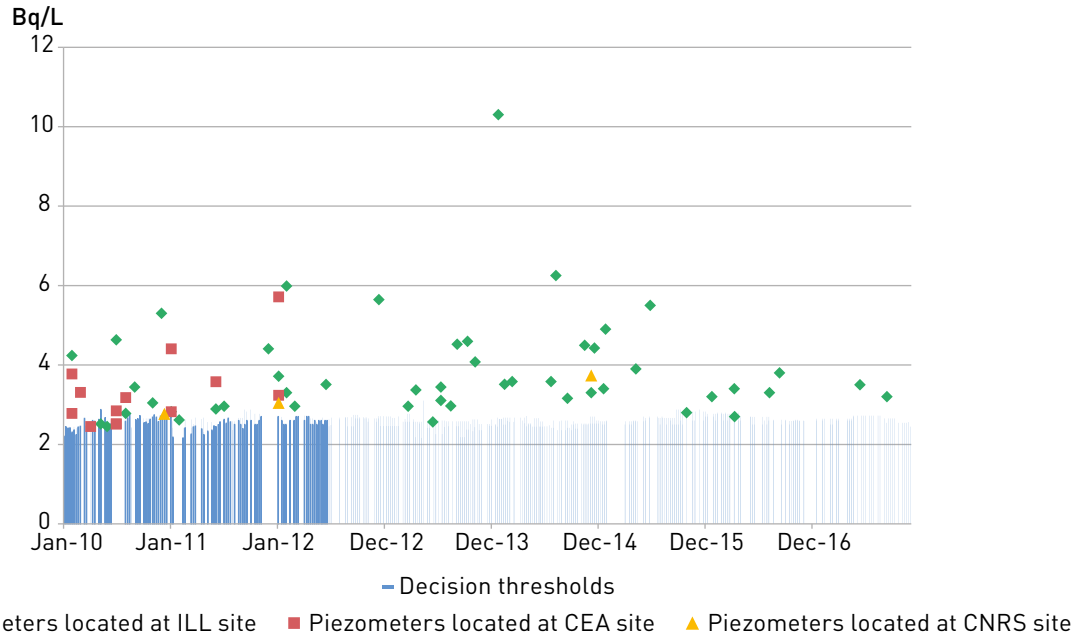


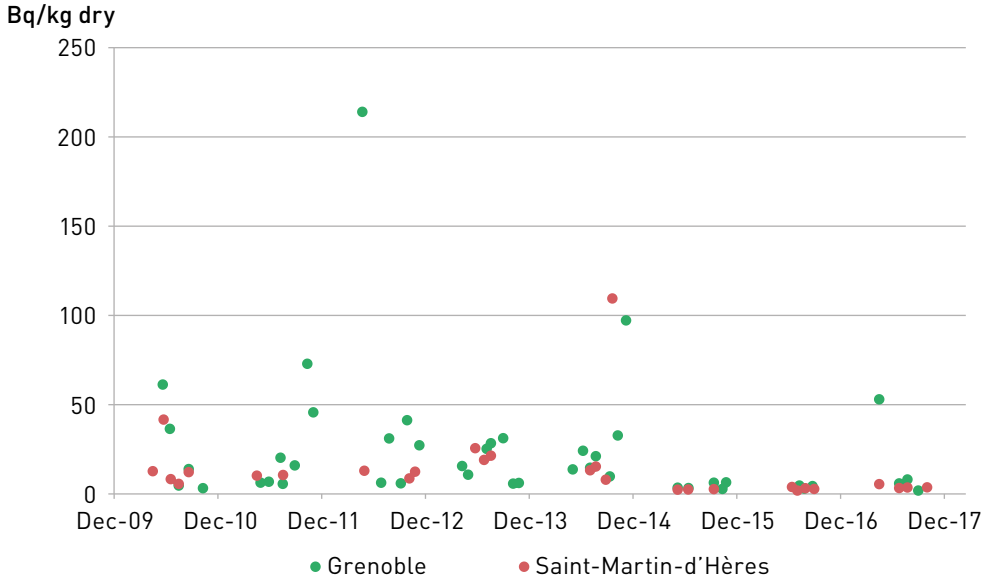
FIGURE 7 / **ACTIVITY BY VOLUME IN GROUND WATER SAMPLES TAKEN USING PIEZOMETERS LOCATED AT OR NEAR TO THE ILL FACILITY BETWEEN JANUARY 2010 AND DECEMBER 2017 (Bq/L)**



Monthly grass samples are taken from May to November. Such samples reliably indicate the contamination of the terrestrial environment as plants integrate the radionuclides. Tritium was almost always detected in this type of matrix over the 2015-2017 period (see figure 8). Detection levels vary from 92% at Grenoble to 82% at Saint-Martin-d'Hères. Activity measurements for the 2015-2017 period range from 2 to 50 Bq/kg fresh at Grenoble in the municipality of Saint-Martin-d'Hères. This difference is mainly due to the distance of the sampling station at Saint-Martin-d'Hères (around 7.5 km to the south-east of ILL) compared with the distance of 1 km (to the west) for the sampling station at Grenoble. As with ambient activity, the decrease in level compared with the 2011-2014 period is probably partially due to the fact that the CEA site at Grenoble ceased discharging gaseous tritiated effluents in July 2013, and to the decrease (approx. 40%) in tritium discharges from the ILL site between 2013 and 2015. The mean activity level of the grass samples taken at Grenoble represents 8.1 Bq/kg dry versus 3 Bq/kg at Saint-Martin-d'Hères. This mean value is mainly higher at Grenoble due to one single value (53 Bq/kg dry), which is well above the other values and was recorded in April 2017. Excluding this result, tritium activity in grass has remained at approximately 5 Bq/kg dry for the nearest site to ILL since 2015.

Milk is also monitored on a monthly basis. Free tritium is detected in around 15% of milk samples at levels of between 2 and 5 Bq/L, reflecting the very low contamination levels in effluents discharged from the site.

FIGURE 8 / **TRITIUM ACTIVITY BY MASS IN GRASS SAMPLES TAKEN AT GRENOBLE AND SAINT-MARTIN-D'HÈRES BETWEEN JANUARY 2010 AND DECEMBER 2017 (Bq/sec kg before 2015 and Bq/kg fresh since 2015)**



Dosimetric evaluation

According to mean ambient tritium activity levels measured by IRSN in 2017 (0.18 Bq/m^3), the dose potentially absorbed by inhaling and transcutaneously by a person living at the location of the sampler would be approx. 0.05 µSv/year. Assuming that food grown locally is at equilibrium with this activity measured in the air, which is highly conservative due to the short distance to the site, and assuming local food consumption as described in chapter 8 of this document, the dose absorbed by eating local food would be approximately 0.034 µSv/year. Activity levels measured in water do not differ significantly from background radiation levels, therefore the dose potentially absorbed by drinking water is not taken into consideration. The total dose attributable to tritiated discharges from the ILL site would therefore reach a maximum value of approx. 0.084 µSv/year. This evaluation is almost identical to the figure calculated by ILL based on gaseous discharges from 2017: 0.083 µSv/year.

CEA DAM centre/Île-de-France region

The CEA-DAM site/Île-de-France region is located in the municipalities of Bruyères-le-Châtel and Ollainville in the south of the Essonne département, in the drainage area for the Orge river, one of the tributaries on the right bank of the Seine, upstream from Paris. This research site works towards the design of French nuclear weapons, as well as guaranteeing the operation and safety of these weapons, using simulations. The site aims to prevent the spread of nuclear weapons and terrorism, and especially oversees the application of international treaties. The nuclear activities of this site were transferred to the Valduc site in 1996.

The site has continued to be purified and decommissioned since 1997. Tritium is discharged as part of these operations and is the only radionuclide which is authorised for discharge from this site. The activity levels discharged have been constantly decreasing since 2003, particularly since 2011 for atmospheric release (see figure 2). Gaseous discharges are tested using bubblers installed on two outlets (CH1 and CH2). Tritium is also detected in liquid effluents discharged from the site in both industrial fluids and rainwater. The tritium content of liquid discharges fell by a factor of 4 between 2007 and 2009. Discharges are now relatively constant and slightly above 0.5 GBq/year (see figure 3). The industrial effluents treated and rainwater are all discharged into Grand Rué steam, which then flows to the Rémarde stream, the receiving environment for liquid effluents discharged from the INBS.

The atmosphere (precipitation and gases), terrestrial (plants and food) and aquatic (sediments, flora and fauna, river and ground water) components are covered by environmental monitoring programmes.

FIGURE 1 / **LOCATION OF THE CEA-DAM SITE /ÎLE-DE-FRANCE REGION AND SAMPLING POINTS**

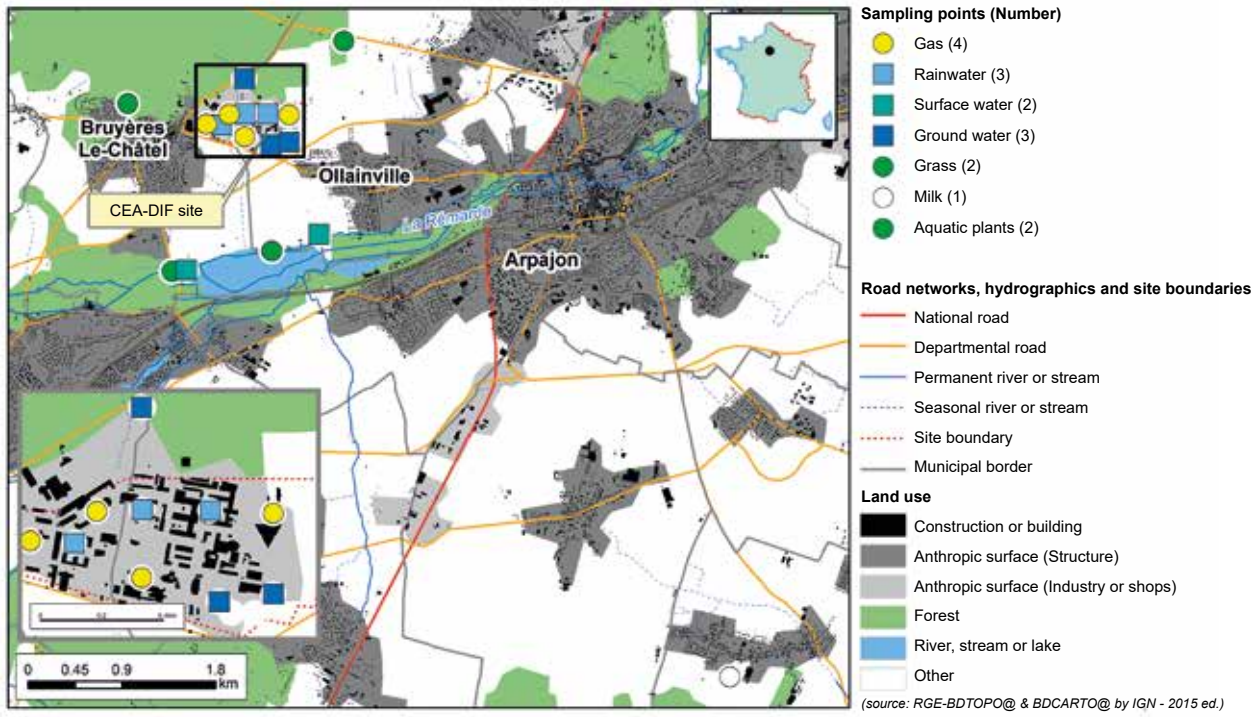


FIGURE 2 / **VARIATION IN GASEOUS TRITIUM DISCHARGES FROM THE CEA-DAM SITE/ÎLE-DE-FRANCE REGION (TBq/year)**

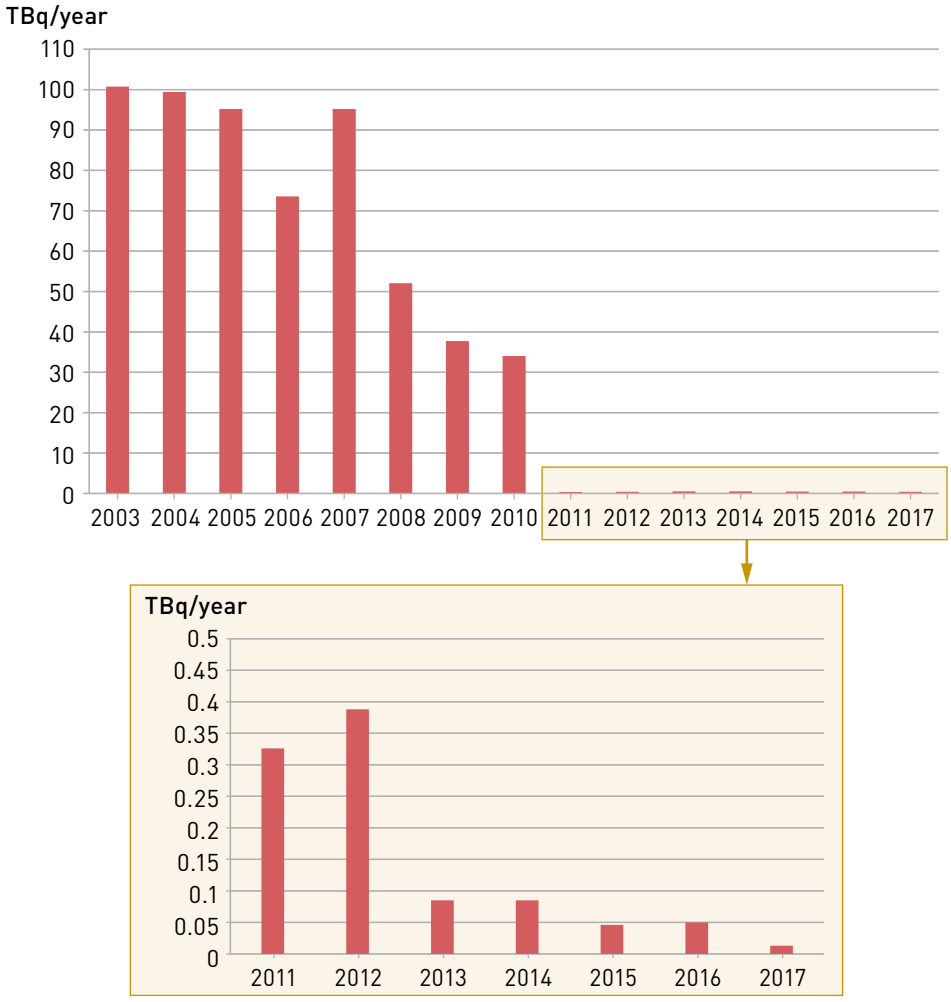
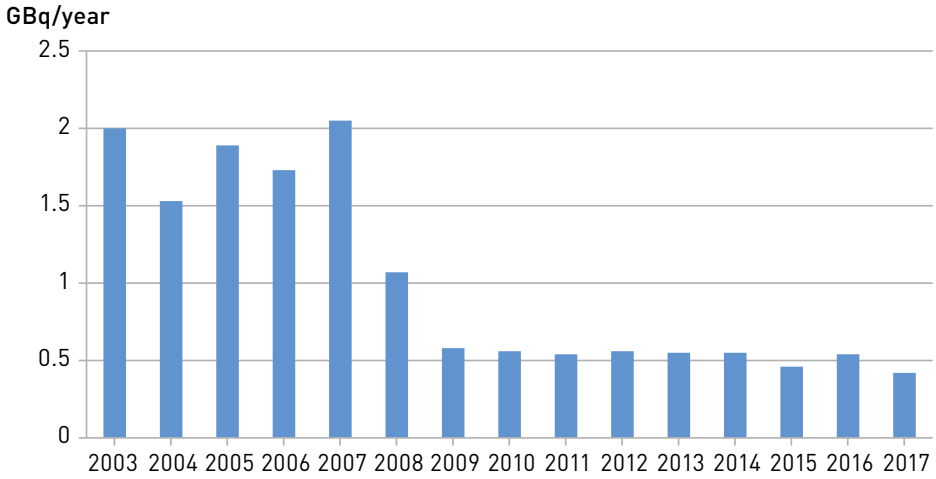


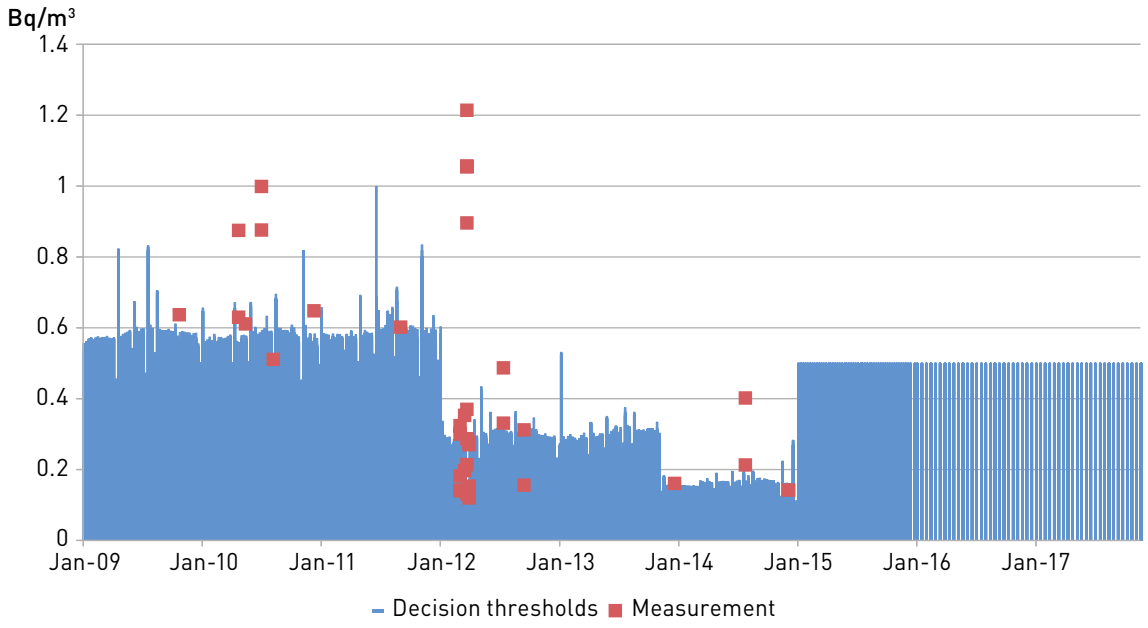
FIGURE 3 / **VARIATION IN LIQUID TRITIUM DISCHARGES FROM THE CEA-DAM SITE/ÎLE-DE-FRANCE REGION (GBq/year)**



The impact of gaseous tritium discharges can occasionally be detected in the atmosphere, as tritiated gas (HT) and tritiated water vapour (HTO), thanks to the bubblers set up at the four cardinal points around the site (see figure 4) up to 2013 and at the east and west points since that time. Total tritium was monitored up to October 2013, and then HT and HTO forms were monitored after this date. Up to October 2013, according to the few tritium measurements obtained for both HT and HTO, the contributions of these two forms were similar.

Ambient tritium concentrations have decreased since 2009 in parallel with the drop in tritium discharges. A few values above the decision threshold were obtained in 2014. These measurements were weak (max. 0.4 Bq/m^3) but well above background radiation levels (0.01 Bq/m^3) highlighting the effects of the discharges from the CEA DAM site/Île-de-Fance region. The decision threshold was increased to approximately 50 times background radiation levels for atmospheric tritium in January 2015. On this basis, such levels cannot be detected and analyses do not decisively indicate if site discharges potentially affect the area.

FIGURE 4 / **AMBIENT TRITIUM ACTIVITY BY VOLUME NEAR TO THE CEA-DAM SITE /ÎLE-DE-FRANCE REGION BETWEEN JANUARY 2009 AND DECEMBER 2017 – BUBBLERS AT THE NORTH, SOUTH, EAST AND WEST SAMPLING STATIONS - TOTAL TRITIUM UP TO OCTOBER 2013 FOLLOWED BY HTO TRITIUM (Bq/m^3)**



Tritium can also be detected in rainwater samples taken from near to the site (see figure 5). The maximum activity level recorded between late-2014 and 2017 reached 63 Bq/L versus 208 Bq/L for the period running from 2011 to late-2014. The decision threshold was raised from 5 to 10 Bq/L from January 2015, which meant that tritium was only measured and characterised in rain on 7 occasions. If the same approach had been applied between July 2011 and 2014, the number of significant measurements would have decreased by approx. 60%. Despite this, as is the case for atmospheric tritium, levels in precipitation generally dropped due to reduced discharges.

The CEA's surface water monitoring programme, organised on a monthly basis for lakes and similar, and on a weekly basis for Grand Rué stream, was stopped in late-2013. Prior to this time, tritium levels in Grand Rué stream varied cyclically with higher values in summer and lower values over the winter (see figure 6). Such variation was caused by substantial differences in flow rate for the Grand Rué stream, meaning that dilution was less likely at the very low water flow reached over the summer. Once again, the general trend was caused by a reduction in discharges, particularly for liquid effluents. Tritium was detected in Remarde stream on 4 occasions in 2014, with measurements at 6 Bq/L or less. The decision threshold was raised from 5 to 10 Bq/L from January 2015, which meant that any traces of tritium could no longer be detected in the Rémarde river and the potential impact of residual liquid discharges in the aquatic environment could not be determined. Half-yearly ground water samples have also been taken at the site, and tritium measurements taken upstream (1 point) and hydrogeologically downstream from the site (2 points), since 2016.

FIGURE 5 / **TRITIUM ACTIVITY BY VOLUME IN RAINWATER NEAR TO THE CEA-DAM SITE / ÎLE-DE-FRANCE REGION BETWEEN JANUARY 2009 AND DECEMBER 2017 (Bq/L)**

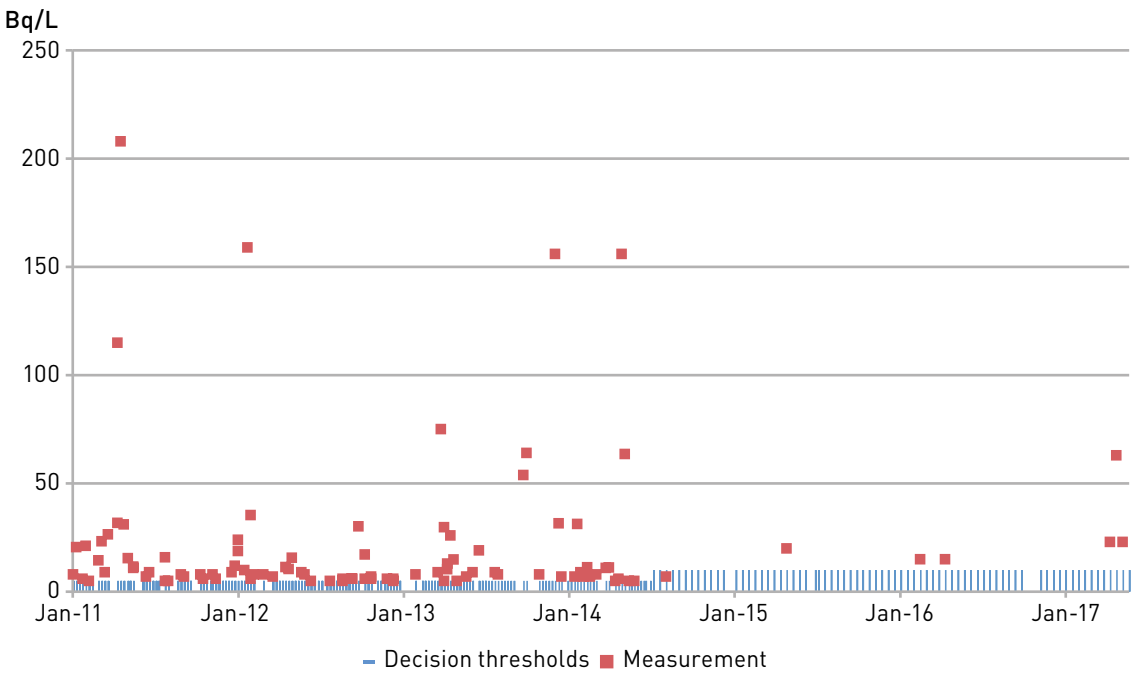
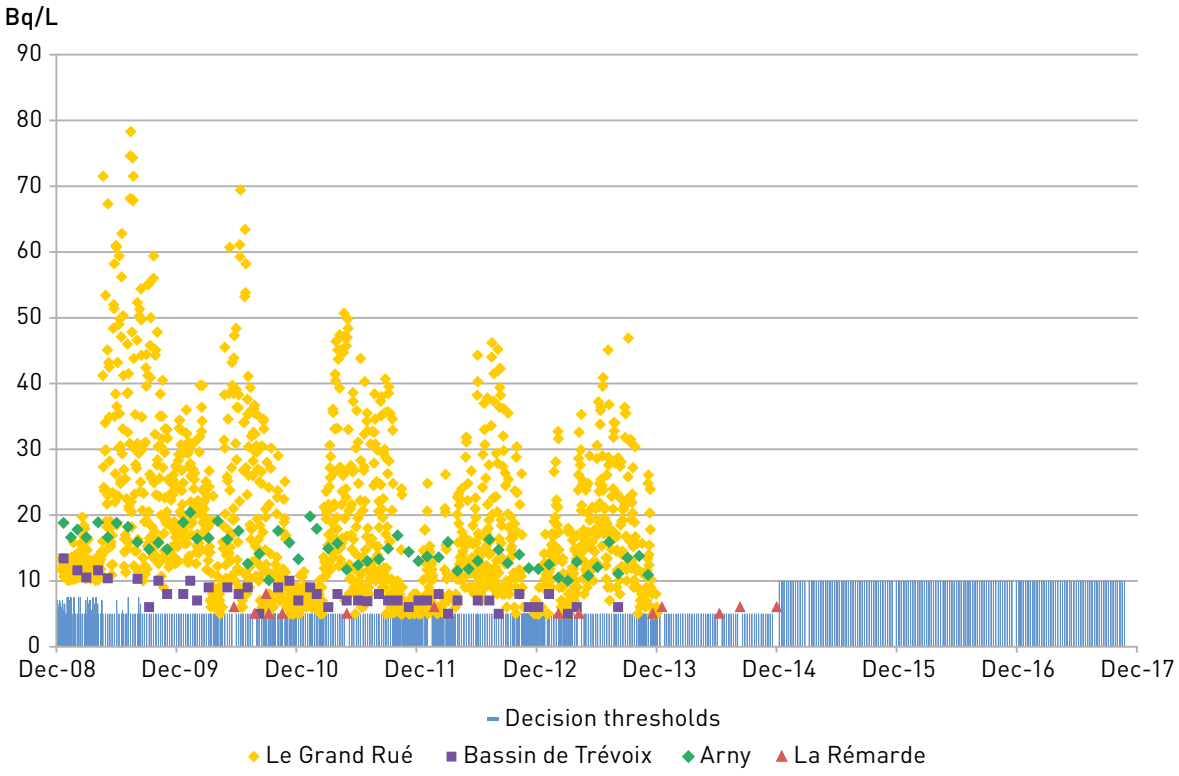


FIGURE 6 / **TRITIUM ACTIVITY BY VOLUME IN SURFACE WATER SAMPLES TAKEN NEAR TO THE CEA-DAM SITE / ÎLE-DE-FRANCE REGION BETWEEN JANUARY 2009 AND DECEMBER 2017 (Bq/L)**



Grass sample analysis results are generally below decision thresholds (only two significant values were recorded in the period running from late-2014 to December 2017, of 8.5 and 9.8 Bq/kg fresh respectively). Such occasional contamination reflects atmospheric discharges from the site. All other measurements taken in the immediate environment of this site are either natural radioactivity (^{40}K, ^{7}Be, etc.) or residual fallout from the Chernobyl accident or the testing of nuclear weapons (^{137}Cs).

Dosimetric evaluation

According to the radiological monitoring results for the immediate environment of the CEA site at Bruyères-le-Châtel, site discharges only affect tritium levels due to atmospheric release. However, due to the continuous decrease in discharge levels, combined with the progressive reduction in residual tritium in the environment, and increased decision thresholds, tritium levels in the environment can no longer be quantified and the dose inherent to the presence of tritium around the CEA DAM site/Île-de-France region cannot be evaluated.

Saclay site

The Saclay site is located in the Essonne département around twenty kilometres from Paris (see figure 1). The site covers a surface area of 125 ha and is home to eight basic nuclear facilities. The largest CEA sites: Orphée reactor (neutron beam reactor), LECI (irradiated fuel research laboratory) and the gamma irradiator, Poséidon. Curium/CIS-Bio international (manufacturer of products used for medical nuclear applications) and the organic molecule marking laboratory are also located at the site. The Osiris reactor was shut down on 16 December 2016.

Discharges and monitoring plans

Figure 2 shows variation in liquid and gaseous discharges over the 2014-2017 period. The activity levels of annual gaseous discharges are relatively constant over time, with the exception of β-γ emitters. In addition to the noble gases, which dissipate in the air and have no effect on the other environmental components, tritium is the main content of both gaseous and liquid discharges by far.

After treatment, the liquid effluents produced by the site are routed *via* the Mineurs aqueduct to Étang Vieux and then *via* the overflow to Étang Neuf. The effluents then join Vauhallan stream, a tributary of Bièvre river (see figure 1).

Table 1 shows the radiological monitoring plans for the environment applicable to the area around the Saclay site and drafted by CEA and IRSN.

FIGURE 1 / **MAP SHOWING THE LOCATION OF THE SACLAY SITE**

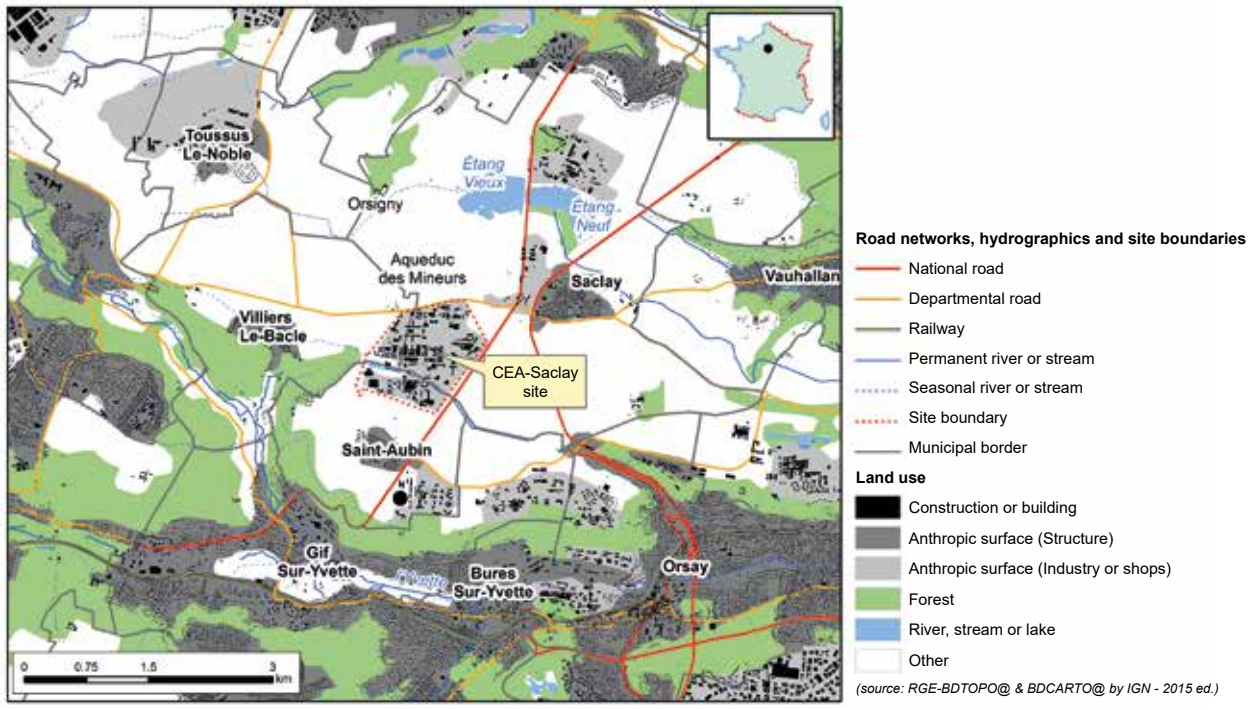
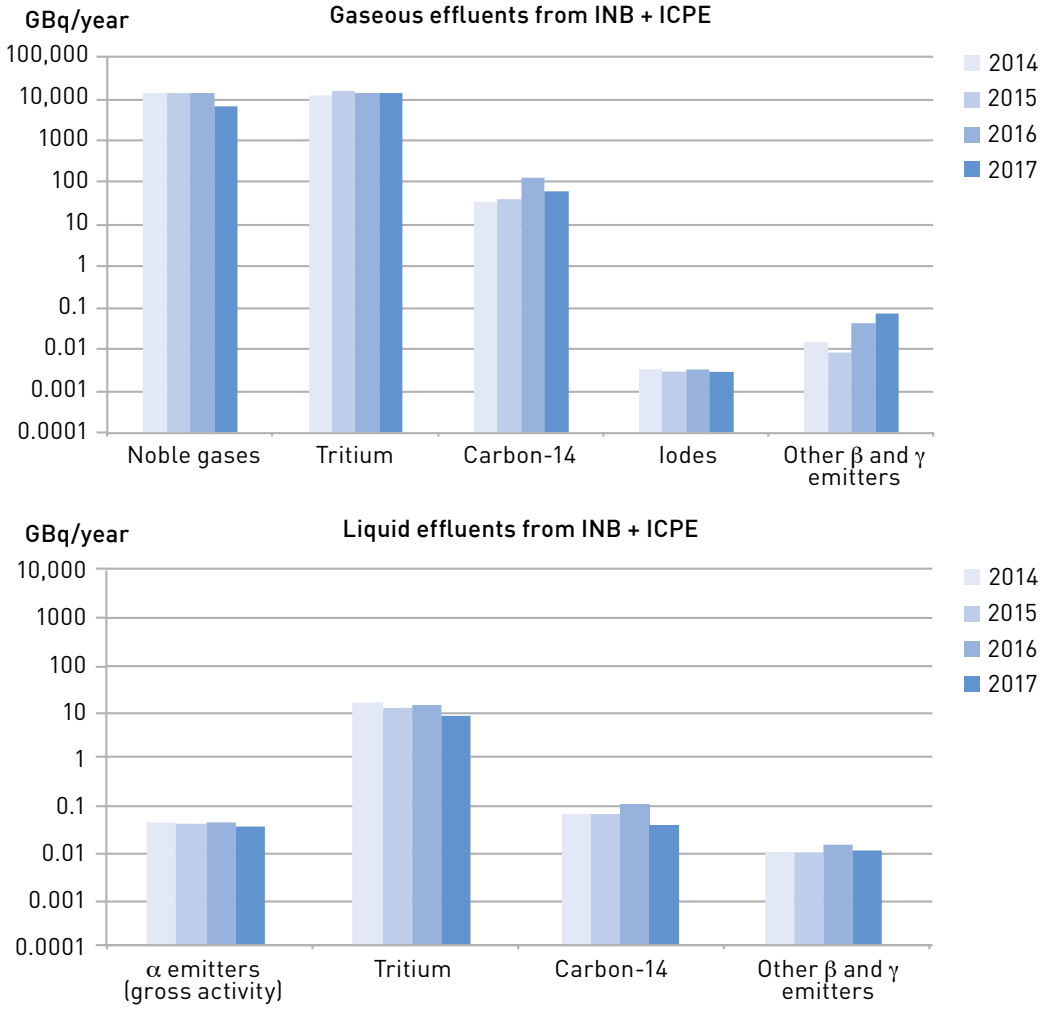


FIGURE 2 / **GASEOUS AND LIQUID DISCHARGES FROM THE SACLAY SITE OVER THE 2008-2013 PERIOD (GBq/year)**



© CEA

Saclay site

TABLE 1 / **MONITORING PLANS FOR THE SACLAY SITE**

Environment monitored or type of testing	CEA	IRSN
Soil air	• 6 continuous sampling points; 4 gross α and β measurements	–
Ambient gamma radiation	• 6 points in the immediate environment + 21 points at the perimeter fence	• 1 point
Soil air	• 4 weekly sampling points; ^{3}H and ^{14}C measurements	• 2 continuous aerosol samplers at flow rates of 7 and 700 m^3/h with 1 γ spectrometry analysis per week
Rain	• 2 weekly and monthly sampling points; ^{3}H and gross β measurements	• 1 sampling point and a monthly ^{3}H measurement
The receiving environment for liquid effluents discharged (water and sediments)	• 14 continuous sampling points, weekly to monthly analyses for ^{3}H, gross α and β activity, potassium, U, Sr and γ spectrometry	• Water: 5 sampling points and a 6-monthly measurement for: ^{3}H, gross α and β, potassium, Uiso, Sr and γ spectrometry • Sediments: 1 sampling point and a 6-monthly measurement for Pu, Am, and Sr; γ spectrometry • Aquatic flora and fauna: free and organically-bound ^{3}H, ^{14}C and γ spectrometry
Ground water	• 23 monthly to annual sampling points; ^{3}H and gross α and β measurements	• 2 sampling points and 6-monthly measurements at each point for ^{3}H, gross α and β activity and potassium
Milk	• 2 monthly sampling points; free and organically-bound ^{3}H, ^{129}I and ^{90}Sr measurements and γ spectrometry	• 1 quarterly sampling point and 1 free ^{3}H, ^{129}I measurement and γ spectrometry
Plants (fruit, vegetables, grass)	• 9 monthly sampling points; γ spectrometry, organically-bound and free tritium and ^{90}Sr	• 6 annual sampling points with free and organically-bound ^{3}H, ^{14}C and γ spectrometry
Cereals	–	• 1 annual sampling point and 1 organically-bound ^{3}H measurement and γ spectrometry

The impact of the Saclay site on its immediate environment and public exposure

Tritium

According to environmental monitoring results, the area is contaminated by tritium from discharges. Tritium activity levels in excess of natural background radiation levels or old residual fallout (see chapter 2), are therefore detected in all environmental components. The air sample analyses performed at the Saclay, Saint-Aubin, Villiers-le-Bâcle and Orsigny samplers detect tritium as water vapour (HTO) and tritium as a gas (HT and organic forms such as CTH3) (see figure 3). Ambient tritium activity by volume levels for these 4 samplers is generally below decision thresholds (≈ 0.12 Bq/m^3), but occasionally detected at levels which are well above the current background radiation levels for atmospheric tritium (approx. 0.01 Bq/m^3 of air for tritiated water vapour). Maximum tritium activity in water vapour between 2014 and 2017 was measured in a sample taken at Saint-Aubin in 2015: 0.81 Bq/m^3 (see figure 3); the highest value for tritiated gas forms (HT + organic forms) was obtained for a sample from Orsigny: 1.9 Bq/m^3.

In the same way, while most of the tritium activity measurements for rainwater are below the decision threshold, activity measurements occasionally exceed background radiation levels (1 - 3 Bq/L): between 4.3 Bq/L and 320 Bq/L (see figure 4).

FIGURE 3 / **TRITIUM ACTIVITY MEASURED IN THE AIR (HTO + TRITIATED GASES) SAMPLES TAKEN AT THE MONITORING POINTS IN THE IMMEDIATE VICINITY OF THE CEA SITE AT SACLAY (Bq/m³)**

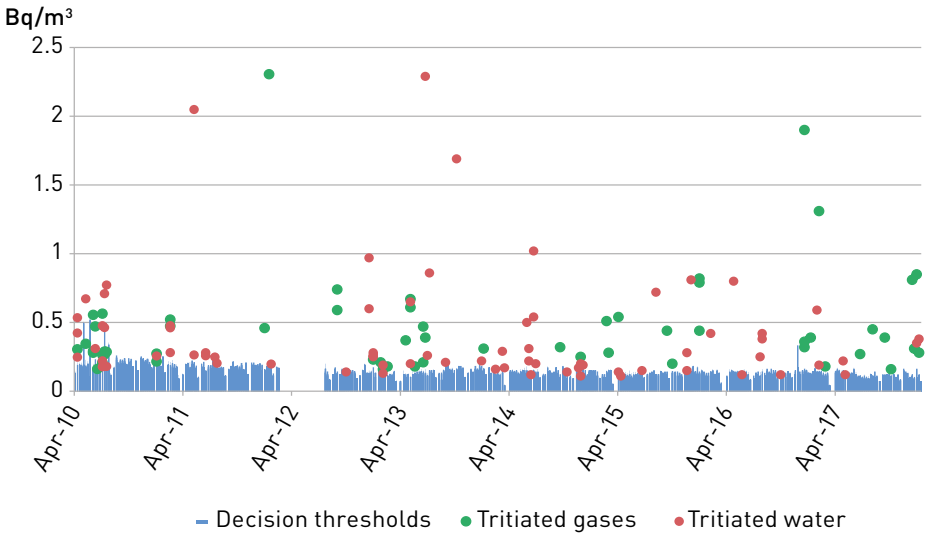
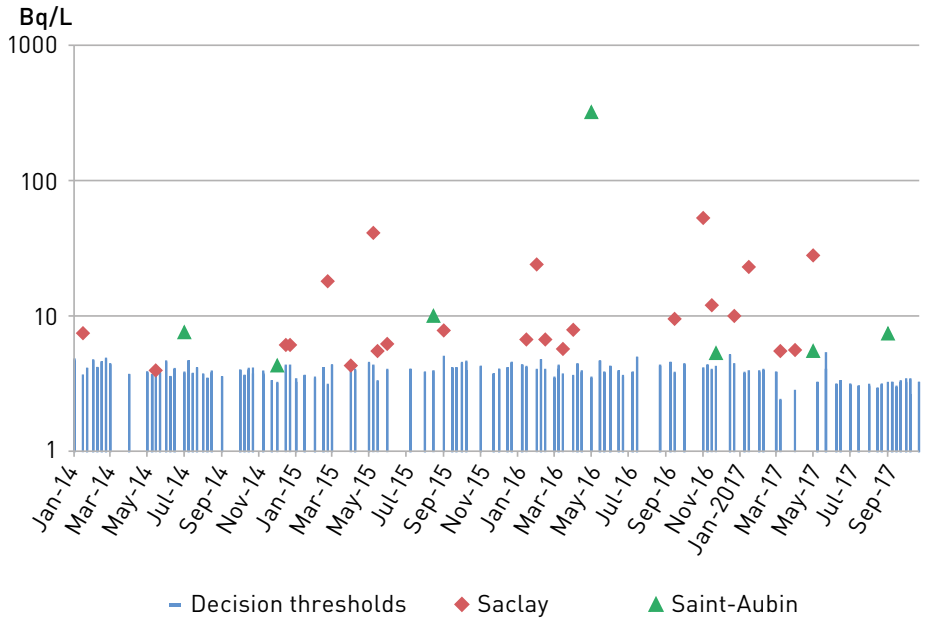


FIGURE 4 /TRITIUM **ACTIVITY MEASURED IN RAINWATER SAMPLES COLLECTED AT SAMPLING STATIONS NEAR TO THE CEA SITE AT SACLAY (Bq/L)**



Due to these occasional tritium activity measurements for both air and rainwater, tritium activity levels in fruit, grass and milk can also exceed background radiation levels (from less than 1 to 3 Bq/L or Bq/kg fresh; see figure 5).

Discharges from the Saclay site also affect the immediate aquatic environment Tritium activity in the Mineurs aqueduct, which transfers effluents discharged from the site, varied from 3.3 to 73 Bq/L over the 2015-2017 period, with a mean activity level of 13.4 Bq/L (see figure 6). The same is true of lake water samples, where the mean tritium activity by volume over the same period reached 10 Bq/L (see figure 7).

FIGURE 5 / **FREE TRITIUM ACTIVITY MEASURED IN MILK, GRASS AND FRUIT SAMPLES COLLECTED IN THE IMMEDIATE ENVIRONMENT OF THE CEA SITE AT SACLAY**

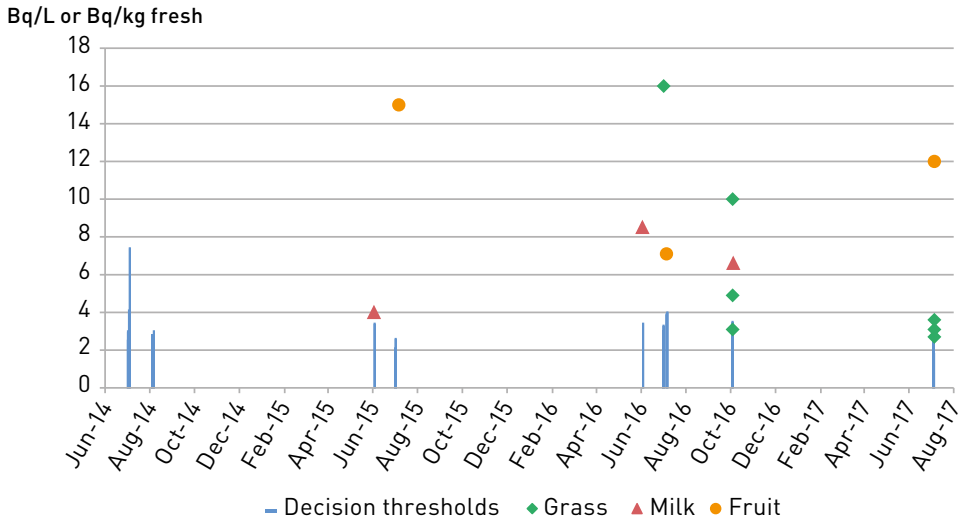


FIGURE 6 /TRITIUM **ACTIVITY MEASURED IN WATER ROUTED VIA THE MINEURS AQUEDUCT AT THE ETANG VIEUX (Bq/L)**

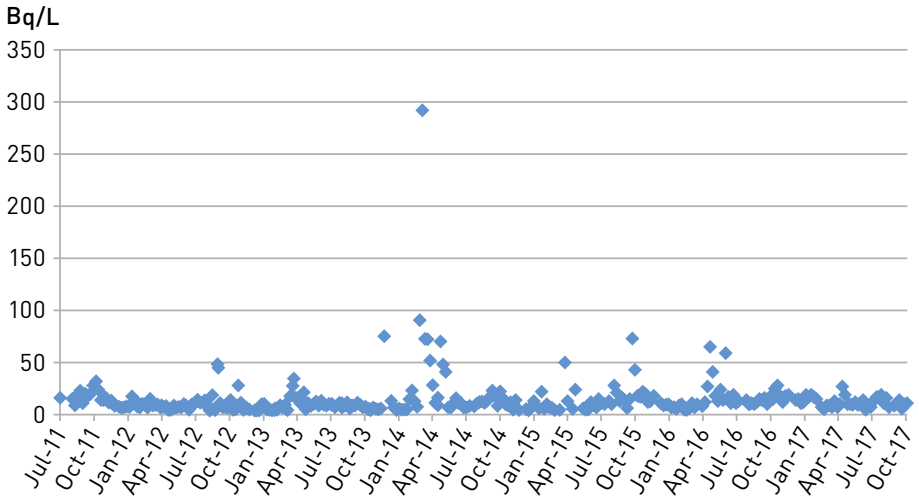
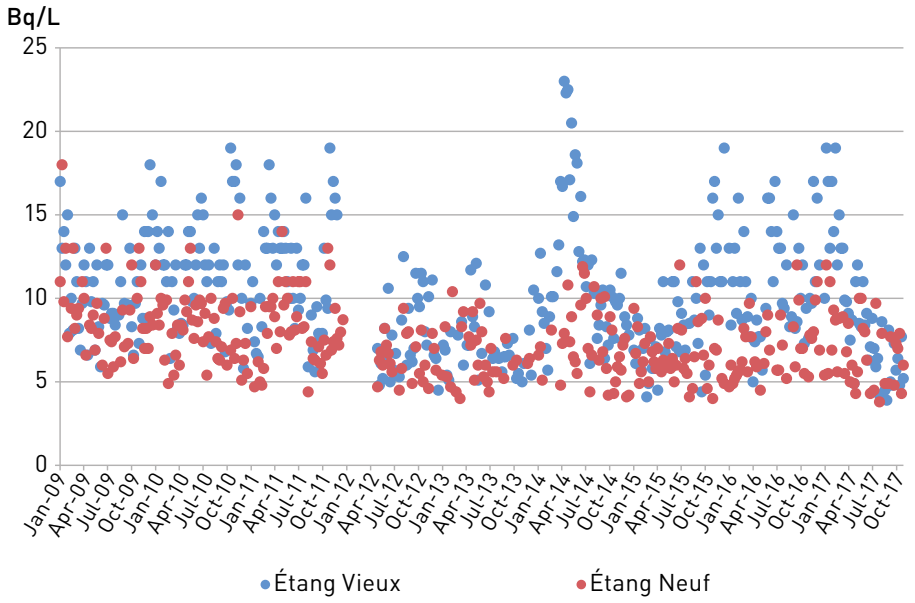


FIGURE 7 / **FREE TRITIUM ACTIVITY IN WATER FROM ETANG VIEUX AND ETANG NEUF (Bq/L)**



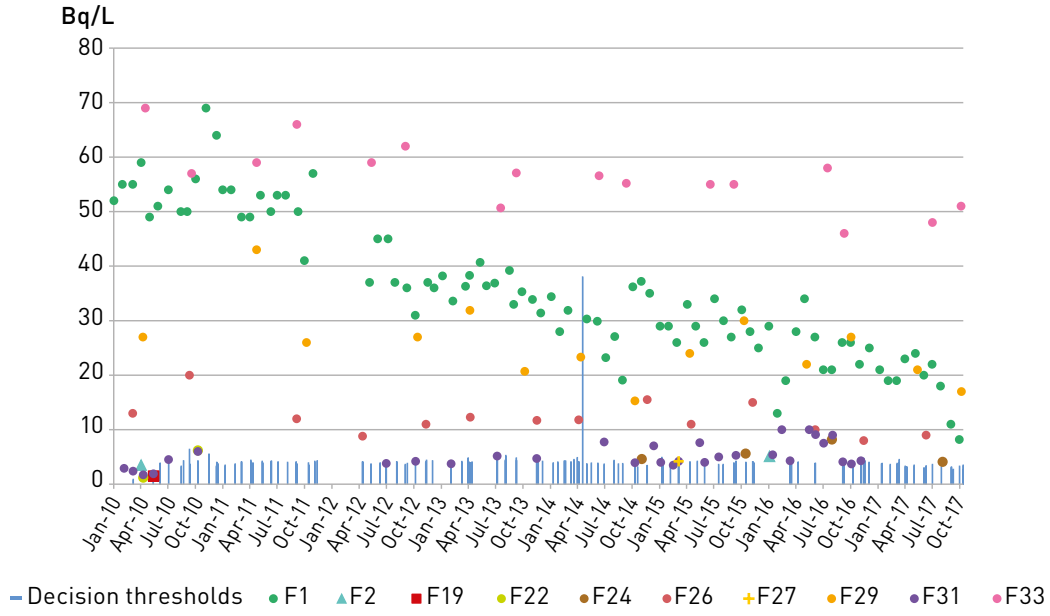
This configuration cannot be identified based on free tritium levels measured in fish and reed samples from the lakes, which are similar to or very slightly above background tritium radiation levels in the immediate environment (1 - 3 Bq /L). On the other hand, organically-bound tritium activity (41 Bq/L) in a fish sample taken in 2017 was above this background radiation as the fish had incorporated tritium throughout its life. This measurement reflects both the past and current contributions of tritiated discharges from the Saclay site.

In the past, CEA uploaded tritium data for ground water samples, acquired using piezometers at the Saclay site, to the RNM database, demonstrating that ground water contamination reached up to 60 Bq/L. This data is no longer available. Despite this, ground water samples taken between 2014 and 2017 off the CEA site have led to tritium activity levels above background radiation, for several piezometers. Mean tritium concentrations represent 13 Bq/L, which is above the background radiation levels for this radionuclide in the immediate environment (1 - 3 Bq/L). We also take note that the activity levels measured in the ground water samples most affected by site discharges are constantly falling (the decrease is more substantial in borehole F1 than the others; see figure 8).

The dosimetric impact of gaseous and liquid effluents discharged containing tritium over the 2015-2017 period could only be calculated for individuals eating local food and drinking local water. In fact, due to the very high number of measurements below the decision threshold in the atmosphere, the doses absorbed by inhaling or transcutaneously could not be calculated. The standard profile assumed is an adult obtaining 100% of their drinking water from a well down to the Fontainebleau sands ground water, eating 5.3 kg[1] of fish per year from Étang Neuf, and purchasing local vegetables and meat/eggs/dairy products. On the basis of the above assumptions, the dose absorbed by this individual would reach 0.15 µSv/year, 99% of which would be due to drinking water. This dose is calculated based on measurements taken during the 2014-2017 period and matches the figures estimated by CEA for 2016 based on discharges: between 0.11 and 0.22 µSv/year for an adult (tritium represents between 10 and 20% of the total dose received by an adult, i.e. 1.1 µSv/year, as estimated by CEA in the 2016 report on nuclear safety and transparency).

1. This value is proposed by InVS-Anses and Afssa for the annual consumption of freshwater fish.

FIGURE 8 / **VARIATION IN TRITIUM CONCENTRATION IN GROUND WATER FROM THE SACLAY PLATEAU (Bq/L)**



Carbon-14

The terrestrial environment around the Saclay site is little affected by atmospheric discharges of carbon-14. Ambient activity was never quantified prior to 2015. Since that time, CEA has regularly measured ambient carbon-14, mainly as HTO, thanks to the lower decision threshold. Activity by volume in this form represents 0.049 Bq/m^3 for the period studied.

Thanks to these metrological improvements, carbon-14 can also almost systematically be measured in milk, grass and fruit samples (figure 9). While mean activity in milk and fruit samples (18.6 Bq/L and 15.7 Bq/kg fresh respectively) cannot be differentiated from background radiation for carbon-14 (approx. 14 to 15 Bq/L or kg fresh), the same is not true for grass. In fact, the results obtained vary from 69 to 210 Bq/kg fresh over the period studied, with a mean value of 139 Bq/kg fresh, which is over 10 times greater than background radiation. This radionuclide was rarely detected between 2010 and 2015 (for 3 out of 19 measurements), but such observations confirm that site discharges had already contaminated this component.

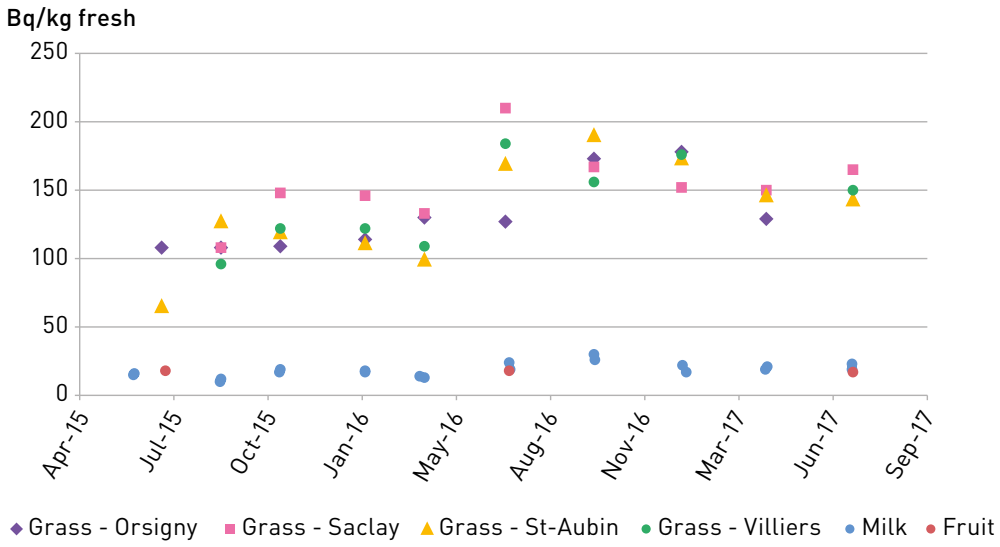
Although annual liquid discharges containing carbon-14 were also limited, according to the study completed over the 2011-2014 period, the activity levels measured in fish samples captured in Étang Vieux and Étang Neuf were very high. Only two fish samples were taken between 2014 and 2017, and analysed in 2017. Mean activity by mass, of 480 Bq/kg fresh, is similar to that calculated during the previous period (494 Bq/kg fresh). These results for this radionuclide can be compared with natural background radiation in fish, which is approx. 22 Bq/kg fresh. The fish taken (carp and catfish) live for a long time, which means that carbon-14 activity probably accumulates over several years, potentially even several decades, of discharges.

Fishing is not authorised in Étang Vieux, which is classed as a ZNIEFF[2]; fishing is, however, authorised in Étang Neuf. If a person eats 5.3 kg/year[3] of fish captured in Étang Neuf, with a mean additional activity of 458 Bq/kg, they will absorb a dose of 1.4 µSv. This mean figure is similar to that calculated for the previous radiological report for the 2011-2014 period. This figure is higher than the CEA's estimate in its 2016 report on nuclear safety and transparency: 0.36 µSv/year assuming that the person eats 8 kg/fish each year.

2. Area with a natural ecological, flora- or fauna-based interest.

3. This value is proposed by InVS-Anses and Afssa for the annual consumption of freshwater fish.

FIGURE 9 / **CARBON-14 ACTIVITY BY MASS MEASURED IN THE TERRESTRIAL ENVIRONMENT BETWEEN 2015 AND 2017**



This difference is probably due to the fact that CEA estimates are based on annual discharges, while the carbon-14 activity levels measured in fish and the inherent potential doses are accumulated over several years, or even decades.

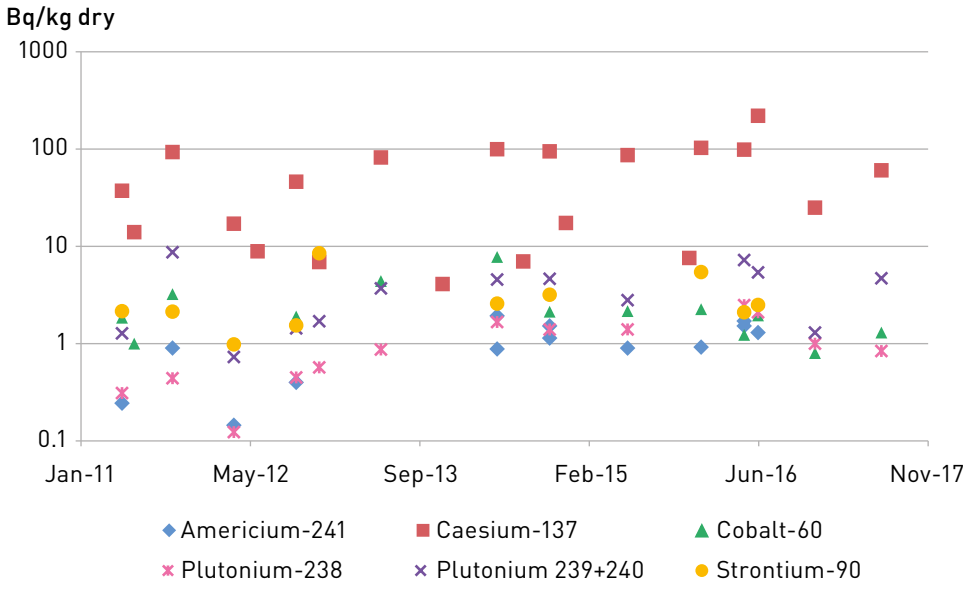
Other radionuclides

With the exception of residual caesium-137 from old fallout, analyses carried out on aerosol filter samples collected at IRSN's high-flow sampling station at Orsay generally led to values below the decision threshold. However, iodine-131 and cobalt-60 were occasionally detected, just like during the previous period. Iodine-131 was measured on 4 occasions during this period. The activities measured in January-February 2017 (0.14 and 0.19 µBq/m^3), part of this run, correspond to the arrival of masses of air from the continent, with higher contamination levels than usual, probably caused by discharges by the radiopharmaceutical industry amplified by weather conditions which were not conducive to dispersing any type of atmospheric pollutants.

The highest activity of 0.24 µBq/m^3 was measured on 17 February 2016 and was a local phenomenon, possibly attributable to discharges from the Saclay site, in the same way as the iodine-131 detected in October 2015 (0.16 µBq/m^3). The same assumption can be made for traces of cobalt-60 detected, ranging from 0.03 to 0.3 µBq/m^3, and measured on 7 occasions over the 2015-2017 period, which were very probably released from the Saclay site. These values are within the range of occasional measurements from the previous period (2011-2014).

According to analyses of sediment samples taken in the Mineurs aqueduct, caesium-137, cobalt-60, plutonium, strontium-90 and americium-241 (see figure 10) are present. Based on the presence of cobalt-60, the activity levels measured (which range from a few becquerel to several dozen or even hundreds of becquerel for caesium-137) and the ^{238}Pu/$^{239+240}$Pu activity ratio, which is 1.6 to 25 times that expected for global atmospheric fallout (approx. 0.03), these activity levels are generally attributable to past liquid effluents discharged from the site. This contamination by the aforementioned radionuclides is also detected in lake sediments, however at lower activity levels and/or less frequently.

FIGURE 10 / **ACTIVITY BY MASS FOR THE MAIN RADIONUCLIDES OF INTEREST IN THE SEDIMENT SAMPLES TAKEN IN THE MINEURS AQUEDUCT AT ETANG VIEUX (Bq/kg dry)**



Finally, out of all of the sediments collected from rivers downstream from lakes, only caesium-137 can be detected at levels similar to background radiation for this radionuclide.

Traces of caesium-137 and strontium-90 can still be detected in lake water. If caesium-137 can be detected, results do not exceed 3.9 mBq/L, while the mean value for strontium-90 represents 2.3 mBq/L for the period studied. ^{137}Cs levels in reeds reach 2.6 Bq/kg dry on average, compared with 0.8 Bq/kg dry for ^{90}Sr. Caesium-137 activity represents approx. 0.5 Bq/kg fresh in fish analysed in 2017, compared with 0.03 Bq/kg fresh for strontium-90. These values are detected due to past discharges from the CEA site and global atmospheric fallout.

Fontenay-aux-Roses site

The Fontenay-aux-Roses site (see figure 1) is located on the Fontenay-aux-Roses plateau in an urban area to the south/south-west of Paris (see figure 2). The basic nuclear facilities at this site were definitively shut down in 2007.

The purification programme for nuclear facilities and laboratories was started in 1999. The nuclear facilities have been replaced by operations focusing exclusively on life sciences.

FIGURE 1 / **FONTENAY-AUX-ROSES SITE**

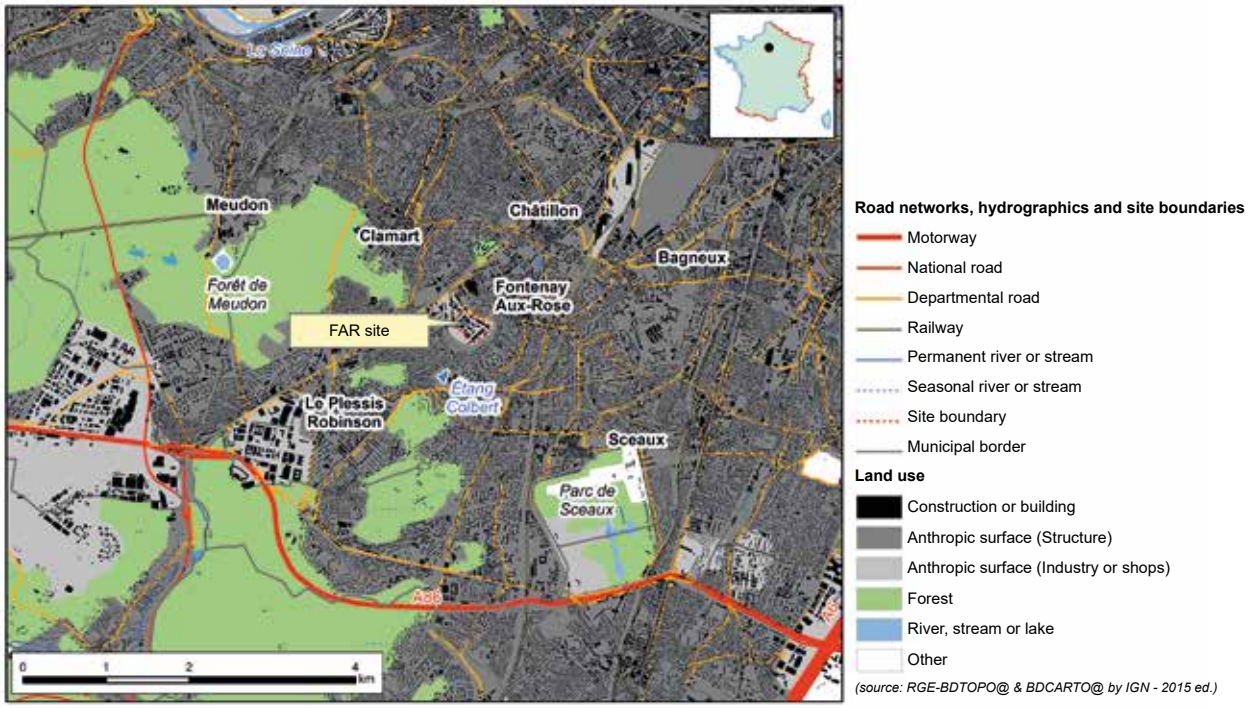
© CEA

Aerial view of the Fontenay-aux-Roses site

© CEA

Piezometer used to take ground water samples

FIGURE 2 / **LOCATION OF THE FONTENAY-AUX-ROSES SITE**



Radioactive discharges

The aerosols produced at the site are filtered by two very high efficiency (VHE) filters before being discharged into the environment. Radioactivity measuring devices are fitted at outlets for gaseous effluents. The effluents discharged can contain aerosols, noble gases and traces of halogens.

Continuous radioactivity measuring devices are used to monitor gaseous radioactive effluents from INBs. These devices are fitted in stacks, after VHE filters, and the pre-discharge filters. These devices determine the activity levels of beta-emitting aerosols and radioactive gases in real time. Real-time test monitors are fitted on nine outlets to monitor the activity levels of beta-emitting aerosols, five of which also test alpha-emitting aerosols. Four of these monitors are fitted with a device for the continuous measurement of radioactive gases.

Measuring results for noble gases based on these test monitors are all below detection limits. The total beta "halogen + aerosol" activity discharged has been less than or equal to 0.002 GBq since 2015 (see figure 3).

No liquid effluents from the laboratories of the former INBs likely to contain radioactive elements are discharged without prior authorisation. Liquids containing radioactive substances are collected in tanks and then routed to a nuclear treatment centre. All other effluents are collected in buffer tanks, and then transferred to the urban sewerage system after obtaining authorisation and checking compliance with the applicable regulations (activity by volume, total activity discharged, chemical conformity of the effluent). Radioactive test devices are fitted at the test station for effluents in the urban sewerage system, located immediately downstream from the facility, as well as a continuous sampling device used to collect samples which are representative of the effluents. The devices installed at the outlets, and on the urban sewerage system, run in real time, and an alarm system is connected to the environmental control panel at the Fontenay-aux-Roses site.

The radiological monitoring of liquid effluent transfers covers alpha emitters (total measurement), beta-gamma emitters (total measurement) and tritium.

Tritium activities by volume measured in the outlets used for liquid effluents transferred from the site regularly exceed 10 Bq/L, but cannot be attributed to site discharges (see figure 4). In fact, similar activity levels are measured in Seine river water, which supplies the Fontenay-aux-Roses facility. These levels are caused by discharges from the EDF facility at Nogent.

Radiological monitoring of the site environment

CEA provides around 6,000 measurements annually based on samples taken from all environmental components (air, water, soil). The atmosphere is monitored based on measurements for four fixed sampling stations (FAR Atmos, FAR 2, Clamart and Bagneux), located at distances of between 0.2 and 2 km around the centre. The air is monitored, including alpha and beta activity level measurements for dust samples collected using filters, the identification of halogens on sampling cartridges, ambient irradiation measurements and gaseous tritium measurements.

FIGURE 3 / **GASEOUS AND LIQUID DISCHARGES FROM THE FACILITIES AT THE FONTENAY-AUX-ROSES SITE OVER THE 2014-2017 PERIOD**

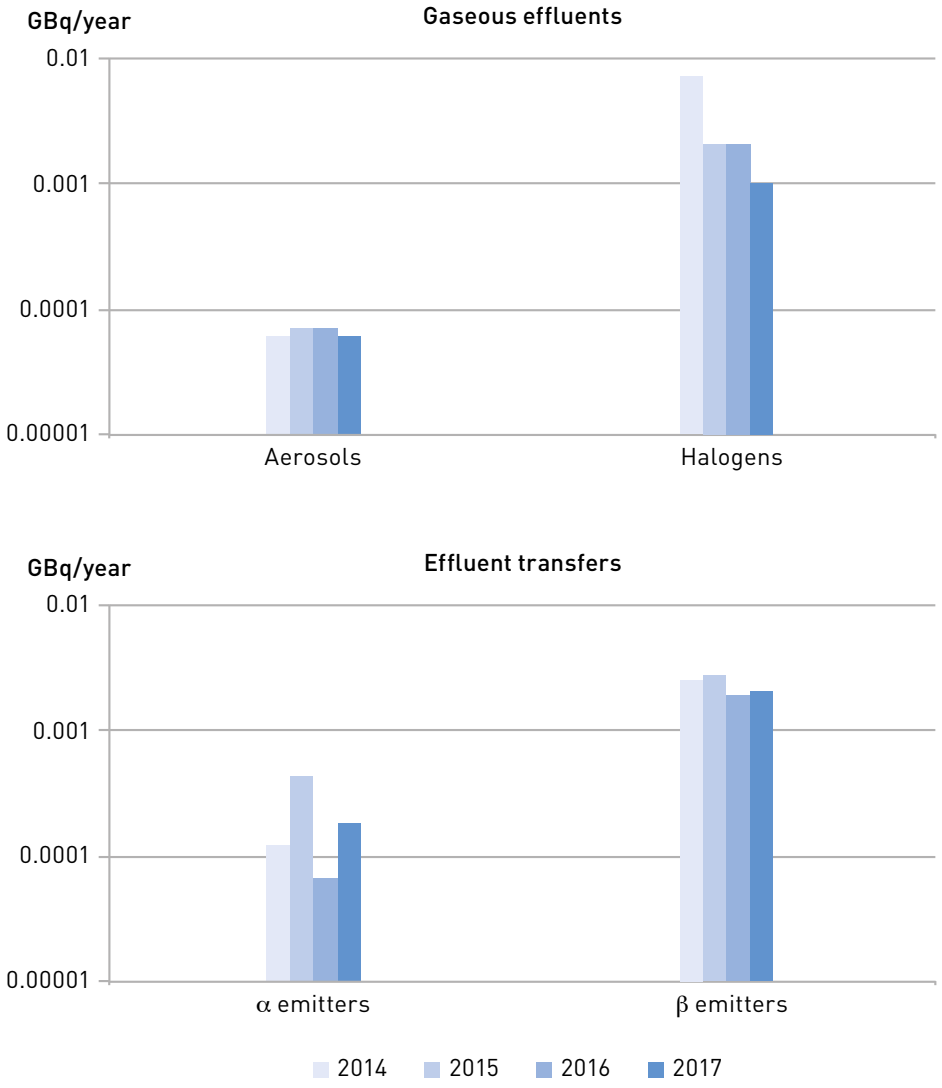
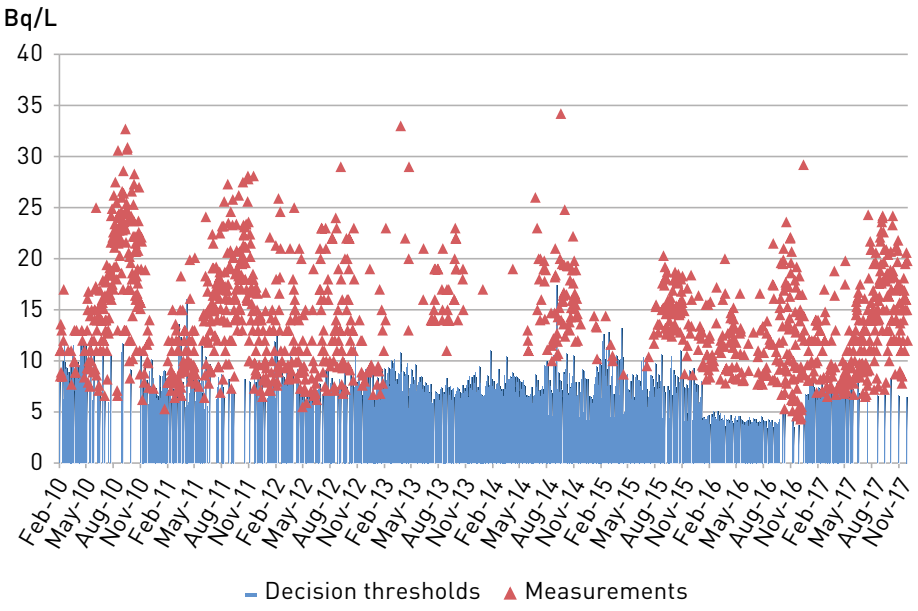


FIGURE 4 / **TRITIUM ACTIVITY MEASURED IN WATER SAMPLES TAKEN IN THE URBAN SEWERAGE SYSTEM FOR THE FONTENAY-AUX-ROSES SITE BETWEEN 2010 AND 2017 (Bq/L)**

Data: CEA



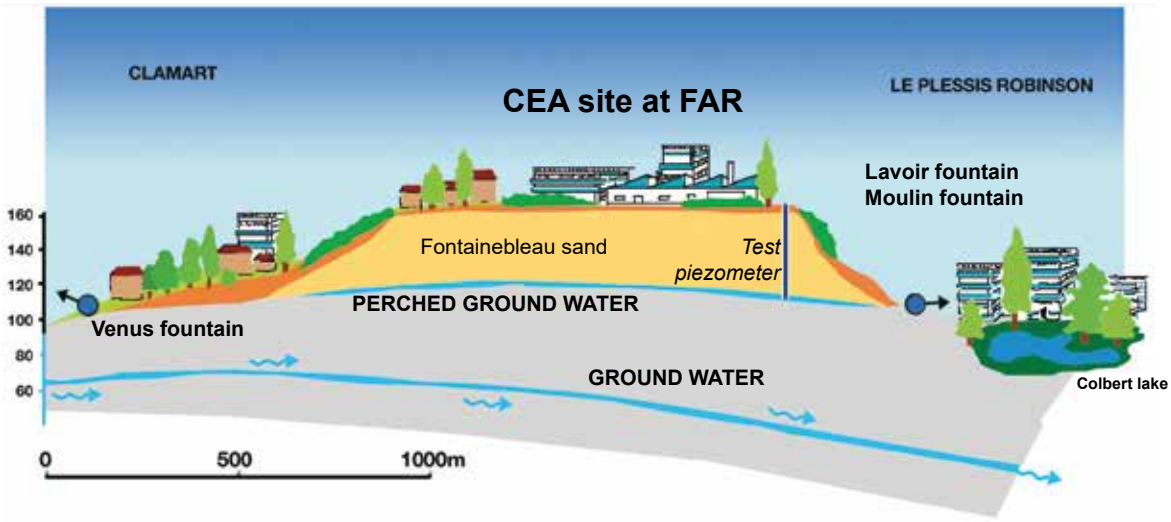
Radiological monitoring also focuses on water (rainwater, ground water and surface water) using measurements taken in the immediate environment of the facility. Rainwater samples collected using rain gauges (2 x 1 m² rain gauges and 2 rain gauges with a collection area of 0.04 m²) are used to measure gross alpha and beta activity and tritium.

Perched ground water is located at a depth 65 metres above general ground water (see figure 5), and is monitored on a monthly basis with samples taken in six bore holes (piezometres) and analysed by laboratories. The perched ground water emerges at two points: Lavoir fountain and Moulin fountain at Fontenay-aux-Roses, which are tested on a monthly basis. Periodic water and sediment samples are taken from Colbert lake near to the site for the purposes of monitoring surface water.

Sediment, soil and plant samples are taken to monitor and determine the impact of discharges on the immediate environment around the Fontenay-aux-Roses site (monthly plant samples are taken at four points located at off-site monitoring stations, annual soil and surface samples are taken at the site and at the four off-site monitoring stations).

FIGURE 5 / **SUB-SURFACE CROSS-SECTION OF THE FONTENAY-AUX-ROSES SITE**

Source: CEA



The impact of the Fontenay-aux-Roses site on its immediate environment

No measurement for the radionuclides targeted in gaseous form in the atmosphere (iodine-131, tritium), exceeds the decision threshold (0.2 mBq/m^3 for iodine-131 and 0.25 Bq/m^3 for tritium).

Tritium has only exceeded the decision threshold in rainwater samples collected near to the site three times since September 2014, with a maximum acitivity level of 7.2 Bq/L.

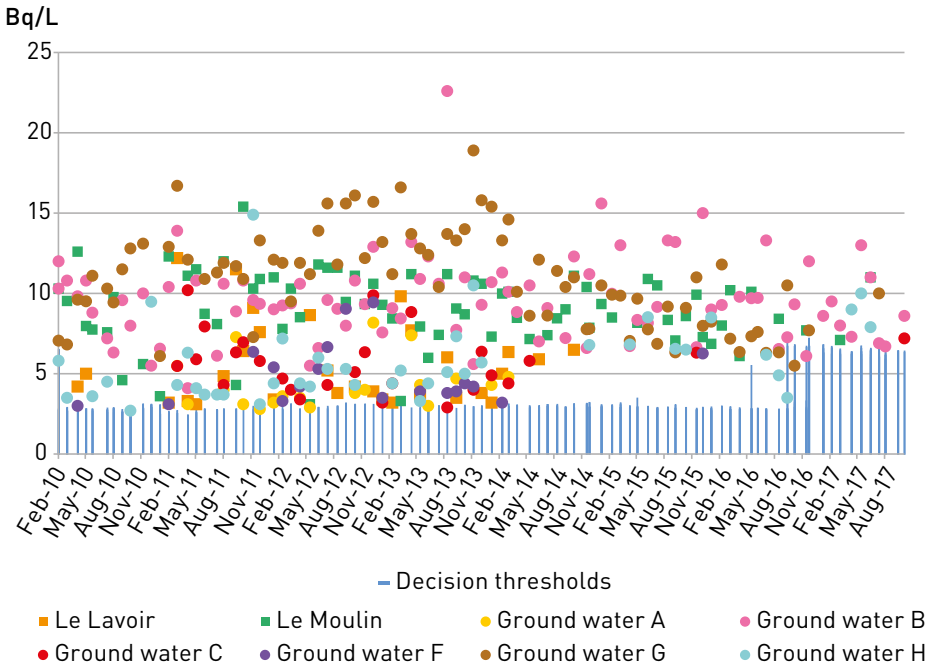
No artificial radionuclide was detected in an analysis of Colbert lake water samples. Tritium has not been detected since October 2014, despite having been measured at levels above the detection threshold in the past.

Tritium levels were measured between the detection threshold (3 - 7 B/L) and 15 Bq/L (figure 6) in perched ground water samples (points A, B, C, F, G and H) and samples from two points where springs emerge (Moulin fountain, Lavoir fountain). These results exceed background radiation in ground water and are attributable to past and current discharges from the Fontenay-aux-Roses site.

Grass sample results for the terrestrial component and food chain, for samples taken near to the Fontenay-aux-Roses site by CEA only indicate natural radioactivity (^{40}K, ^{7}Be, etc.). No activity levels were recorded above background radiation for the artificial radionuclides targeted during the study period.

FIGURE 6 / **TRITIUM ACTIVITY BY VOLUME MEASURED IN GROUND WATER NEAR TO THE FONTENAY-AUX-ROSES SITE BETWEEN JULY 2011 AND DECEMBER 2016 (Bq/L) AND THE ASSOCIATED DECISION THRESHOLDS (DT)**

Data: CEA



© F. Jannin/CEA

Taking samples using an aerosol filter

3.5. NUCLEAR NAVAL BASES

Four of the French Navy's military ports in mainland France are home to nuclear naval bases. These nuclear facilities are special in that they are geographically part of large urban areas: Toulon, Brest and Cherbourg.

These sites are responsible for hosting and providing local support for military vessels based at or transiting through the ports.

Brest military port and Île-Longue operational base

As the leading military port on the Atlantic coast, the military port in Brest (Finistère) is used to maintain and for stopovers for French military nuclear-powered vessels such as ballistic missile submarines (SNLE), attack submarines (SNA), and aircraft carriers.

An operating base at Île-Longue, to the south of the Brest naval base, is used to launch ballistic missile submarines, and represents a strategic ocean component for the purposes of dissuasion. All SNLE and the equipment fitting out sixteen intercontinental missiles are maintained at this site.

Cherbourg military port

The military port at Cherbourg (on the Channel) hosts the DGA (Direction Générale de l'Armement - Military procurement office), and is mainly dedicated to constructing or decommissioning nuclear-powered submarines (attack or missile versions).

In addition, the naval base at Cherbourg can host nuclear-powered submarines and vessels both docked and anchored.

Toulon military port

The military port at Toulon (Var) is the main French naval base, alongside of Brest. 70% of the French fleet is based here, including six attack submarines (SNA) and the "Charles de Gaulle" aircraft carrier. These vessels are all nuclear powered.

When at the site, the nuclear steam supply systems of the submarines and aircraft carriers are systematically stopped or set to very low power.

FIGURE 1 / **CHERBOURG NAVAL BASE**

© Marine nationale

Radioactive discharges

Radioactive effluents can potentially be discharged, with authorisation, as part of some nuclear operations carried out in military ports, such as through-life support for nuclear-powered vessels or major maintenance works on the steam supply systems of nuclear submarines.

These discharges are mainly likely to contain the following radionuclides: noble gases (krypton, xenon), tritium, carbon-14 and gamma emitters such as caesium-137 and 134 and cobalt-60.

Radiological monitoring of the environment

The analysis, monitoring and appraisal laboratories of the French Navy (LASEM) at each naval base and IRSN take samples as per a monitoring plan defined based on discharge properties, the environment and the features of the facilities for the purposes of monitoring the radiological profiles of sites.

The atmosphere is monitored at each site with continuous on-site measurements of ambient gamma dose rate via the French Navy's nuclear monitoring system (2SNM) and the IRSN's Téléray network, and using air and rainwater samples.

Military ports are also monitored with multiple regular samples taken in the aquatic environment (sea water, sediments, sand, shellfish, molluscs, fish, algae). These samples are analysed for gross beta and tritium activity and subjected to gamma spectrometry.

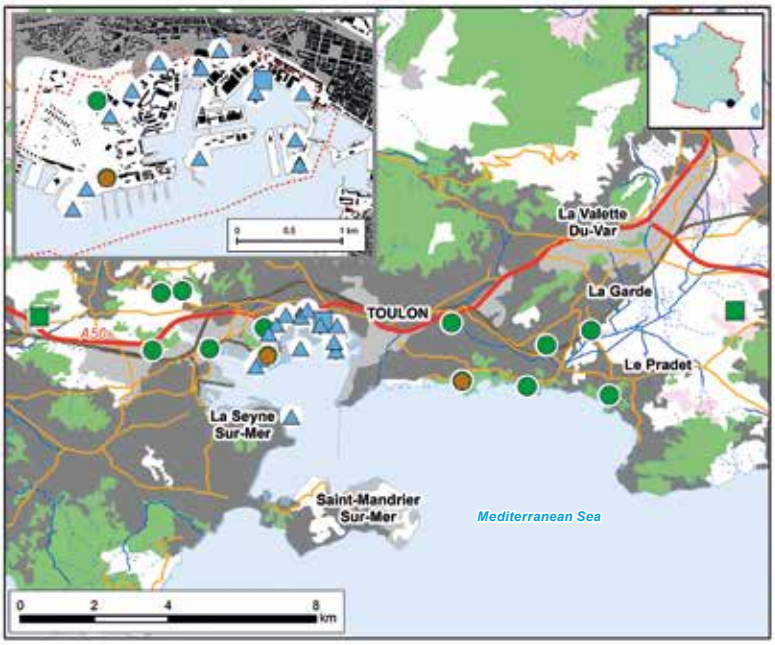
Milk and plant (grass, tree leaves) samples are taken as per the prevailing winds in the terrestrial environment. Samples of the main farming outputs (fruit, vegetables) are also taken from topsoil. Gamma spectrometry is performed and tritium activity is measured in terrestrial samples, and carbon-14 activity is analysed in plants and milk.

© Marine nationale

Take samples of ocean sediments

FIGURE 2 / **MONITORING PLAN FOR THE FRENCH NAVY'S SITE AT TOULON (2A) AND IRSN SITE (2B)**

2A



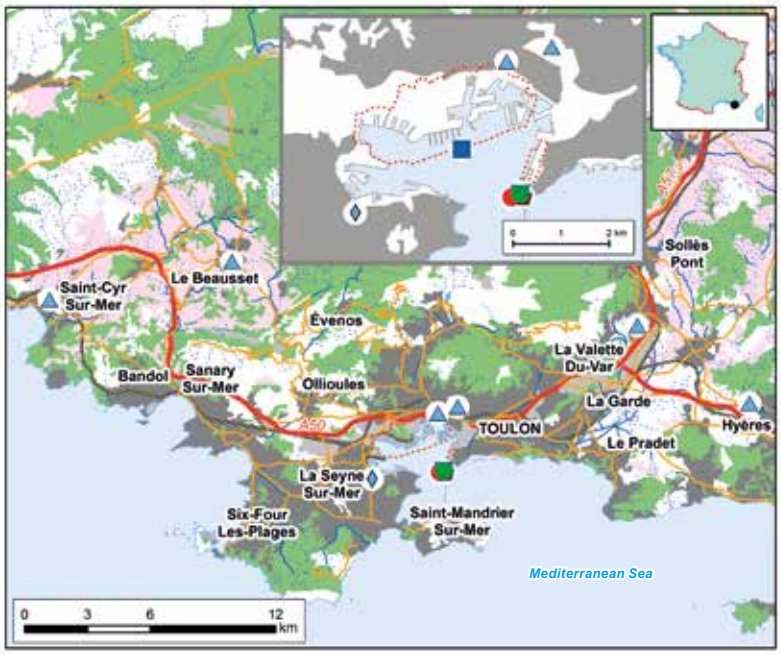
French Navy sampling points (Number)
- Ambient gamma radiation (13)
- Aerosols or gas (3)
- Rainwater (1)
- Grass (12)
- Vegetable (2)
- Tree leaves (12)
- Sediment (2)

Road networks, hydrographics and site boundaries
- Motorway
- Departmental road
- Railway
- Permanent river or stream
- Seasonal river or stream
- Site boundary

Land use
- Construction or building
- Anthropic surface (Structure)
- Anthropic surface (Industry or shops)
- Vineyards and orchards
- Forest
- River, stream or lake
- Mediterranean Sea
- Other

(source: RGE-BDTOPO@ & BDCARTO@ by IGN - 2015 ed.)

2B



Sampling points (Number)
- Ambient gamma radiation (6)
- Aerosols or gas (1)
- Sea water (1)
- Aquatic plants (1)
- Aquatic fauna (2)
- Sediment (1)

Road networks, hydrographics and site boundaries
- Motorway
- Departmental road
- Railway
- Permanent river or stream
- Seasonal river or stream
- Site boundary

Land use
- Construction or building
- Anthropic surface (Structure)
- Anthropic surface (Industry or shops)
- Vineyards and orchards
- Forest
- River, stream or lake
- Other

(source: RGE-BDTOPO@ & BDCARTO@ by IGN - 2015 ed.)

TABLE 1 / **ENVIRONMENTAL MONITORING PLAN FOR THE TOULON SITE APPLIED BY THE FRENCH NAVY AND IRSN**

Environment monitored or type of testing	French Navy	IRSN
Ambient gamma radiation	• **26 sensors on-site, 3 sensors off-site at Fort de Six-Fours, Fort de la Croix Faron and Fort du Cap brun:** ambient γ dose rate, including 16 sensors able to resist exceptional events (earthquakes, flooding, etc.) and/or 14 alpha, beta, and noble gas sensors	• **8 sensors in the immediate environment: Barjols, Hyères, La Farlede, Le Beausset, Rians, St-Cyr-Sur-Mer, Toulon and Toulon-Arsenal:** ambient γ dose rate
Atmospheric aerosols	• **3 sampling point at the site:** gross β activity (daily), γ spectrometry if gross β > 2 mBq/m^3	• **1 sampling point at Seyne-sur-Mer:** γ spectrometry (weekly)
Ambient tritium	• **1 sampling point at the site:** ambient tritium (HTO - HT) (weekly)	
Rainwater	• **1 sampling point at the site:** gross α and β activity levels, tritium (for each event)	
Seawater		• **1 sampling point, Tour Royale:** tritium (monthly)
Sediments	• **2 sampling points at Toulon west – Ollioules and Toulon west – Le Pradet:** γ spectrometry (annual)	• **1 sampling point, Tour Royale:** γ spectrometry, Pu, Am (annual)
Aquatic fauna		• **1 sampling point, Tour Royale: mussels,** γ spectrometry, Pu, Am (annual), **fish,** γ spectrometry (annual)
Aquatic plants		• **1 sampling point, Tour Royale: algae,** γ spectrometry, Pu, Am, OBT (annual)
Grass	• **2 sampling points at Toulon west and Toulon east:** γ spectrometry (monthly); carbon-14 (annual) and tritium (distillation water) (quarterly)	
Tree leaves	• **2 sampling points at Toulon west and Toulon east, 2 – lentisk and cypress species:** γ spectrometry (monthly), carbon-14 (annual)	
Vegetables	• **2 sampling points, Toulon west and Toulon east, samples taken for 4 vegetable species (lettuces, tomatoes, potatoes and courgette) :** γ spectrometry (annual), tritium (distillation water) for lettuces, tomatoes, courgettes (annual) and carbon-14 (annual) for lettuces	

Site impacts on the environment

Weekly tritium samples are taken for both tritiated hydrogen (HT) and water vapour (HTO) using bubblers at the 4 sites of the French Navy for measurements.

The level of atmospheric tritium (HTO and HT) detected over the 2015-2018 period is similar to that measured since 2009, although 9.5% of current activity measurements are above the decision threshold (between 0.017 and 0.37 Bq/m^3), compared with the previous 6.2%. If we exclude the 7 unusual values measured at the Toulon site in March and April 2017, due to the temporary storage of tritiated plates in a building located near to the sampling point, activity by volume oscillates around 0.1 Bq/m^3 (between 0.039 and 0.27 Bq/m^3). This range of values is above background radiation levels in areas unaffected by nuclear facilities (between 0.005 and 0.01 Bq/m^3), but will have no impact on human health.

Tritium activity is also analysed in rainwater samples taken near to these facilities. Activity levels range between 2.16 and 4.31 Bq/L with 10.5% of data above the decision threshold, which is similar to results for atmospheric tritium. Mean activity levels recorded at all sites are similar to the background radiation range (from less than 1 to 3 Bq/L).

Tritium is also measured in the terrestrial environment around the Cherbourg base, in plants such as grass and gorse, with 29 out of the 32 samples analysed exceeding the decision threshold. The values obtained vary from 1.16 to 5.74 Bq/fresh kg in plants, with a mean measurement of 2.3 Bq/fresh kg, which is within the background radiation range (from less than 1 to 3 Bq/fresh kg).

Background radiation for this radionuclide in the ocean environment, in areas unaffected by facilities discharging tritium, is approximately 0.1 - 0.2 Bq/L (see chapter 2).

Activity levels recorded in samples taken in Cherbourg port, near to the naval base, are much higher than these values and in line with measurements taken in the immediate environment around the La Hague site (see chapter 3.3 on the La Hague site). They are caused by discharges from this site. Measurements vary widely between 2.96 and 21.2 Bq/L (see figure 4).

Living organisms, particularly algae, shellfish and fish will integrate the tritium in this environment. The results obtained for these samples taken by the French Navy since 2015 range between 2.59 and 8.18 Bq/fresh kg and confirm this transfer.

In the same way, the brackish ground water from the Homet zone at Cherbourg is contaminated due to the tritium contributed from sea water, with a mean tritium value of 4.8 Bq/L for the 2015-2017 period and results which fluctuate between 2.72 and 10.58 Bq/L.

FIGURE 3 / **AMBIENT TRITIUM (both HT and HTO) ACTIVITY BY VOLUME NEAR TO THE MILITARY PORTS OF THE FRENCH NAVY BETWEEN 2009 AND 2017 (Bq/m^3) - ONLY RESULTS EXCEEDING THE DECISION THRESHOLD ARE SHOWN**

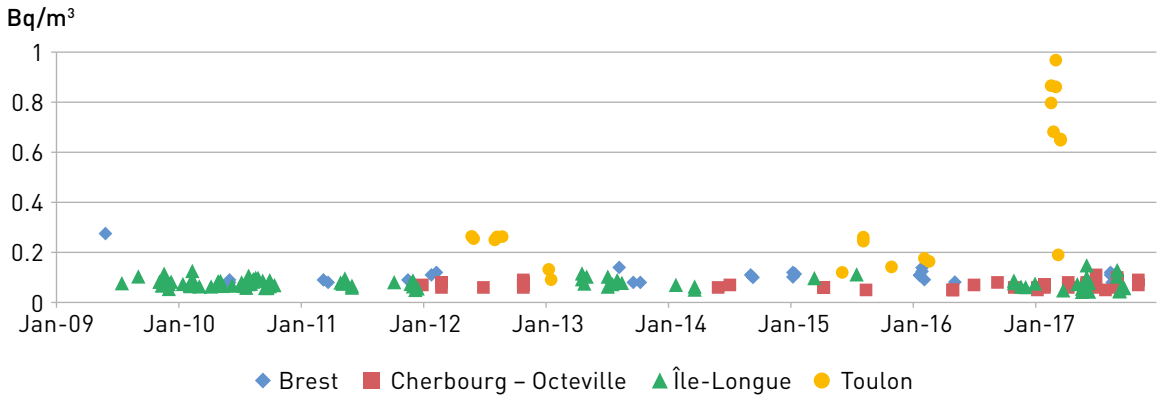
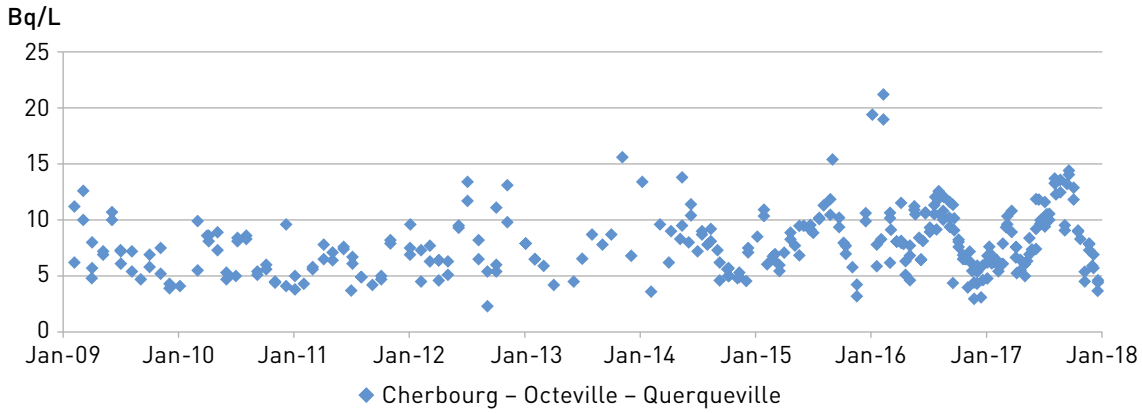


FIGURE 4 / **TRITIUM ACTIVITY BY VOLUME FOR SEAWATER SAMPLES TAKEN NEAR TO THE MILITARY PORT OF CHERBOURG BETWEEN 2009 AND 2017 (Bq/L) – ONLY RESULTS EXCEEDING THE DECISION THRESHOLD ARE SHOWN**



IRSN very rarely detects tritium in sea water samples taken from Brest bay despite the advanced equipment used (see figure 5). The maximum value recorded of 3.2 Bq/L is within the background radiation range for tritium.

In Toulon bay, 5 results were recorded above the decision threshold, for 31 samples analysed by IRSN, between 0.18 and 11.1 Bq/L, mostly well above the tritium background radiation for the marine environment (see figure 5). The source of this tritium has not been identified.

Most of the measurements taken in the other components of the marine environment fail to indicate any radiological impact attributable to the facilities of the French Navy. The radionuclides measured are either historical residual fallout (see chapter 2), such as caesium-137 in algae, fish or sediments, for which values fluctuate between 0.2 and 1 Bq/dry kg and are therefore within the range of background radiation (0.02 - 2 Bq/dry kg), or discharges from the La Hague site for the immediate environment around Cherbourg.

The impact of La Hague site is particularly clear for cobalt-60 and iodine-129 measurements. In fact, over the 2015-2017 period, cobalt-60 was repeatedly detected in sea water samples taken in the immediate environment of the Cherbourg naval base, especially in algae, shellfish and sediments. In the same way, iodine-129 is frequently detected in aquatic fauna samples and systematically in algae.

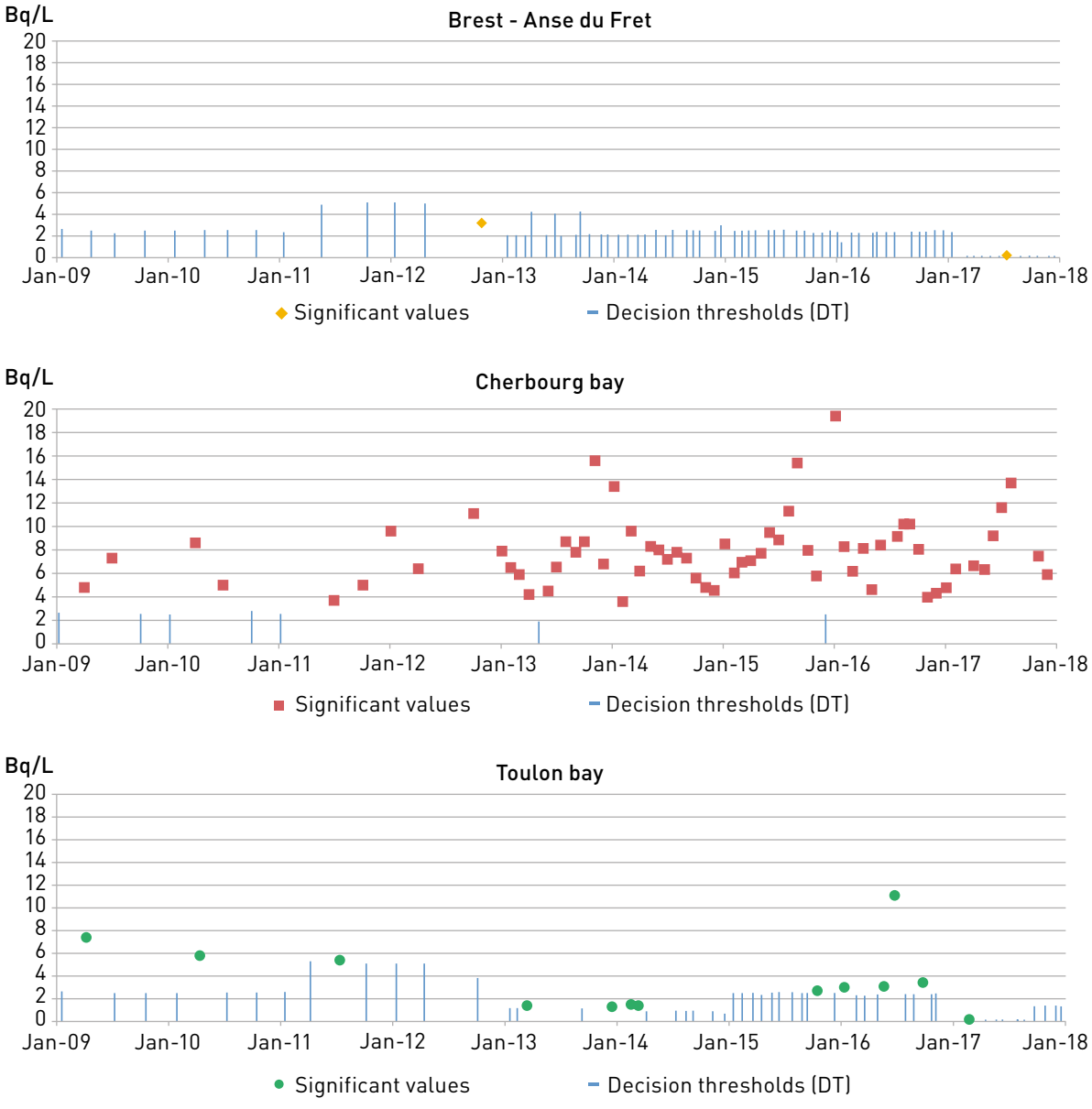
These data match those recorded over the entire coast of Normandy on either side of the La Hague site (see chapter 3.3; La Hague site).

TABLE 2 / **COBALT-60 AND IODINE-129 ACTIVITY LEVELS MEASURED IN THE OCEAN ENVIRONMENT IN AND NEAR TO CHERBOURG PORT**

2015-2017 period	Alga (fucus)	Aquatic fauna (spider crabs)	Sediments
Cobalt-60	0.31 - 0.86 Bq/dry kg 9/14	0.06 - 0.19 Bq/fresh kg 5/5	0.22-6.86 Bq/dry kg 43/150
Iodine-129	14 - 46.7 Bq/dry kg 18/18	0.06 - 0.64 Bq/fresh kg 7/13	- -

FIGURE 5 / **TOTAL TRITIUM ACTIVITY BY VOLUME FOR SEAWATER SAMPLES TAKEN NEAR TO THE MILITARY PORTS OF THE FRENCH NAVY BETWEEN 2009 AND 2017 (Bq/L)**

IRSN data



According to the data acquired for plutonium isotopes between 2015 and 2017 and measured in sand and ocean sediment samples in the immediate environment around the military port of Cherbourg, the $^{238}Pu/^{239+240}Pu$ ratio is greater than 0.2 (0.27 - 0.63), which indicates an industrial source (see chapter 2).

Finally, measurements for terrestrial sample results (cow's milk, grass, vegetables, fruit, tree leaves) taken near to the French Navy's military ports are generally below decision thresholds. The only values measured in the terrestrial environment around these sites are either natural radioactivity (^{40}K, ^{7}Be, etc.) or residual fallout from the Chernobyl accident or the testing of nuclear weapons (for Caesium-137).

Caesium-137 has been systematically detected in the 16 soil samples taken near to Brest bay since 2015, with wide-ranging values, including some above background radiation levels (0.20 - 29.56 Bq/dry kg). A special programme has been launched to identify the causes of these phenomena.

FIGURE 6 / **GAMMA SPECTROMETRY MEASUREMENTS BY LASEM AT BREST**

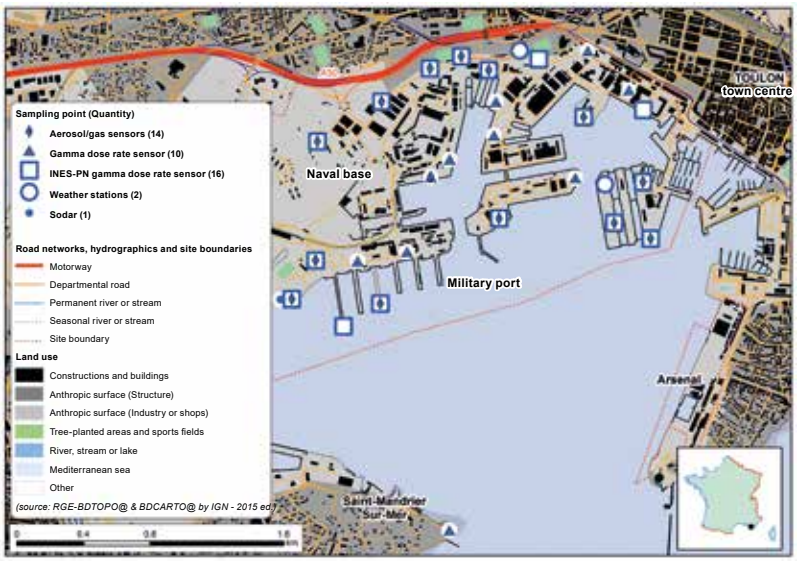
© Marine nationale

FOCUS ARTICLE
PLANNED RENOVATION OF THE FRENCH NAVY'S NUCLEAR MONITORING SYSTEM

The French Navy has redesigned its radioactivity monitoring system since 2015. The new version (2SNM V2) can both regularly monitor the environment and track and forecast discharges in case of an accident. This system will be commissioned in 2018 at the military base in Toulon, followed by the Île-Longue, Brest and Cherbourg sites by late-2019.

FIGURE A / **MAP SHOWING THE LOCATIONS OF 2SNM V2 MONITORING SENSORS AT THE TOULON NAVAL BASE**

Map by the French Navy



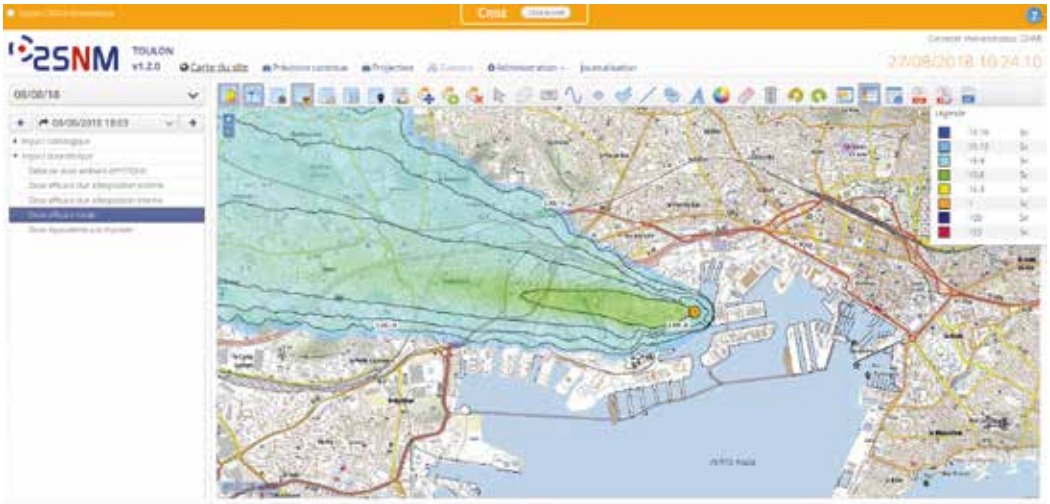
INES-PN gamma sensor

Aerosol and gas measuring system

This system comprises 26 ambient gamma dose rate sensors at the Toulon site. 15 of these sensors are also equipped with earthquake-resistant solar panels (INES-PN) placed in an area away from flooding risks. Hard wired communications are reinforced with radio transmissions. 14 sensors able to measure the activity by volume of gases and aerosols are also fitted. The network is completed with two weather stations and a SODAR, providing indispensable information in view of data analysis.

Data are collected using a centralisation system, which is also used to manage and supervise radiological alarms. This data is forwarded to the decision-making help and information system (SIAD) If an alarm is activated, this application can be used to model the plume and calculate doses every 15 minutes, particularly based on terrain effects and meteorology, as well as forecast variation over various time intervals.

FIGURE B / **DECISION-MAKING HELP AND INFORMATION SYSTEM**



Landscape of the flooded open-pit mine at Jaladis

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04
FORMER MINING SITES

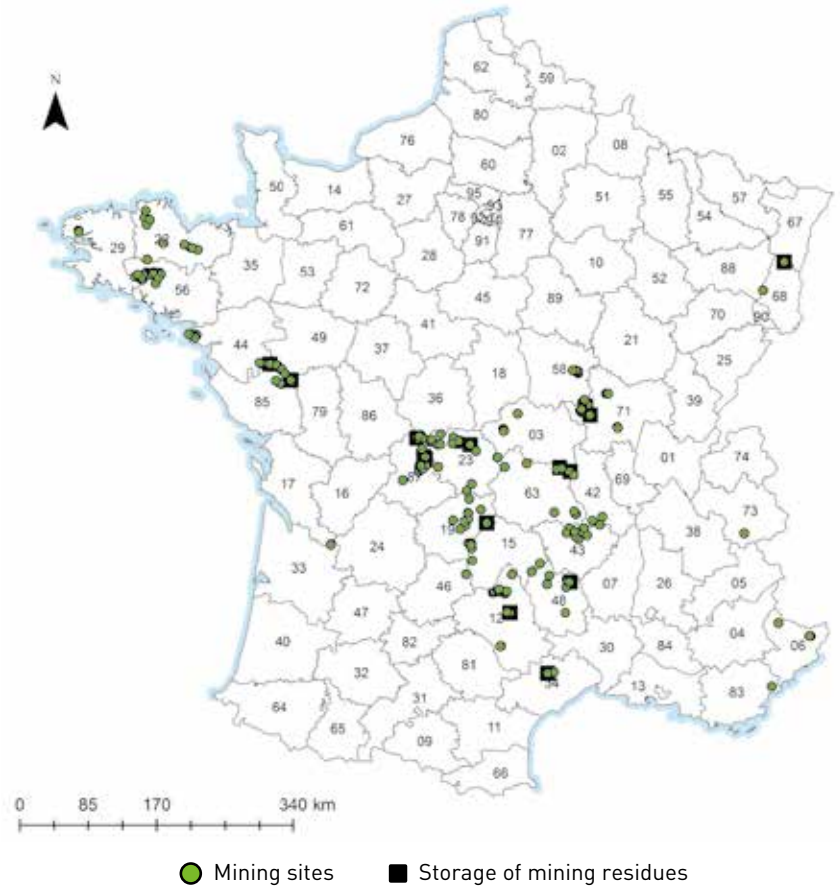
04
FORMER MINING SITES

4.1. INTRODUCTION

An exhaustive survey of all former exploration, mining and processing sites for uranium ore was undertaken by IRSN as part of a programme entitled MIMAUSA (Mémoire et impact des mines d'uranium : synthèse et archives - Inventory and impact of uranium mines: summary and archives) at the request of the French Ministry of Ecology. All the available data is accessible *via* a cartographic interface on the IRSN website (https://mimausabdd.irsn.fr/).

Currently, the MIMAUSA database covers 250 mining sites spread over 27 French departments (cf. figure 1). These 250 sites differ widely in terms of their size (from several hundred square metres to several hectares), the mining activities that were practised there (simple reconnaissance work to the presence of an ore treatment plant, etc.) or the quantities of uranium produced by the mining activity (from 20 kg to more than 14,000 tonnes for the Le Bosc site in the Hérault department, cf. figure 2). The former mining sites therefore today present widely differing characteristics and challenges, not only in terms of the mining work and industrial activities practised on the

FIGURE 1 / **LOCATION OF FORMER URANIUM MINES AND URANIUM ORE PROCESSING TAILINGS REPOSITORIES IN FRANCE**
From MIMAUSA data



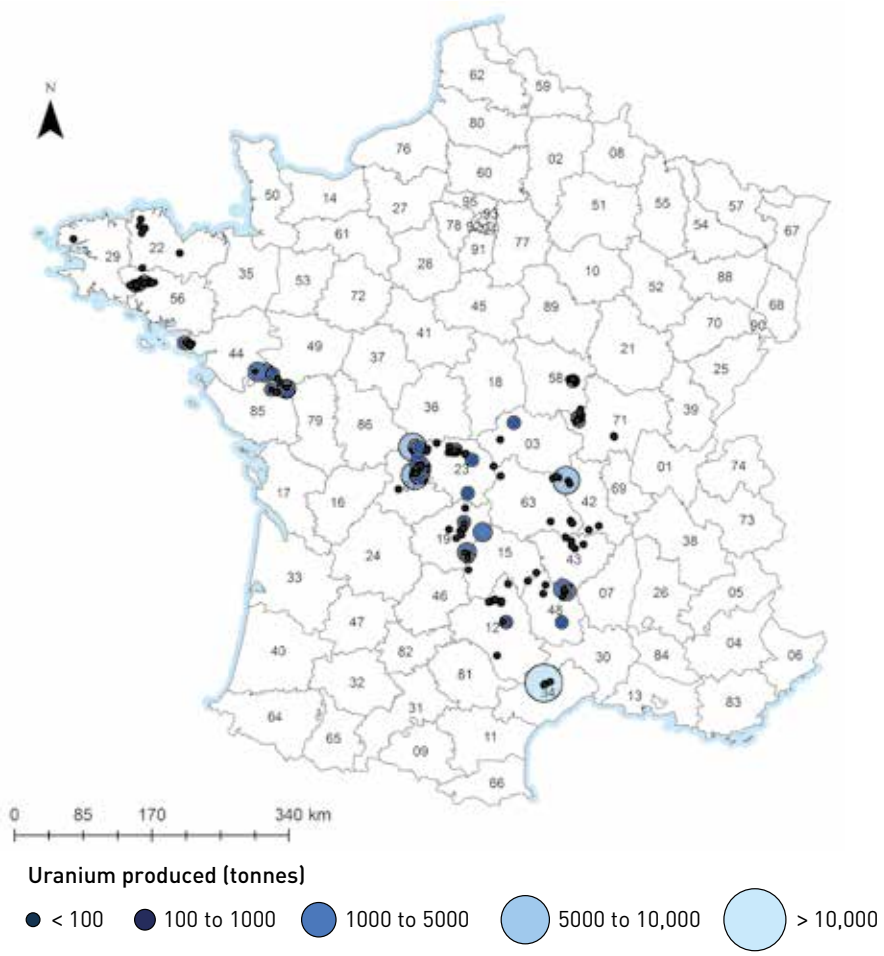
sites, but also with respect to the redevelopments conducted after their closure, their environment and the use made of this environment.

This chapter of the Radiological report first of all presents general information about the former French uranium mining sites. It provides information about the types of mining operation, the industrial activities practised on the sites, the by-products generated and the management of these by-products, and the different types of redevelopment. Next, the report presents the various potential influences that a mining site can have on its environment, and the monitoring that can be done to characterise this influence and the potential exposure of the local population that may result from this. Lastly, to illustrate these general factors, four sites were selected for a detailed presentation.

General information on mining sites

Industrial mining of uranium in France began after World War II and ceased in 2001 with the closure of the country's last working mine. The CEA (French Atomic Energy Commission, as was) was the first to prospect for and mine uranium. These operations were pursued by its subsidiary, COGEMA (*Compagnie générale des matières nucléaires*) from 1976, and by several small private companies. Progressively, COGEMA, then Areva and, currently, Orano, assumed operator responsibility for most of the former mining sites. Only a few, operated by companies that have disappeared without being previously taken over, today directly depend on the French State.

FIGURE 2 / **GEOGRAPHIC DISTRIBUTION OF FRENCH URANIUM PRODUCTION**
From MIMAUSA data



The former mines are mainly distributed across granitic massifs such as the Massif Central or the Massif Armoricain. These formations are naturally rich in uranium, with the highest local concentrations. Uranium is in fact present in nature in many minerals (such as pitchblende, coffinite or autunite). Rock containing these minerals in sufficiently abundant proportions to justify mining operations is then qualified as ore. Prior to full-scale mining, small-scale reconnaissance work could be carried out to estimate the feasibility of a mining operation. This work could consist in excavating trenches or small shafts linked to the surface *via* a pit. In France, the ore was then extracted *via* two mining methods:

- open-pit mining;
- underground mining.

Uranium mining and the processing of uranium ores led to the generation of two types of by-product: **tailings** and **processing residues**. Indeed, accessing the ore required, in some cases, excavation of rocks with uranium content too low for the industrial exploitation of the geological formation. These rocks are designated "tailings" (cf. table 1). Two types of tailings may be distinguished:

- **Waste rock tailings** corresponding to the country rock surrounding the granitic or sedimentary deposits that have been extracted to access the deposits. This waste rock has low uranium content, in the order of several g/t.
- **Uranium deposit tailings** which correspond to the materials from the deposit whose uranium content has been judged insufficient, and below the "cut-off threshold", for consideration as marketable ore. The cut-off threshold value changed over time in line with changes to the price of uranium and the development of mining techniques. At the start of the 1990s, with the collapse of the uranium price, the cut-off threshold went from 100 to 400 g/t for open-pit mines and from 200 to 400 g/t for underground mines (higher costs).

When the mines were running, these tailings were disposed of in waste piles or used for the redevelopment of the mining sites.

Once separated from the rock, the ore was ground then treated chemically to extract the uranium from it. The corresponding industrial operations were conducted either in-plant (processing by dynamic leaching) or in piles on managed areas on the mining site (processing by static leaching). There were eight ore extraction plants distributed over the various mining sites and which processed the rich ores of neighbouring mines. Ore considered as poor was placed in hermetic areas where it was watered with water and sulphuric acid to extract the uranium by solubilisation (static processing). After the processing steps, two products were recovered:

- the uranium in the form of yellow concentrate called "yellowcake", used in the preparation of fuel for nuclear reactors;
- the processing residues.

TABLE 1 / **ORDERS OF MAGNITUDE OF URANIUM CONTENT AND RADIOACTIVITY LEVELS TRADITIONALLY ASSOCIATED WITH MATERIALS AND RESIDUES PRESENT ON MINING SITES**

	Uranium content (g/t)	U-238 activity (Bq/kg)	Ra-226 activity (Bq/kg)
Average for soils and rocks in France*	Several g/t	Several dozen	Several dozen
Granitic rock**	Several dozen g/t	Several hundred	Several hundred
Tailings	Several dozen to several hundred g/t	Several hundred to several thousand	Several hundred to several thousand
Residues	Several dozen to several hundred g/t	Several hundred to several thousand	Several tens of thousands
Ores	Around 1000 g/t	Several tens of thousands	Several tens of thousands

* Average values observed for soils and rocks in France, whatever the geological context concerned.

** Excluding ore.

The ore processing residues were stored as they were produced close to the ore processing activities in open-pit mines, in ponds surrounded by dikes or in valley bottoms enclosed by dikes. These dikes consisted of waste rock, static processing residues and/or cyclone sand from dynamic processing.

A little over 48 million tonnes of ore was extracted from French mines. After processing, around 76,000 tonnes of uranium were produced over half a century and 48 million tonnes of uranium ore processing residue were stored in 16 tailings repositories distributed around 15 former mining sites and on a tailings repository at Gueugnon (which hosted an ore processing plant with no mining operation) (cf. figure 2).

Once mining operations ceased, the mine works were made safe to prevent mine-related risks (in particular, ground subsidence) and the sites were redeveloped so as to reduce their impact on man and the environment and integrate them into the landscape (cf. figure 3). Access to the shafts were blocked off, the pits sealed and the underground mine works flooded and, in certain cases, backfilled. Open-pit mines not used as a receptacle for processing residues were either flooded, thus creating artificial lakes, or backfilled with tailings. Lastly, the land was re-shaped using waste piles to mitigate the topographical modifications generated by the mining operation and to limit run-off. Nowadays, the traces of past mining activity are limited visually to a more or less marked modification of the topography (hollows associated with old open-pit mines, mounds consisting of mining waste deposits, etc.). The old plants were dismantled and a multi-layer covering, generally consisting of static leaching residues, tailings and soil was laid over the mining residue tailings repositories. This coverage provides physical and radiological protection by limiting the emission of gamma radiation and the release of radon directly above the tailings repository. It should be noted that there is a tailings repository for which the protection from gamma radiation is provided by a layer of water covering the residues. This is the site of Les Bois Noirs Limouzat. The tailings repository at La Commanderie is also under a layer of water, but unlike Les Bois Noirs Limouzat it also has a solid multi-layer covering.

The operations and plant dismantling waste was also stored with the residues. Furthermore, certain tailings repositories may periodically receive sludge from the wastewater treatment plants located on some old uranium mining sites, subject to prefectural authorisation.

Some of the land concerned by mining exploration and operation was surrendered to private individuals, municipal authorities or companies, while some of it remained the property of Orano. This meant that land directly concerned by the mining activity (in particular waste deposit zones and open-pit mines) were returned to their initial usages or assigned new usages such as agricultural, forestry or recreational use (fishing, country walks, etc.). Orano retains responsibility for as long as the sites have not been subject to legitimate administrative closure, whether or not it owns the land.

FIGURE 3 / **OPEN-PIT MINE ON THE BELLEZANE SITE (Haute-Vienne) BEFORE AND AFTER REDEVELOPMENT** *Source: Orano*

Bellezane open-pit mine during operation.

Bellezane open-pit mine after redevelopment.

4.2. POTENTIAL INFLUENCE OF FORMER MINING SITES ON THEIR ENVIRONMENT AND PUBLIC EXPOSURE

Around a mining site the public may be exposed:

- to gamma radiation (external exposure) produced by the various sources that may be present on the mining site (tailings, residues). This gamma radiation may have an influence on the site itself or on its immediate environment, leading to a modification of the external dose received by persons likely to frequent its locality;
- to radon, an isotope of the decay series of uranium-238, naturally present in granitic massifs and therefore in the materials from the mine (tailings, residues);
- to airborne particles from the radioactive materials present on the site. However, the redeveloped sites are not theoretically likely to generate significant dust emissions on account of the landscaping carried out (presence of plant cover, etc.) and, in the absence of any changes (e.g., worksite projects), the release of airborne particles on and around a mining site is generally negligible;
- to radionuclides present in the food chain or drinking water. Indeed, mine water run-off or rainwater run-off on the mining site can affect the natural radionuclide content of waterways, lakes and pools situated downstream of the site, and of sediments. Food is therefore mainly likely to be impacted by the irrigation or livestock watering usages with water affected by a mining site.

Furthermore, to limit the impact on the food chain and water supply, water from certain mining sites and tailings repositories undergoes treatment before being discharged into the environment. There are currently fifteen water treatment plants in operation. The treatment may concern the radiological parameters, in particular the uranium content and/or radium-226 activity, as well as physical-chemical parameters such as the pH or, in certain cases, the metals content.

Conducting an impact analysis on the population makes it possible to check that the influence of the sites on their environment remains limited. Exposure is therefore assessed according to the spread of the population on and around the site and, above all, according to the usage that the population makes of this environment: frequentation of locations in close proximity to the site or on the site, recreational fishing in the waterways or in the old open-pit mines, use of water for irrigating crops or watering livestock, etc.

Inasmuch as the mining sites are situated on territory that is naturally rich in uranium, the impact attributable to a given site is assessed by the difference between the results of monitoring around the site and the measurements made at reference stations or reference points beyond the influence of the site.

4.3. MONITORING THE ENVIRONMENT AROUND FORMER MINING SITES

Monitoring should make it possible on the one hand to assess the radiological impact of mining sites on population and environment and, on the other, to check the efficiency of the redevelopments. This is why the monitoring around former mining sites relates to uranium-238 and its progeny, and may concern the various compartments of the environment: air, surface and/or underground water, soils, sediments and foodstuffs.

Regulatory aspects

Tailings repositories are "Installations Classified for the Protection of the Environment" (ICPE) and are subject to environmental monitoring. Certain former mining sites, which are still governed by the Police des Mines, are also subject to environmental monitoring by Orano. The monitoring may be regulatory and/or involve complementary monitoring initiated by the operator. How regulatory monitoring is conducted is defined on a case-by-case basis in prefectural orders, generally on the basis of the provisions laid out in the "general regulations for the extractive industries" (RGIE). A distinction is to be made between:

- prefectural orders regulating site discharges and defining the monitoring required for assessing the impact of these discharges on the environment;
- prefectural orders determining the provisions applicable to certain environments subject to the influence of mining when these environments are used for sensitive purposes: swimming, fishing, drinking water supply.

In addition to the monitoring conducted by Orano, checks are carried out by the DREAL (Directions régionales de l'environnement, de l'aménagement et du logement - Regional Departments for the Environment, Development and Housing), in particular involving inspections with sampling for analysis. Spot measurement campaigns are also conducted by several bodies. These campaigns may result from questions arising from the population, elected representatives, local or national associations, or in response to a request from the authorities. IRSN can provide technical support to the DREAL or in response to any request from the authorities. Furthermore, as part of its specific national radiological monitoring mission, IRSN also conducts regular monitoring of the local environment around some former mining sites. In addition, IRSN conducts wider-scale studies of the impact of former uranium mining sites on the regional scale. For example, the Institute conducted, from 2011 to 2015, a radiological study to characterise the influence of the former mining sites of the drainage basin of the Dordogne[1].

General description of monitoring mechanisms

Radiological monitoring conducted around certain former mining sites is designed to characterise a site's radiological impact on the environment, and in particular to quantify the possible changes with respect to the local natural background radiation, and to estimate the potential exposure of the population resulting from this:

- Monitoring air quality: this consists in tracking the potential alpha energy concentration (PAEC) due to short-lived daughter isotopes of radon-222 and radon-220 (cf. chapitre 1, p. 12) and the activity per unit volume of long-lived alpha emitters contained in dust.
- Monitoring the dose rate: this is done using sensors positioned permanently on the site, in its immediate environment and in the surrounding inhabited areas (cf. chapter 1, pp. 9-10 and chapter 2, pp. 50-52).
- Monitoring surface water: this essentially involves measurements of uranium and radium-226 made in the water and sediments of the waterways system around the sites.
- Monitoring the food chain: this monitoring concerns various foodstuffs (vegetables, fruit, milk, fish, etc.) that are likely to be impacted by the site *via* irrigation or the watering of livestock. Based on these measurements, Orano makes assessments of the doses that would be received by people in the general public who may consume them.

4.4. DETAILED PRESENTATION OF 4 FORMER MINING SITES CHOSEN FOR THE RADIOLOGICAL REPORT

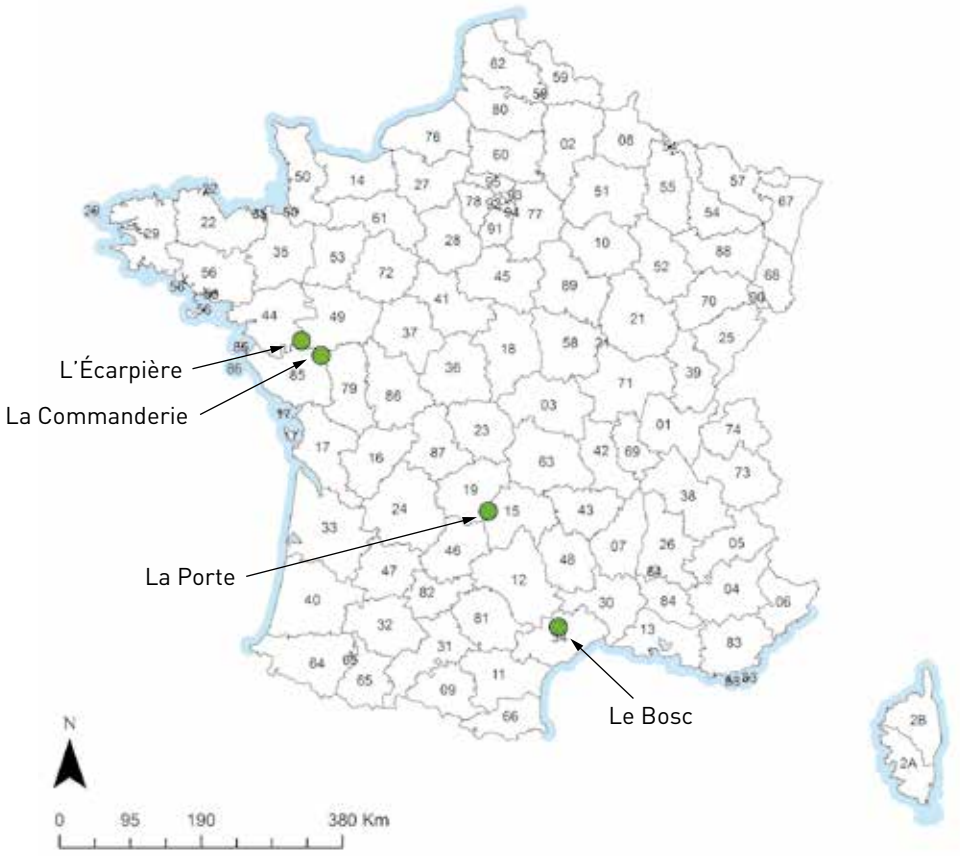
Considering the large number of sites, the choice was made to present monitoring conducted only around four former mining sites: L'Écarpière, La Commanderie, Le Bosc and La Porte (cf. figure 4). These sites were selected according to various criteria. The first criterion is the existence of a regulatory monitoring obligation

1. IRSN, 2016, Mining radiological report for the drainage basin of the Dordogne based on a pluralistic approach conducted with stakeholders in the territory.

making it possible to have access to a set of measurements over several years, such as is the case with the other facilities presented in this report. Some 30 sites are concerned by such a regulatory monitoring obligation, which include sites containing a tailings repository. Furthermore, concerning the latter, the choice was made to present as a priority the sites for which regulatory monitoring of the food chain is carried out. Hence, the sites of L'Écarpière and Le Bosc were chosen because, in addition to the aforementioned criteria, these sites played host to significant mining activity and an ore processing plant, and both have a working water treatment plant. Moreover, these two sites make it possible to illustrate two different geological contexts: granitic for L'Écarpière and sedimentary for Le Bosc. The choice of the La Commanderie site may be explained by the fact that this is a site which has a tailings repository but did not host a plant (only static ore processing). This site was chosen as it illustrates the use of mining water for crop irrigation. To illustrate the variability of site types, it was also decided to include the La Porte site, which is not a tailings repository but a flooded former open-pit mine.

It is important to note that these sites illustrate situations specific to them (in particular in terms of usages) and should not, as such, be taken as representative of all situations existing in France.

FIGURE 4 / **LOCATION OF THE L'ÉCARPIÈRE, LA COMMANDERIE, LA PORTE AND LE BOSC SITES**



L'Écarpière site

The L'Écarpière site is located in the municipalities of Gétigné (Loire-Atlantique) and Saint-Crespin-sur-Moine (Maine-et-Loire), along the Moine river. Covering an area of 240 ha, this site was operated from 1952 to 1990, with underground mine works and four open-pit mines, producing 4109 tonnes of uranium (cf. table 1). An ore processing plant, which processed most of the ore in the region, was also in operation from 1956 to 1991 (cf. table 1). This plant was dismantled and the entire site was redeveloped (cf. figure 1). Currently, the site has a tailings repository containing dynamic and static processing residues from uranium ore (cf. table 1), a water treatment plant and the operator's offices. Part of the site has been upgraded with the installation of a solar park.

Monitoring plan

The L'Écarpière site is subject to regulatory monitoring prescribed by prefectural order. The Orano monitoring plan is presented below (cf. table 2 and figure 2), involving the monitoring of the following:

- site water (from the old mining works zone: run-off water, water from mining work, drainage water from the tailings repository);
- gamma radiation on and around the site;
- air quality on and around the site (radon and dust);
- the aquatic environment around the site (the Moine river);
- the food chain around the site;
- underground water.

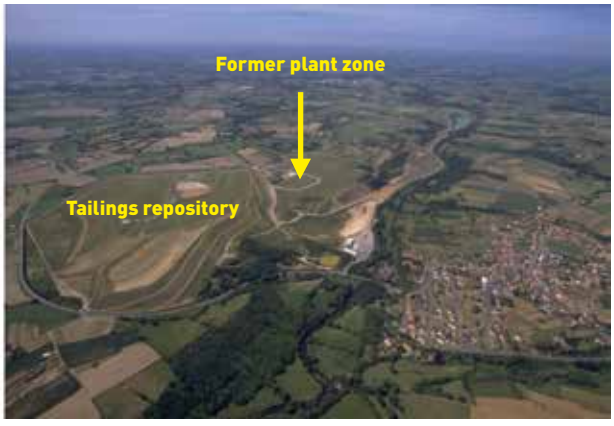
This is complemented by regular monitoring by IRSN downstream of the site and by spot analyses, in particular in the framework of random checks and the MIMAUSA programme.

TABLE 1 / **TONNAGE OF DIFFERENT PRODUCTS ISSUING FROM THE L'ÉCARPIÈRE MINE AND THE PROCESSING FACILITIES**

Uranium extracted by the L'Écarpière mining operation (tonnes)	Tonnage of ore processed at the L'Écarpière plant (tonnes)	Uranium produced in the plant (tonnes)	Uranium produced by static processing (tonnes)	Tailings from dynamic processing (millions of tonnes)	Tailings from static processing (millions of tonnes)
4109 *or 5.1%* *of French production*	9,292,000	14,761 *or 18.3 %* *of French production*	1266	7575 *or 24.7%* *of tailings from dynamic processing produced in France*	3775 *or 21%* *of tailings from static processing produced in France*

FIGURE 1 / **THE L'ÉCARPIÈRE SITE BEFORE AND AFTER REDEVELOPMENT** *Source: Orano*

L'Écarpière site during operation (1989)



Redeveloped L'Écarpière

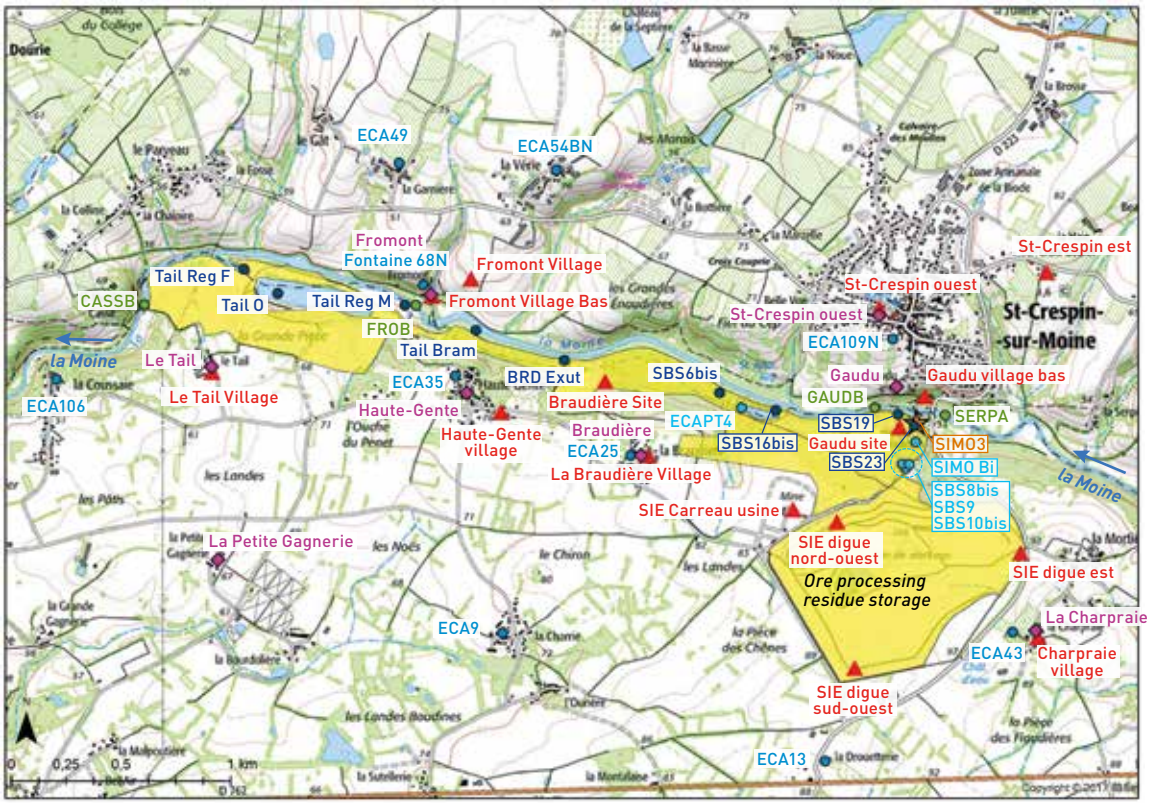
TABLE 2 / **MEASUREMENTS MADE ON AND AROUND THE L'ÉCARPIÈRE SITE**

Monitored environment or nature of inspection	Orano	IRSN	DREAL and ASN
Site water	**Regulatory monitoring:** • 15 sampling points • At discharge (point SIMO3): weekly measurement of uranium, ^{226}Ra, flow rate, pH, TSS, COD, barium and iron • Other points: monthly measurements		**Random checks (2009 and 2010):** • 3 points (at the regulatory monitoring points: SIMO3, SBS10bis and TAILO) • Spot measurements of uranium, ^{226}Ra and physical-chemical parameters
Gamma radiation	**Regulatory monitoring:** • 19 measurement stations: 4 in the natural environment, 9 in the surrounding villages and 6 on-site		
Air (radon-222 and radon-220)	**Regulatory monitoring:** • 19 measurement stations: 4 in the natural environment, 9 in the surrounding villages and 6 on-site • Monthly measurements of the ^{222}Rn PAEC, the ^{220}Rn PAEC and the dust		
Continental aquatic environment	**Regulatory monitoring:** • 4 measurement points in the Moine river • Water: half-year measurements (in the event, measurements made monthly) of uranium (soluble), ^{226}Ra (soluble and insoluble), flow rate, pH, TSS and iron • Sediments: annual measurements of ^{238}U, ^{226}Ra, and ^{210}Pb • Aquatic plants: annual measurements of ^{238}U, ^{226}Ra, and ^{210}Pb	**Environment monitoring since 2009:** • 1 measurement point in the water of the Moine river entirely downstream of the site • Quarterly measurements of uranium, ^{226}Ra, global alpha decay, global beta decay, ^{235}U and ^{234}U... **MIMAUSA programme in 2013:** • Water: 4 points (at point SERPA, in the Moine river at the discharge point, near monitoring point FROB and far downstream of the site), spot measurements of uranium and ^{226}Ra • Sediments: 1 point (entirely downstream of site near monitoring point CASS B), spot measurements of radionuclides of the uranium-238 chain	**Random checks (2009 and 2010):** • 3 points (water and sediments) at the regulatory monitoring points: SERPA, GAUDB and CASSB and a point in the Moine river at the point of discharge (water only) • Water: spot measurements of uranium, ^{226}Ra and physical-chemical parameters • Sediments: spot measurements of ^{238}U, ^{226}Ra, and ^{210}Pb
Overground environment (food chain)	**Regulatory monitoring:** • Annual measurements of ^{238}U, ^{226}Ra, ^{230}Th, ^{210}Pb and ^{210}Pb around the site		
Underground water	**Regulatory monitoring:** • 9 wells around the site Half-yearly measurements of uranium and ^{226}Ra		

TTS: total suspended solids.
COD: chemical oxygen demand.

FIGURE 2 / **MAP OF LOCATIONS OF SAMPLES LINKED TO THE REGULATORY MONITORING OF THE L'ÉCARPIÈRE SITE**

Mining site footprint: Source Orano



Gaudu SITE — Inspection of air and dose rate (dosimeter + thermoluminescent dosimeters)

Gaudu — Inspection of food chain

SIMO3 — Physical discharge point of water treatment station (...)

ECA9 — Water sampling: farm wells

SBS19 — Sampling of untreated site water

SBS9 — Sampling of treated site water

SERPA — Sampling: surface water, sediments and aquatic plants

Footprint of old mine operation

Influence of the L'Écarpière site on its environment

Gamma radiation and air quality

For the period 2015-2016, the dose rate varied between 120 and 303 nGy/h on average for the measurement stations located on-site, and between 93 and 260 nGy/h on average for those located in the villages around the site (cf. figure 3). These values are consistent with the values generally observed on former mining sites and in their environment.

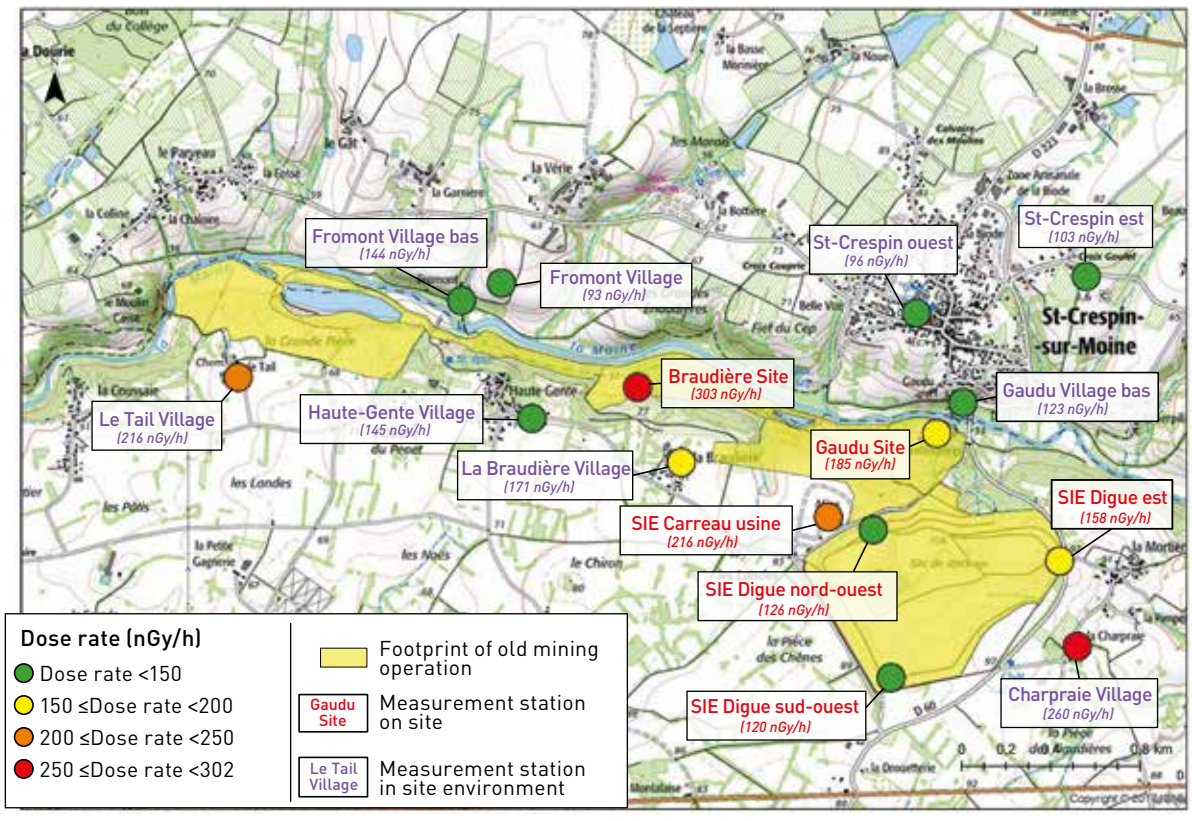
The different values measured on the site can be explained by the nature of the soils at the measurement stations:

- The lowest averages were to be found at the stations positioned on the tailings repository: the gamma radiation from the mining residues is attenuated by the cover on top of these residues.
- The intermediate values were recorded at the redeveloped former industrial zones (pit head, plant, etc.).
- The highest average was recorded at the La Braudière Site station, directly above an old open-pit mine, partly filled in with mine tailings.

For the surrounding villages, the highest average was recorded in La Charpraie village, around 200 m from the tailings repository (cf. figure 3). Considering the distance, this dose rate cannot result from radiation emitted by the site (cf. chapter 1). This high dose rate, compared to the other villages, can be explained most probably by a local variation of the dose rate at the measurement station. More generally, a difference in the average dose rate was observed between the villages situated on the left bank of the Moine river (mining site side) and those on the right bank. This is explained by a variation in the geology between these two banks, with the geological formation on the left bank being richer in uranium.

FIGURE 3 / **2015-2016 AVERAGE OF DOSE RATES MEASURED BY ORANO ON AND AROUND THE L'ÉCARPIÈRE SITE (nGy/h)**

Mining site footprint: Source Orano



The PAEC measurements for ^{222}Rn on and around the site for 2015-2016 illustrate the influence of the topography on the measurement of this quantity, independently of the location of the measurement station on-site or off-site (cf. figure 4). The highest averages are therefore to be found in the stations located in the valley bottom, a situation less conducive to the dispersion of radon in the air. Conversely, the lowest averages correspond to the stations located in summit position, more conducive to radon dispersion. The off-site PAEC measurement of ^{222}Rn can be explained more by the station's exposed situation to the winds than by the geology, unlike the dose rate.

Surface water

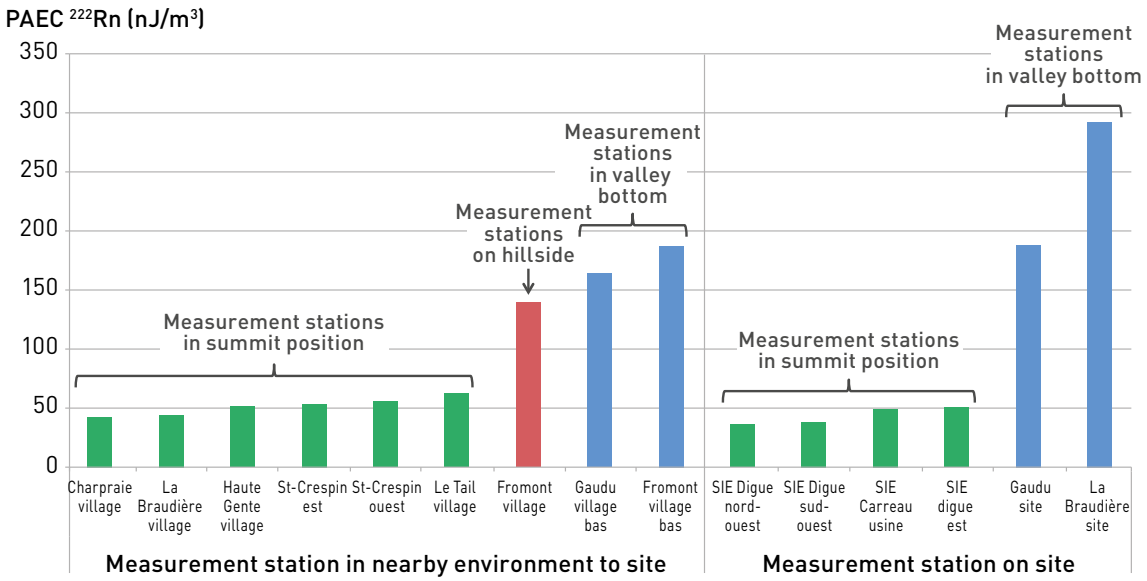
Currently, some of the water issuing from the site is collected at the water treatment plant on the L'Écarpière site, to reduce the water's radium-226 activity and its uranium and iron concentration, and to neutralise the pH. The treatment consists first of all in precipitating the iron and trapping the uranium with the previously-formed iron hydroxides and oxyhydroxides. Treatment by precipitation and coagulation – flocculation – decantation is then carried out to reduce the radium-226 activity. The reagents used are milk of lime, barium chloride and an anionic organic flocculant.

The treated water is the water from the drainage of the tailings repository, representing less than 5% of the total treated volume (points SBS8bis, SBS9, SBS10bis) and the pit water from the underground mining works (point ECA PT4) (cf. figure 2). The run-off water from the mining zone, the pit water from the old mining works zone and the water from the tailings repository are not subject to treatment, but they are monitored.

The water from the L'Écarpière site, after treatment, is discharged at point SIM03 into the Moine river (cf. figure 2). The discharge standards, determined by prefectural order, are as follows:

- The pH must be between 5.5 and 8.8.
- The uranium, radium-226 and iron must, respectively, be less than 1800 µg/L (in soluble form), 370 mBq/L (in soluble form) and 5 mg/L, as a monthly average for the samples taken weekly.

FIGURE 4 / **2015-2016 AVERAGE OF ^{222}Rn PAEC MEASURED BY ORANO FOR THE MONITORING ON AND AROUND THE L'ÉCARPIÈRE SITE (nJ/m^3)**



The measurement logs show that the water treatment enables a reduction in the uranium concentration and the radium-226 activity and compliance with the discharge values (cf. figures 6 and 7). Furthermore, the uranium concentration in the discharges has reduced since 2006 (cf. figures 6 and 7), whereas the radium-226 activity in these same discharges has increased since 2015. This increase results from a reduction in the quantity of reagent used by Orano for treating the water, with the objective of optimising the consumption of reagents and reducing the chemical impact of the barium on the environment while respecting the regulatory value (source: Orano).

The measurements also show that the discharges have little influence on the uranium concentration and the radium-226 activity in the waters of the Moine, close downstream of the discharge point (point GAUD B - cf. figures 5 to 7). Indeed the averages, for the period 2006-2016, for these two parameters are of the same order of magnitude at point GAUD B (U = 2.7 µg/L et ^{226}Ra = 29.1 mBq/L) as upstream of the site at point SERP A (U = 1.6 µg/L and ^{226}Ra = 27.4 mBq/L).

As far as the water discharged without treatment is concerned, the monitoring of run-off water from the mining zone and the tailings repository conducted between 2006 and 2016 (points Tail RegF, Tail RegM, Tail Bram, BRD EXUT, SBS 6bis, SBS 19 and SBS 23) indicates that the average concentrations of uranium in this water is between 13.6 µg/L (point SBS6Bis) and 867.5 µg/L (point Tail RegF) and that the average radium-226 activity is between 46.3 mBq/L (point Tail RegM) and 191.3 mBq/L (point Tail Bram). These values, in particular at points Tail Bram and Tail RegF, are in some cases significantly higher than those measured at point SERP A (upstream of site). It should be noted that the run-off water flows are discontinuous.

The measurements made in the Moine river reveal an average radium-226 activity in the same order of magnitude entirely downstream of the site (measurement point CASS B) as upstream, and an average uranium concentration three times higher (U = 5.8 µg/L).

FIGURE 5 / **AVERAGE MEASUREMENTS OF URANIUM AND RADIUM-226 MADE BETWEEN 2006 AND 2017 IN THE MOINE RIVER (purple labels) AND THE UNTREATED SITE WATERS (red labels)**

Mining site footprint: Source Orano

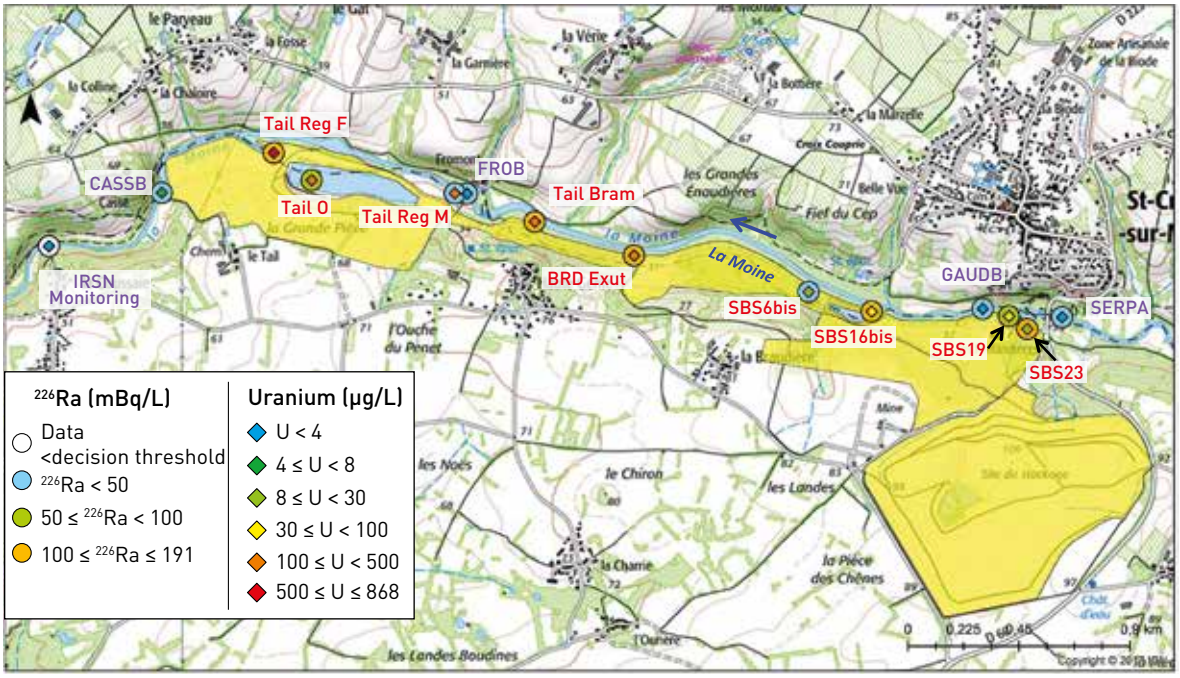


FIGURE 6 / **URANIUM CONCENTRATION IN THE SITE WATERS BEFORE TREATMENT, AT THE DISCHARGE POINT AFTER TREATMENT AND IN THE MOINE RIVER (µg/L)**

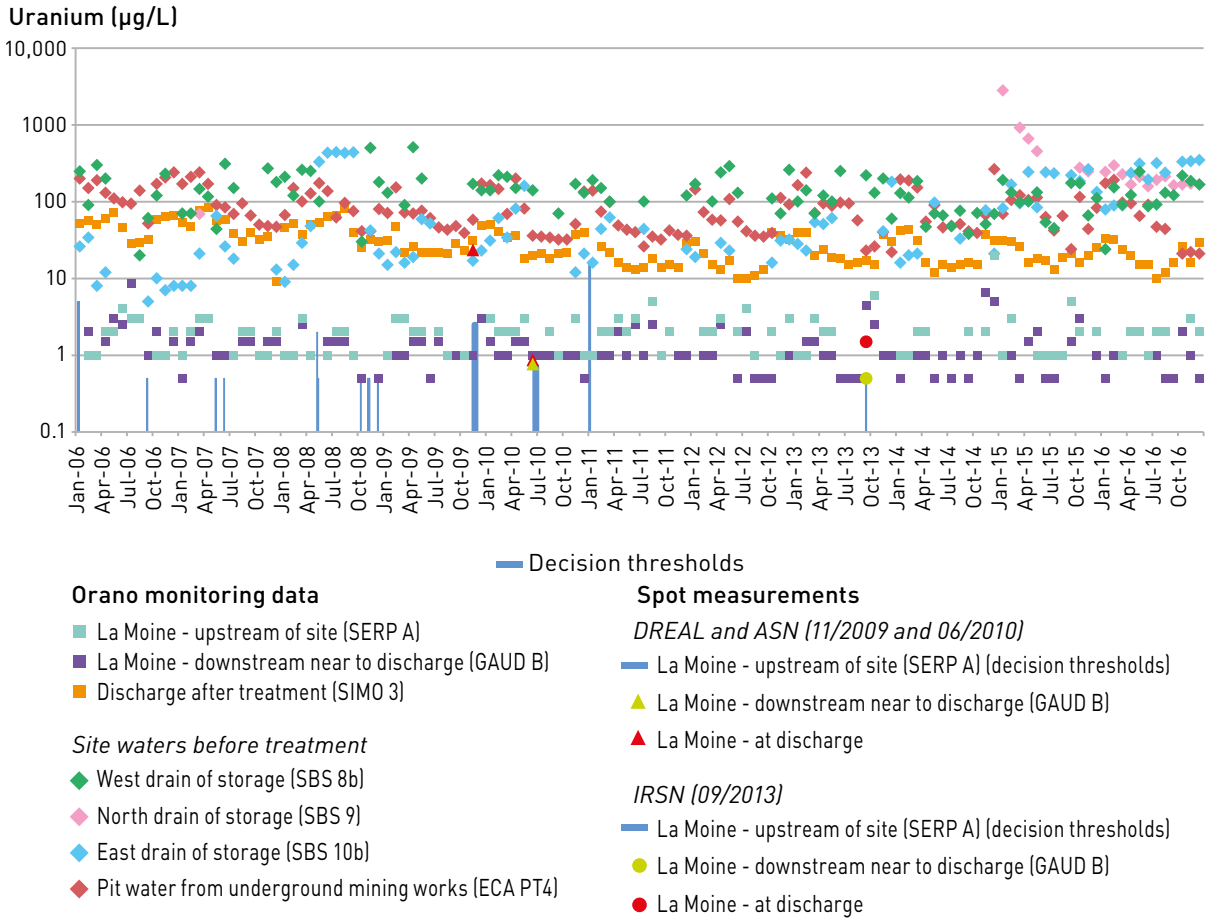
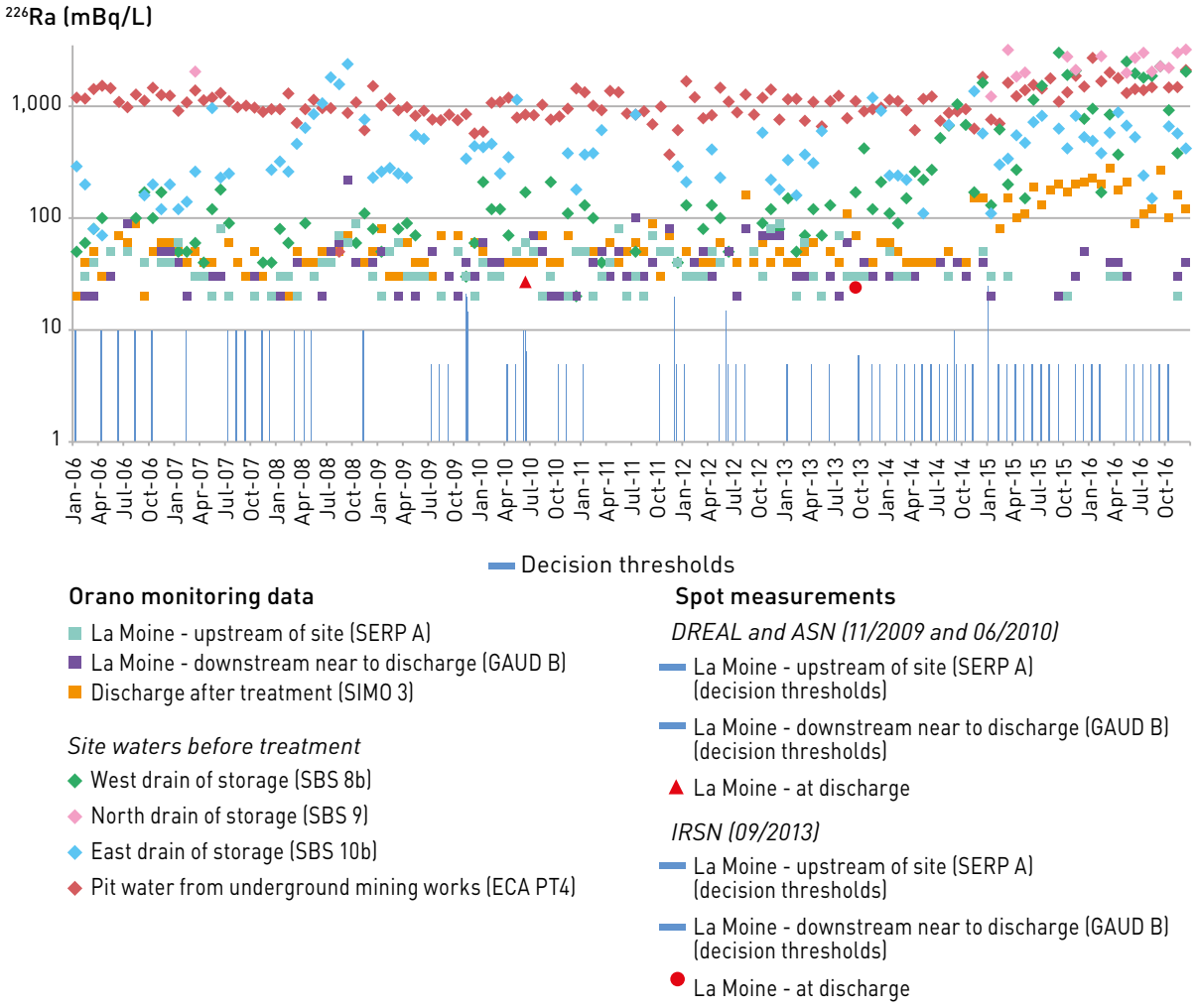


FIGURE 7 / **RADIUM-226 ACTIVITY IN THE SITE WATERS BEFORE TREATMENT, AT THE DISCHARGE POINT AFTER TREATMENT AND IN THE MOINE RIVER (mBq/L)**



Sediments

The results of monitoring the sediments in the Moine river, between 2006 and 2016, indicate that the average uranium-238 and radium-226 activity levels are higher at points GAUD B and CASS B (cf. table 3) compared to those upstream (SERP A). The results of spot measurements made by the ASN at the same sampling points also confirm this trend.

TABLE 3 / **ACTIVITY PER UNIT MASS OF URANIUM-238 AND RADIUM-226 IN THE SEDIMENTS SAMPLED FROM THE MOINE RIVER BETWEEN 2006 AND 2016 (Bq/kg sec)**

Name of sampling point	Orano monitoring (2006-2016)		DREAL and ASN inspections (2009 and 2010)		IRSN second-level MIMAUSA inspection (2013)	
	^{238}U (Bq/kg dry)	^{226}Ra (Bq/kg dry)	^{238}U (Bq/kg dry)	^{226}Ra (Bq/kg dry)	^{238}U (Bq/kg dry)	^{226}Ra (Bq/kg dry)
SERP A	Average: 91.8 [min.: < 50; max.: 150]	Average: 82.7 [min.: 40; max.: 130]	*2009* 81 *2010* 119	< 69 138		
GAUD B	Average: 247.9 [min.: < 50; max.: 654]	Average: 251.8 [min.: 90; max.: 560]	*2009* 463 *2010* 170	964 300		
FRO B	Average: 78.0 [min.: < 30; max.: 148]	Average: 81.8 [min.: 50; max.: 130]				
CASS B	Average: 259.5 [min.: < 65; max.: 1500]	Average: 175.5 [min.: 50; max.: 470]	*2009* / *2010* 1100	/ 86		
Downstream of site					160	100

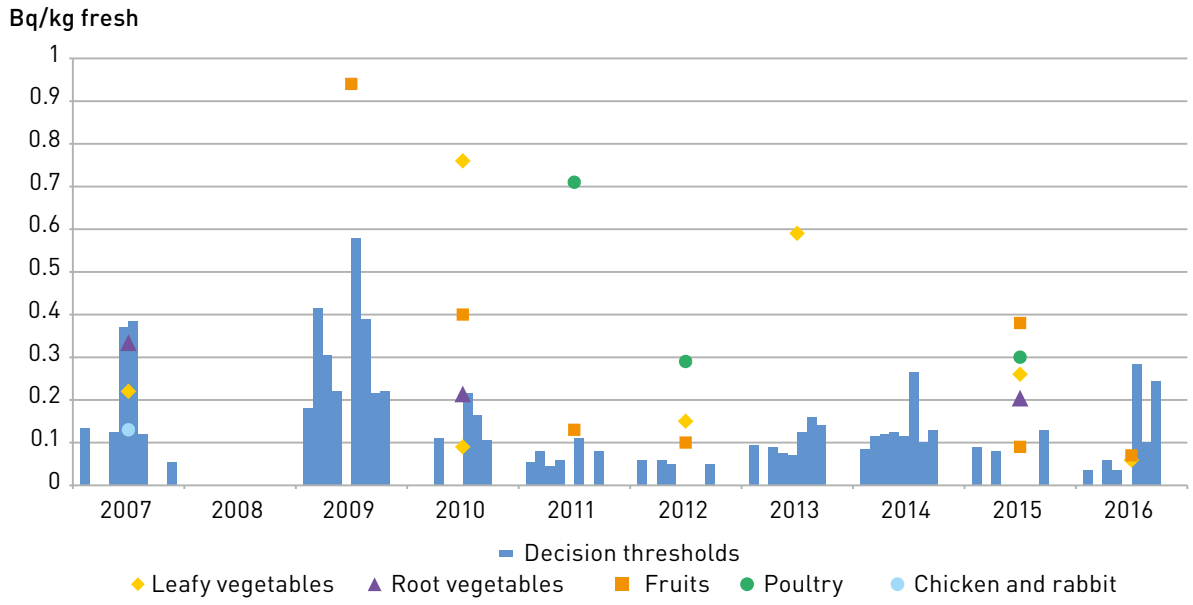
Food chain

Figure 8 presents the radium-226 activity levels measured in certain foodstuffs sampled around the site. Since 2009, measurements have been made on mixtures of foodstuffs of the same category taken from several villages located on the right bank of the Moine river (Saint-Crespin-sur-Moine, Fromont, Gaudu) and on its left bank (Braudière, Haute-Gente and Charpraie). The radium-226 activity levels are between:

- 0.037 (decision threshold) and 0.76 Bq/kg fresh for leafy vegetables;
- 0.035 (decision threshold) and 0.33 Bq/kg fresh for root vegetables;
- 0.070 (decision threshold) and 0.94 Bq/kg fresh for fruits;
- 0.050 (decision threshold) and 0.71 Bq/kg fresh for poultry;
- 0.055 (decision threshold) and 0.13 Bq/kg fresh for a mixture of chicken and rabbit.

These values are situated within the ranges observed in France in zones with "high natural radioactivity levels" (abbreviated as HNRN, cf. chapter 2 figure 10), and indeed in zones that are less rich in natural uranium.

FIGURE 8 / **RADIUM-226 ACTIVITY FOR VARIOUS FOODSTUFFS SAMPLED AROUND THE L'ÉCARPIÈRE SITE (Bq/kg fresh)**



Le Bosc site

The Le Bosc site is situated in the Hérault department in the municipalities of Soumont and Le Bosc, located several kilometres to the south-east of Lodève. The Lergue river runs to the west of the site and has several tributary streams that partially drain the Le Bosc site (cf. figure 2). The Lodève region is characterised by a Mediterranean climate with a "Cévennes"-type rainfall pattern (i.e.: very intense rain spells that can extend over 2 to 3 days). This particular rain pattern can lead to intense leaching of the soils over a short period.

Covering an area of around 220 ha, this site was operated from 1978[2] to 1997, with underground mine works and several open-pit mines, producing 14,632.5 tonnes of uranium (cf. table 1). An ore processing plant was also in operation on the site between 1981 and 1997. This plant was dismantled and the entire site was redeveloped (cf. figure 1). Currently, the site contains a uranium ore processing tailings repository (4,142 Mt of dynamic processing tailings) and a water treatment station. Furthermore, part of the site was redeveloped as an industrial zone and another part turned into a solar park.

TABLE 1 / **TONNAGE OF DIFFERENT PRODUCTS ISSUING FROM THE LE BOSC MINE AND THE PROCESSING FACILITIES**

Uranium extracted by the Le Bosc mining operation (tonnes)	Tonnage of ore processed at the Le Bosc plant (tonnes)	Uranium produced in the plant (tonnes)	Tailings from dynamic processing (millions of tonnes)
14,633 or 18.1% of French production	4,141,518	12,853 or 15.9% of French production	4142 or 13.5% of tailings from dynamic processing produced in France

FIGURE 1 / **THE LE BOSC SITE BEFORE AND AFTER REDEVELOPMENT**

Source: Orano

2. Small-scale reconnaissance work took place on this site starting in 1959.

Monitoring plan

The Le Bosc site is subject to regulatory monitoring, along with complementary monitoring at the initiative of the operator. The Orano monitoring plan is presented below (cf. table 2 and figure 2), involving the monitoring of the following:

- site water (discharge and drainage waters from the tailings and mining works);
- gamma radiation on and around the site;
- air quality on and around the site (radon and dust);
- the aquatic environment around the site;
- the food chain around the site;
- underground water on the site and in the environment.

One of the specific characteristics of the site is the presence, in the uranium deposit rocks, of minerals containing molybdenum and arsenic. For this reason, the concentrations of arsenic and molybdenum are also among the parameters included in the monitoring, as well as the radiological parameters.

This monitoring is complemented by spot analyses, in particular in the framework of random checks or of the MIMAUSA programme.

TABLE 2 / **MEASUREMENTS MADE ON AND AROUND THE LE BOSC SITE**

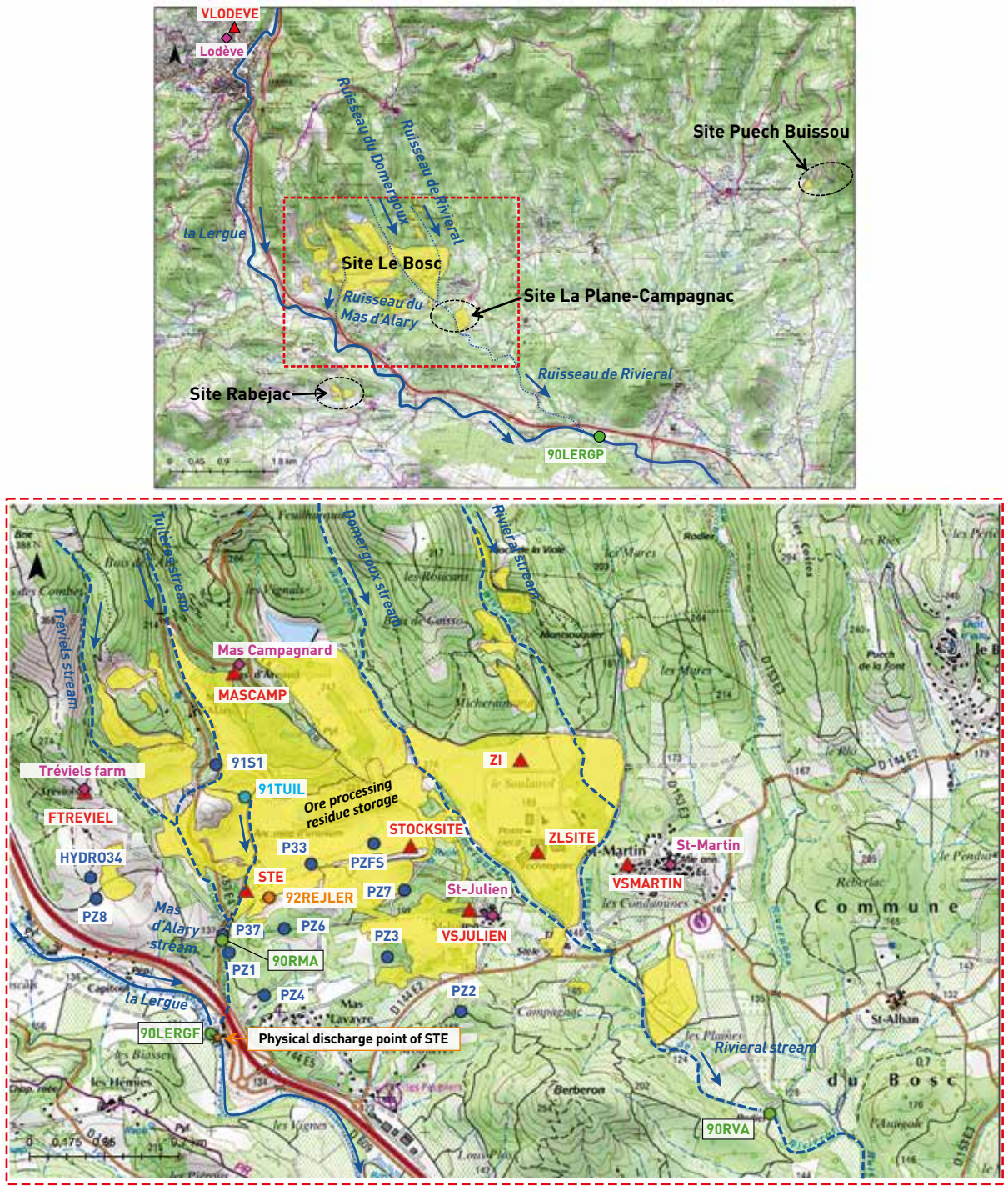
Monitored environment or nature of inspection	Orano	DREAL	IRSN
Site water	• **Regulatory monitoring at the discharge point (point 92REJLER)** Measurements: – Continuous: flow rate, pH, soluble uranium – Weekly on an average daily sample: T°, TSS, SO_4^{2-}, ^{226}Ra (in event of ^{226}Ra processing) – Quarterly on an average daily sample: COD – Every 3 days on an average sample over 3 days: uranium, barium (in event of processing with barium chloride), ^{226}Ra (in event of processing with barium chloride), arsenic (in event of processing arsenic) – Monthly on an average daily sample: molybdenum, arsenic (except in the event of processing arsenic)	• **Random checks (2010 and 2013):** At the discharge point: spot measurements of uranium, ^{226}Ra, and ^{210}Pb	
Gamma radiation	• **Regulatory monitoring:** 9 measurement stations: 1 in the natural environment, 4 in the surrounding villages and 4 on-site		
Air (radon-222 and radon-220)	• **Regulatory monitoring:** 9 measurement stations: 1 in the natural environment, 4 in the surrounding villages and 4 on-site. Monthly measurements of the ^{222}Rn PAEC and the ^{220}Rn PAEC		

Monitored environment or nature of inspection	Orano	DREAL	IRSN
Continental aquatic environment	• **Regulatory monitoring:** – Water: 3 sampling points (90 RMA, 90 RVA and 90 LERGP) Monthly measurements of uranium, ^{226}Ra, ^{210}Pb, pH, SO42-, arsenic and molybdenum. Quarterly measurements of the COD. – Sediments: 4 sampling points (90 RMA, 90 RVA, 90 LERGF and 90 LERGP), measurements made every 5 years (^{238}U, ^{226}Ra, ^{210}Pb and particle sizes) – Bio-indicators (aquatic plants, fish): 4 sampling points (90 RMA, 90 RVA, 90 LERGF and 90 LERGP), measurements made every 5 years (^{238}U, ^{226}Ra and ^{210}Pb) • **Monitoring at the operator's initiative:** 1 additional monitoring point for surface water (90 LERGF). Monthly measurements of uranium, ^{226}Ra, ^{210}Pb, pH, SO_4^{2-}, arsenic and molybdenum. Quarterly measurements of the COD.	• **Random checks (2010 and 2013):** Surface water: – 2010: 5 sampling points (points 13 = LERGF, 14 = LERGP, 12 = Mas d'Alary, 16 = far upstream the Lergue, 15 = Rivieral stream). Spot measurements of uranium, ^{226}Ra and ^{210}Pb. – 2013: 4 sampling points (points LERGF, LERGP, Mas d'Alary, Rivieral stream). Spot measurements of uranium, ^{226}Ra and ^{210}Pb.	• **MIMAUSA programme in 2014:** Water: 9 points – 1 point at regulatory monitoring point 90RMA. – Other points: Lergue river: entirely upstream of the site – near Lodève, at point LERGF, immediately downstream of Le Bosc site discharge, Mas d'Alary stream: ahead of confluence with the Lergue; Domergoux stream: entirely downstream of site; Rivieral stream: entirely downstream of site, downstream of confluence with Domergoux stream, immediately downstream of La Plane Campagnac site • Spot measurements of uranium and ^{226}Ra
Overground environment (food chain)	• **Regulatory monitoring:** Every 2 years, for 5 food categories (composite samples)		
Underground water	• **Regulatory monitoring:** 10 piezometers on and around the site; Quarterly measurements of uranium, ^{226}Ra, ^{210}Pb, pH, SO_4^{2-}, arsenic and molybdenum. • **Monitoring at the operator's initiative:** 2 additional points: 91 S1: uranium and ^{226}Ra measurements 91 TUIL: uranium measurements	• **Random checks (2013):** 2 points (piezometer FS and P33). Spot measurements of uranium, ^{226}Ra and ^{210}Pb	

TTS: total suspended solids, COD: chemical oxygen demand.

FIGURE 2 / **MAPS OF LOCATIONS OF SAMPLES LINKED TO THE REGULATORY MONITORING OF THE LE BOSC SITE**

Mining site footprint: Source Orano



Influence of the Le Bosc site on its environment

Gamma radiation and air quality

For the period 2015-2016, the dose rate varied between 139 and 225 nGy/h on average for the measurement stations located on the Le Bosc site, and between 140 and 216 nGy/h on average for those located in the villages around the site (cf. figures 3 and 4). These values are consistent with the values generally observed on former mining sites and in their environment.

The different values measured on the site can be explained by the nature of the soils at the measurement stations:

- The lowest average is located at the station close to the water treatment plant (STE). This was installed directly above a former open-pit mine partially backfilled with mining waste.
- The intermediate values are to be found in the former industrial zone (former ore processing plant), which has been redeveloped (stations ZI = dismantled industrial zone and ZLSITE = developed/re-converted industrial zone).
- The highest average is recorded at the station located on the tailings repository.

The dose rate measurements in the villages illustrate the variability of this parameter according to the geology. Indeed, the measurement stations can be categorised according to the geology of the land on which they are located (cf. figure 4).

- The villages of Saint-Martin and Saint-Julien, situated over rock belonging to the "red" Autunian stage, present average dose rate values of 140 and 141 nGy/h respectively.
- Mas Campagnard and Ferme de Tréviel, situated over rock belonging to the "grey" Autunian stage, present average dose rate values of 185 and 216 nGy/h respectively.

FIGURE 3 / **2015-2016 AVERAGE OF DOSE RATES MEASURED BY ORANO ON THE LE BOSC SITE (nGy/h)**

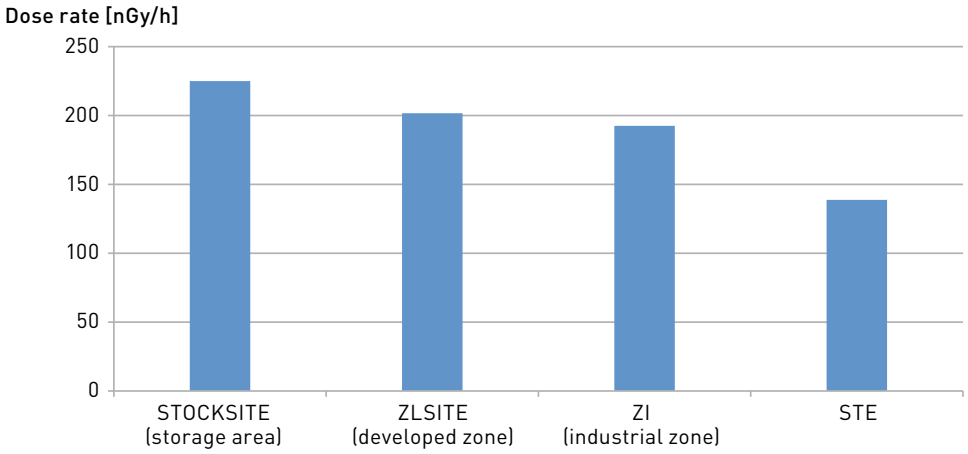
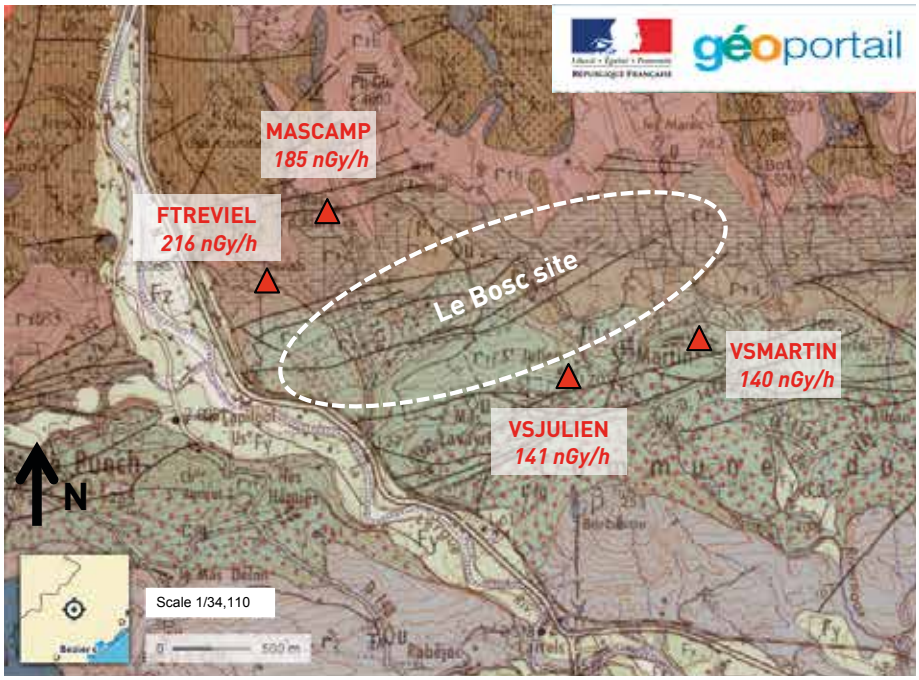


FIGURE 4 / **SITING OF MEASUREMENT STATIONS AND AVERAGE 2015-2016 DOSE RATES (nGy/h) MEASURED BY ORANO AROUND THE LE BOSC SITE AGAINST THE GEOLOGICAL MAP BACKGROUND**

Map background: geological map 1/50,000th No. 989 Lodève sector ©BRGM. Source: Géoportail.



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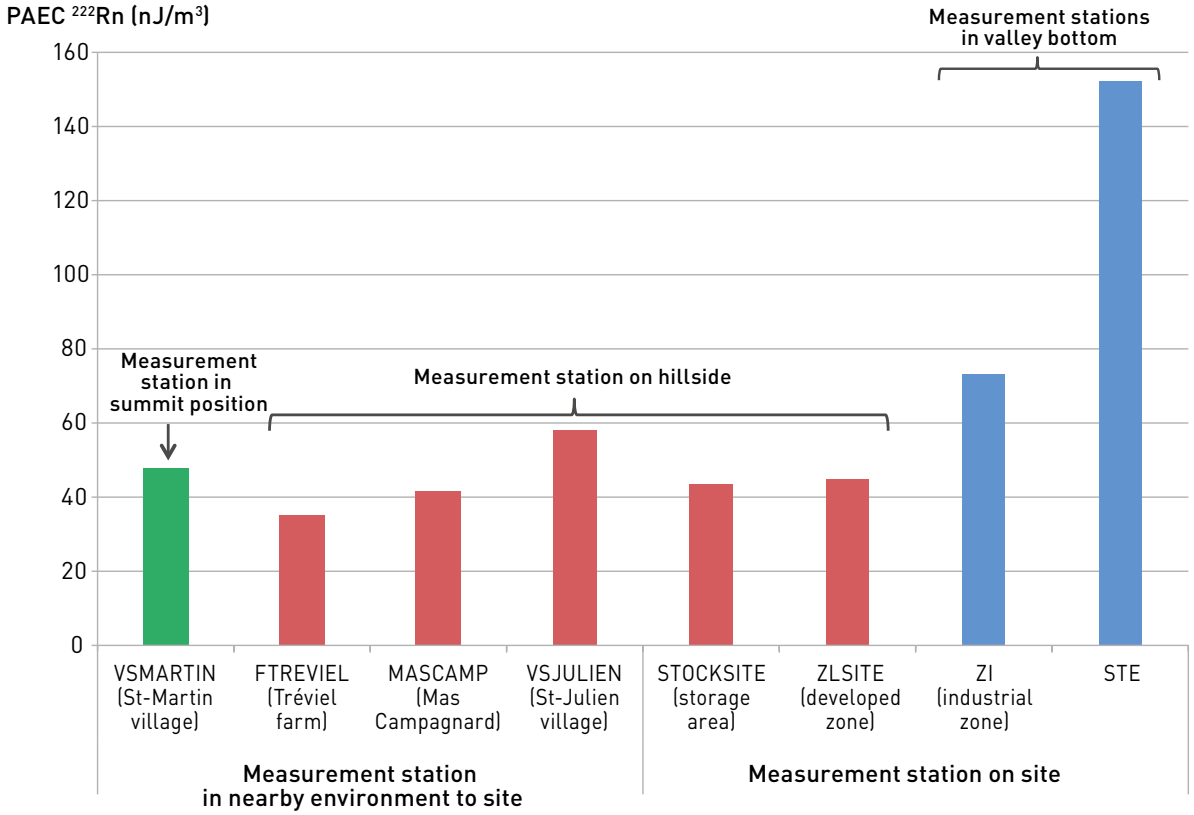
Solar panels on the Le Bosc site

The average ^{222}Rn PAEC values for 2015-2016 amount to between 35 and 58 nJ/m^3 in the villages and between 43 and 152 nJ/m^3 on the site (cf. figure 5). The highest averages are therefore to be found in the stations located in the valley bottom (stations STE and ZI), a situation less conducive to the dispersion of radon in the air. It should be noted that the measurements made for the topographical situations most conducive to the dispersion of radon ("summit" and "hillside") at L'Écarpière present comparable levels (cf. p. 264). This can be explained by the fact that the environment of the Le Bosc site presents a relief that is less markedly conducive to the dispersion of radon.

FIGURE 5 / **2015-2016 AVERAGE OF ^{222}RN PAEC MEASURED BY ORANO FOR THE MONITORING ON AND IN THE SURROUNDING ENVIRONMENT OF THE LE BOSC SITE (nJ/m^3)**



Surface water

The water issuing from the underground mining works (pumped *via* well P33) along with the water issuing from the drainage of the ore processing tailings repository are treated before being discharged into the Lergue river. One of the challenges of this site is the management of the seasonal flow rate variations, which can be very significant, such as during "Cévenne"-type heavy rain episodes. To manage these flow rate variations, therefore, the site has two water treatment processes:

- uranium sequestration on ion-exchanging resins (in normal operation);
- treatment by precipitation-decantation after addition of lime (in periods of heavy rain or failure of sequestration on resins).

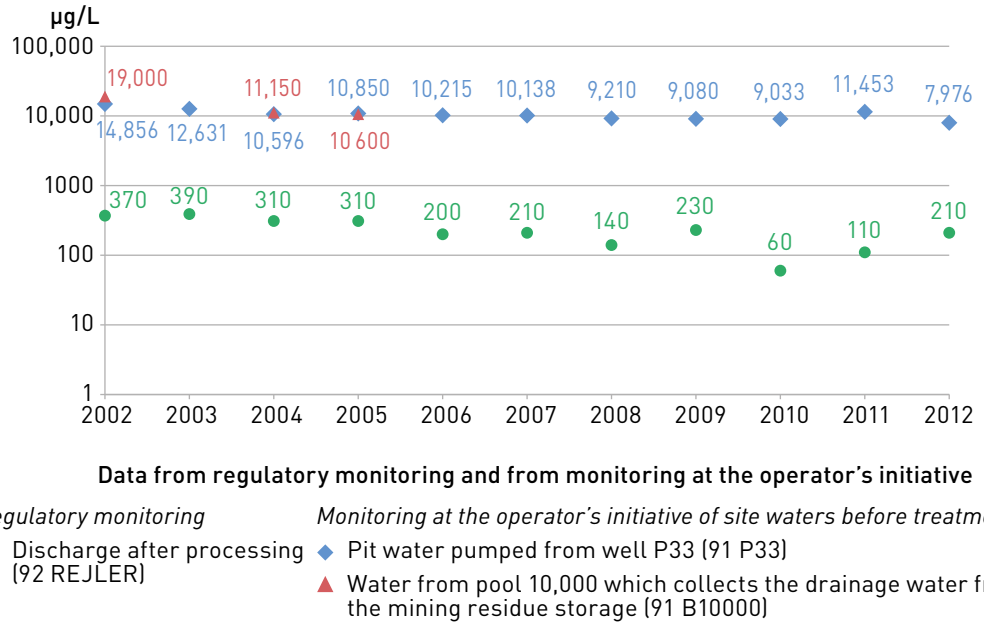
The purpose of this processing is to lower the uranium content in the water so as to comply with the regulatory limit of 1800 µg/L for uranium. For the period 2010-2016, the average concentration of uranium in the discharges was 242 µg/L.

Figure 6 shows that the uranium concentrations in the water to be processed are very high (around 10,000 µg/L on average) compared to the other mining sites. By way of comparison, the water treated on the L'Écarpière site presented average concentrations (2006-2016 period) of between 90 µg/L and 411 µg/L. It next appears that the treatment has been very efficient, with a more than tenfold reduction in the uranium concentration.

The measurements made around the site, for the period 2010-2016, show that the streams draining the various zones of the site (points 90RMA and 90RVA, cf. figure 7) presented higher uranium concentrations than the point located upstream of the site (point LERGF, U_{LERGF} = 1.5 µg/L, cf. figure 7). The average uranium concentrations at points 90RMA and 90RVA are therefore 1230.2 µg/L and 574 µg/L respectively. The streams of Mas d'Alary and Rivieral receive the rainwater of the site, which might explain these high concentrations. These various streams and the discharge have an influence on the Lergue river downstream of the site, with the average

FIGURE 6 / **AVERAGE URANIUM CONCENTRATIONS BETWEEN 2002 AND 2012 IN THE WATERS BEFORE TREATMENT (points 91 P33 and 91 B10000) AND AFTER TREATMENT (point 92 REJLER) (µg/L)**

Source: Orano



uranium concentration around 3 times higher at point LERGP (U_{LERGP} = 5.8 µg/L) than upstream of the site (U_{LERGF} = 1.5 µg/L).

For the period 2010-2016 (cf. figure 8), the highest radium-226 activity was recorded at the discharge point (^{226}Ra =257.6 mBq/L on average) and, to a lesser extent, in the streams of Mas d'Alary and Rivieral (average activity: $^{226}Ra_{RMA}$ =82.1 mBq/L, $^{226}Ra_{RvA}$ =75.1 mBq/L). It should be noted that there were nine occasional overshoots of the regulatory discharge limit for radium-226 (which is 740 mBq/L) between December 2015 and the end of April 2016 following an exceptional "Cévennes"-type heavy rainfall episode in late 2015. Generally, the discharge and the contribution from the streams have very little influence on the radium-226 activity in the Lergue river. Indeed, the measurements made entirely downstream of the site reveal average radium-226 activity of similar magnitude to that measured upstream (upstream: $^{226}Ra_{LERGF}$ = 31.9 mBq/L, downstream: $^{226}Ra_{LERGP}$ = 42.6 mBq/L) for the entire measurement period.

The results of the various spot measurements carried out in the framework of random checks or the MIMAUSA programme are consistent with those deriving from the monitoring of the operator (cf. figures 7 and 8).

FIGURE 7 / **URANIUM CONCENTRATION, BETWEEN 2010 AND 2016, AT THE DISCHARGE POINT AND IN THE SURFACE WATERS IN THE ENVIRONMENT OF THE LE BOSC SITE (µg/L)**

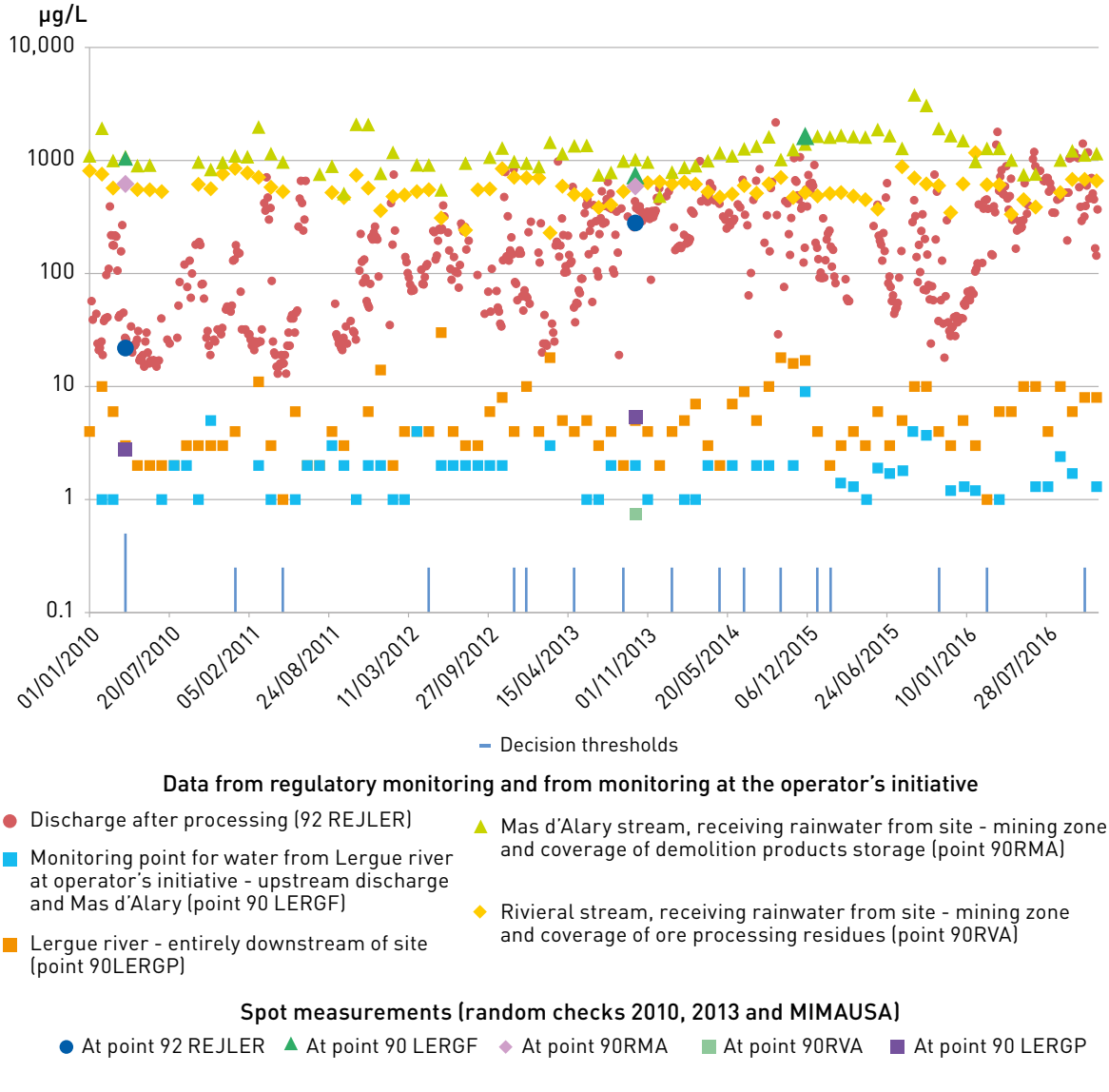


FIGURE 8 / **RADIUM-226 ACTIVITY, BETWEEN 2010 AND 2016, AT THE DISCHARGE POINT AND IN THE SURFACE WATERS IN THE ENVIRONMENT OF THE LE BOSC SITE (mBq/L)**

Sediments

The results of the monitoring of the sediments around the Le Bosc site, between 2006 and 2016, indicate that the average ^{238}U and 226R activity is higher in the streams of Mas d'Alary and Rivieral (points 90RMA and 90RVA, cf. table 3) than in the Lergue river. These results are consistent with the markings observed in the water of these two streams. Furthermore, these results indicate that there is no significant marking in the Lergue river downstream of the site.

Fish

The radium-226 and polonium-210 activity measured in two fish species (chub and barbel), sampled in the Lergue river upstream and downstream of the site, was found to be (cf. figure 9):

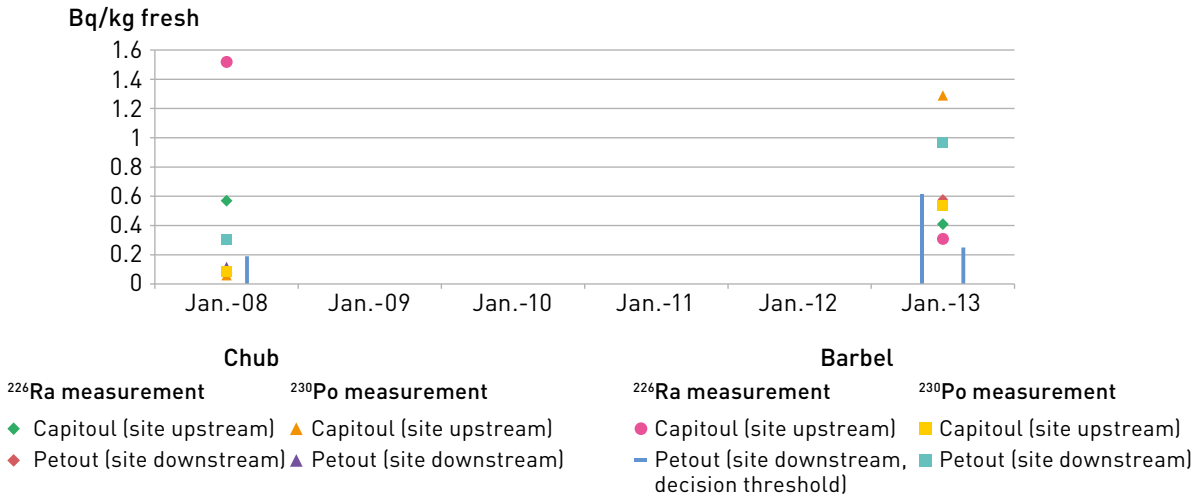
- for radium-226, between 0.31 and 1.52 Bq/kg fresh upstream and < 0.25 (decision threshold) and 0.58 Bq/kg fresh downstream;
- for polonium-210, between 0.06 and 1.29 Bq/kg fresh upstream and < 0.113 (decision threshold) and 0.97 Bq/kg fresh downstream.

It should be noted that fish taken downstream of the sites may also spend time upstream, which makes it difficult to compare the results obtained.

TABLE 3 / **AVERAGE ACTIVITY PER UNIT MASS OF URANIUM-238 AND RADIUM-226 IN THE SEDIMENTS SAMPLED AROUND THE LE BOSC SITE BETWEEN 2006 AND 2016 (Bq/kg dry)**

Names of sampling points	Orano monitoring (2006-2016)	
	^{238}U (Bq/kg dry)	^{226}Ra (Bq/kg dry)
Lergue – Upstream of site (90LERGF)	Average: 70.4 [min.: 25; max.: 300]	Average: 59.9 [min.: 40; max.: 87.6]
Lergue – Downstream of site (90LERGF)	Average: 47.7 [min.: 31.8; max.: 75]	Average: 67.2 [min.: 40; max.: 120]
Rivieral stream (90RVA)	Average: 280 [min.: 170; max.: 420]	Average: 378 [min.: 261; max.: 510]
Mas d'Alary stream (90RMA)	Average: 344.7 [min.: 245.2; max.: 503.7]	Average: 329.7 [min.: 285.9; max.: 399]

FIGURE 9 / **RADIUM-226 AND POLONIUM-210 ACTIVITY IN FISH FLESH (chub and barbel) SAMPLED AROUND THE LE BOSC SITE (Bq/kg fresh)**



La Commanderie site

The La Commanderie site is situated between the municipalities of Treize-Vents (Vendée) and Mauléon (Deux Sèvres). This site is located on granitic terrain, with an area of around 60 ha, and was operated from 1955 to 1990, with underground mine works and an open-pit mine, producing 3977 tonnes of uranium (cf. table 1). In 1969, a static leaching processing facility for low-content ore (150 to 600 ppm of uranium) was set up on the La Commanderie site. The ore, crushed down to 80 mm and placed in a sealed area, was watered with a mixture of water and sulphuric acid. This process enabled the uranium to be extracted by solubilisation. The uranium liquor obtained in this way was then transported to the L'Écarpière plant. The product residues (0.25 Mt) were then stored with the materials issuing from the dismantling of the static processing facility (pools, concrete storage area for the ore, leaching area) at the bottom of the open-pit mine under a cover consisting of a layer of lime and mine tailings. The open-pit mine was then flooded. The site now plays host to diverse activities such as a solar park and agricultural and industrial activities. Furthermore, the water from the La Commanderie open-pit mine has been used for irrigation purposes since 1993.

TABLE 1 / **TONNAGE OF DIFFERENT PRODUCTS ISSUING FROM THE LA COMMANDERIE MINE AND THE PROCESSING FACILITIES**

Uranium extracted by the La Commanderie mining operation (tonnes)	Uranium produced by static processing (tonnes)	Tailings from static processing (millions of tonnes)
3977.5 *or 4.9% of French production*	Included in the production of the L'Écarpière plant	0.25 *or 1.4 % of tailings from static processing produced in France*

FIGURE 1 / **THE LA COMMANDERIE SITE, DURING MINING OPERATION, BEFORE AND AFTER REDEVELOPMENT**
Source: Orano


La Commanderie during operation (1975)


La Commanderie during redevelopment


La Commanderie after redevelopment

Monitoring plan

The La Commanderie site is subject to regulatory monitoring prescribed by prefectural order, amended in January 2017. However, in the framework of this *Radiological report*, only the data obtained until 2016 are presented. The complementary points deriving from the new monitoring plan are indicated for information purposes in table 2. The monitoring conducted before 2017 by Orano is presented below (cf. table 2 and figure 2), involving the monitoring of the following:

- site waters (waters of the open-pit mine);
- the aquatic environment around the site (La Commanderie stream, La Boisdrotière stream);
- the food chain around the site (in particular the fields and crops that are irrigated by the water from the mine).

This monitoring by the operator is complemented by spot analyses, in particular in the framework of random checks or of the MIMAUSA programme.

It should be noted that the monitoring of the air quality and gamma radiation ceased in 1995 upon production of the site relinquishment and partial abandonment report, which is why no measurement concerning these two parameters is presented below.

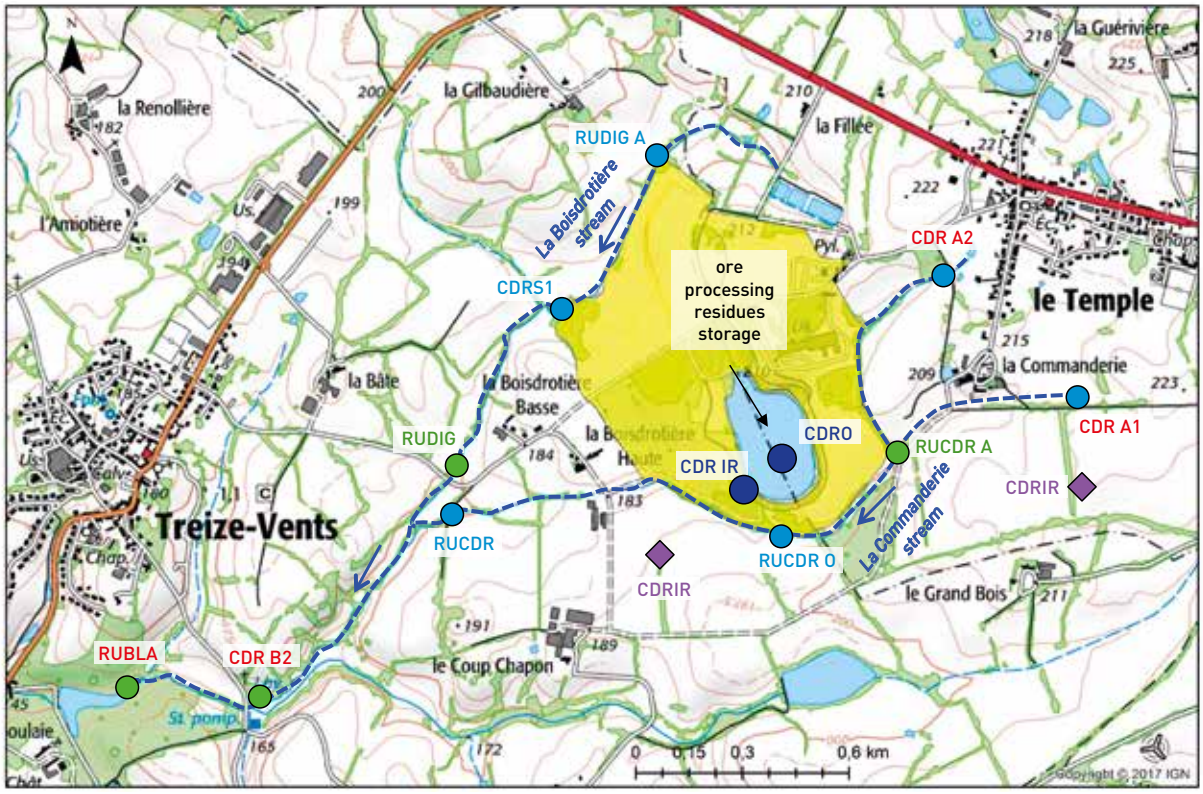
TABLE 2 / **MEASUREMENTS MADE ON AND AROUND THE LA COMMANDERIE SITE**

Monitored environment or nature of inspection	Orano	IRSN	DREAL and ASN
Site water	• **Regulatory monitoring:** • **Open-pit water:** surface water (CDR O) and bottom of pool (water used for irrigation = CDR IR) • **Measurements:** ^{238}U, ^{226}Ra, pH, Al, As, Fe, Mn - for point CDR O: quarterly measurements - for point CDR IR: at the start of each pumping campaign then monthly during the pumping campaign		• **Random checks (2009 and 2010):** 1 point (CDR O), spot measurements of uranium, ^{226}Ra and physical-chemical parameters
Continental aquatic environment	• **Regulatory monitoring:** • **Water:** 6 sampling points (RUCDR A, RUDIG A, RUCDR O, RU CDR, CDR S1, RUDIG) Quarterly measurements of ^{238}U, ^{226}Ra, pH, Al, As, Fe and Mn. 5 additional points from 2017: CDRA1, CDRA2, CDRB1, RUBLA, MALLB • **Sediments:** 2 sampling points (RUCDRA, RUDIG), annual measurements ($U_{by\ weight}$ by gamma spectrometry) 2 additional points from 2017: CDRB1, RUBLA	• **MIMAUSA programme in 2013:** • **Water:** 4 sampling points - 3 points at the regulatory monitoring points: RUCDRO, RUDIG and a little further upstream from point RUDIGA). - Other point : the La Commanderie stream, at the foot of the mining waste pile. Spot measurements of uranium and ^{226}Ra • **Sediments:** 1 point (La Commanderie stream, at the foot of the mining waste pile), spot measurements of radionuclides of the uranium-238 chain	• **Random checks (2009 and 2010):** 9 points • **Water:** 5 points at the regulatory monitoring points (RUDIGA, RUDIG, RUCDRA, RUCDRO, RUCDR). - Other points: the La Boisdrotière stream downstream of the confluence with the La Commanderie stream, the La Boisdrotière stream, downstream of point RU CDR B, at the level of a lavoir, southeast stream at the level of the lavoir (2 different points). Spot measurements of uranium, ^{226}Ra and physical-chemical parameters • **Sediments:** same sampling points as for the water. Spot measurements of ^{226}Ra, ^{238}U and ^{210}Pb

Monitored environment or nature of inspection	Orano	IRSN	DREAL and ASN
Overground environment (food chain)	• **Regulatory monitoring:** • **Soils and crops:** - fields irrigated by water from the open-pit mine - fields not irrigated by water from the open-pit mine -> composite soil and crop samples per crop variety (annual measurements: $U_{by\ weight}$ by gamma spectrometry) • **From 2017: beef** (adult cattle, born and reared on site), every 3 years, measurements of the ^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po • **Monitoring at the operator's initiative:** beef (cattle fed with irrigated maize), measurements of the ^{238}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po		

FIGURE 2 / **MAP OF LOCATIONS OF SAMPLES LINKED TO THE REGULATORY MONITORING IN THE IMMEDIATE ENVIRONMENT OF THE LA COMMANDERIE SITE**

Mining site footprint: Source Orano



Influence of the La Commanderie site on its environment

Surface water

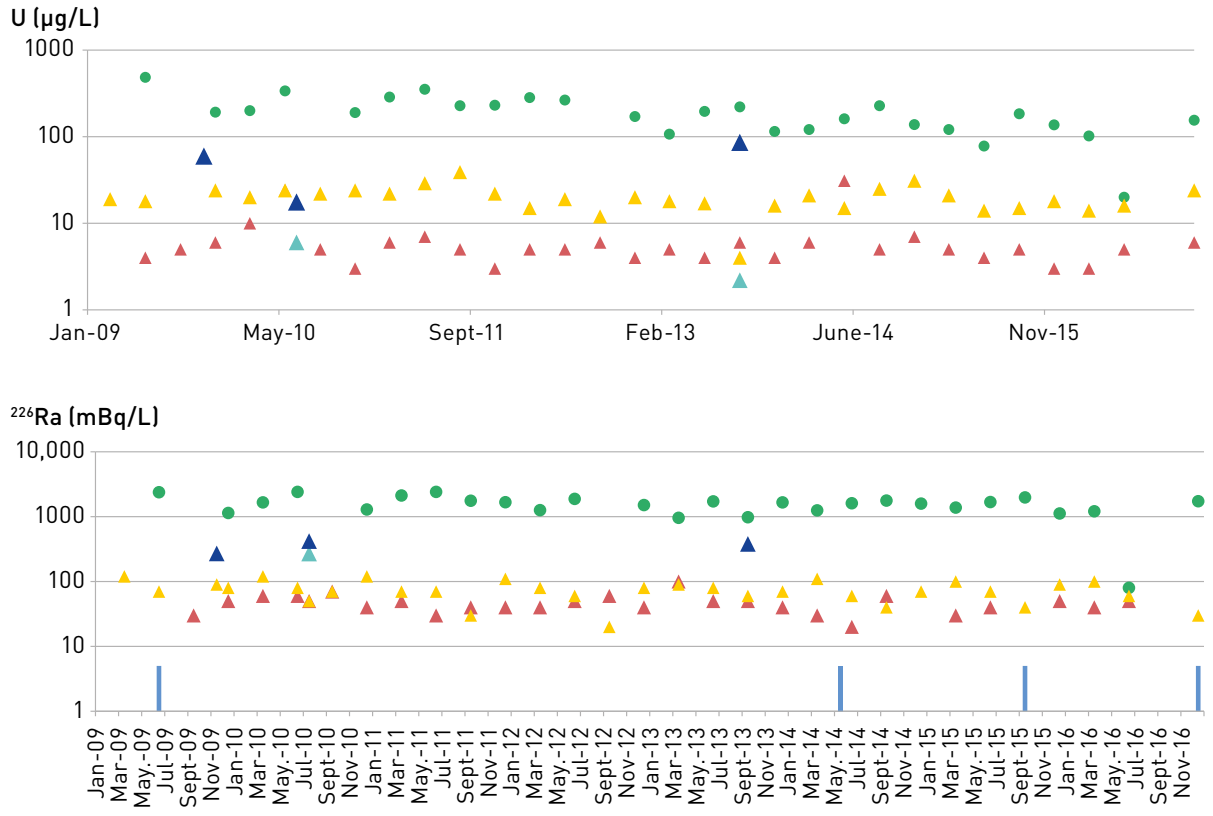
The two monitoring points considered as upstream of the site, one in the La Boisdrotière stream (point RUDIG A), the other in the La Commanderie stream (point RUCDR A, cf. figures 2 to 4) present different average values, with higher average values in the La Commanderie stream (point RUCDR A):

- RUDIG A: U = 6.6 µg/L and ^{226}Ra = 42.3 mBq/L;
- RUCDR A: U = 17.5 µg/L and ^{226}Ra = 173 mBq/L.

The various spot measurement campaigns (cf. figures 3 et 4) also show values globally higher at point RUCDR A than at point RUDIG A. One of the theories put forward is that point RUCDR A is probably already under the influence of the mine. The new monitoring points located further upstream on the La Commanderie stream (points CDR A1 and CDR A2, cf. figure 2) will enable this theory to be verified.

The measurements made in the La Boisdrotière downstream of the site revealed average values of uranium concentration and radium-226 activity (U = 19.9 µg/L and ^{226}Ra = 74.7 mBq/L at point RUDIG, cf. figure 3) approximately 1.5 to 3 times higher than upstream (point RUDIG A).

FIGURE 3 / **URANIUM CONCENTRATION (µg/L) AND RADIUM-226N ACTIVITY (mBq/L) MEASURED BETWEEN 2009 AND 2016 IN THE LA BOISDROTIÈRE STREAM**



Regulatory monitoring data

La Boisdrotière stream

- RUDIGA (La Boisdrotière stream - upstream)
- RUDIG (La Boisdrotière stream - downstream)

Other

- Emergence of a source at the foot of the waste pile

- Decision thresholds

Spot measurements (random checks 2009, 2010 and MIMAUSA)

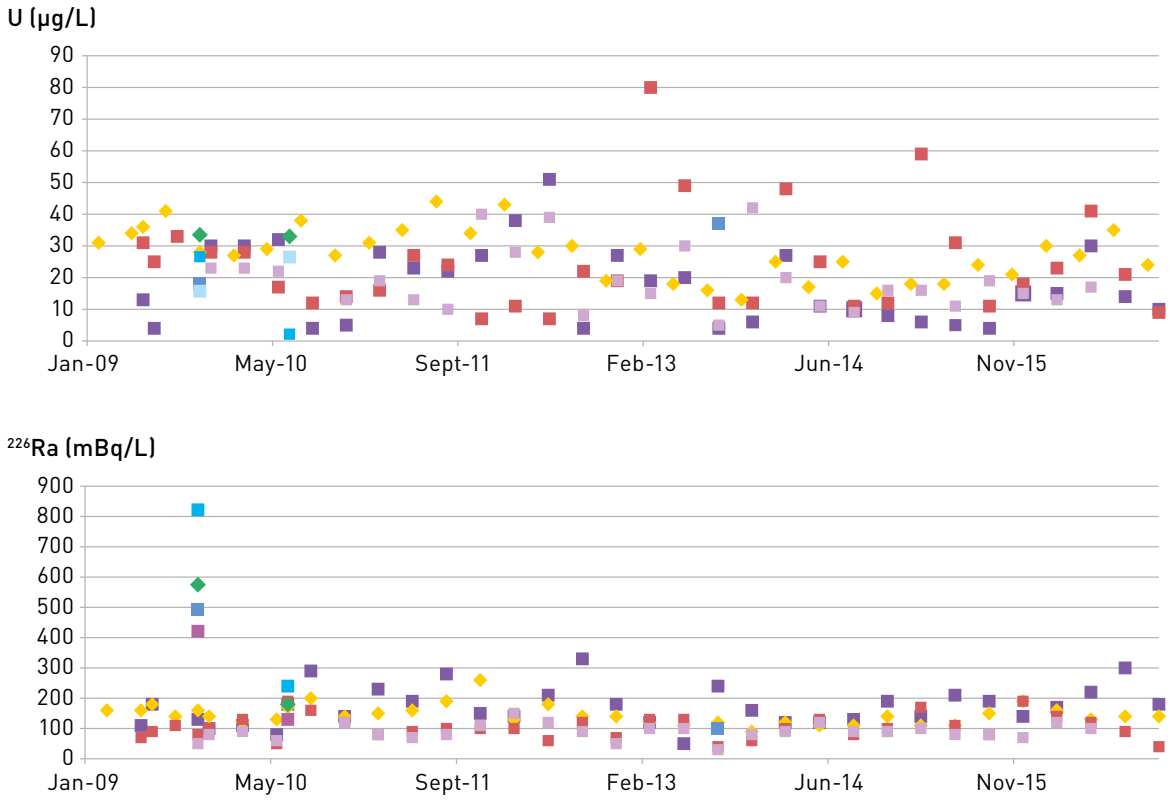
La Boisdrotière stream

- At point RUDIGA (La Boisdrotière stream - upstream)
- At point RUDIG (La Boisdrotière stream - downstream)

The existence of a source located at the foot of the waste pile (point CDRS1, cf. figures 2 and 3), which presents the highest measurements around the site, could explain the increase in the values recorded downstream of the site at the level of the La Boisdrotière stream.

For the La Commanderie stream (cf. figure 4), the high values of uranium concentration and radium-226 activity at point RUCDR A, potentially already under the influence of the mine as indicated previously, do not make it possible to determine a clear trend downstream of the site.

FIGURE 4 / **URANIUM CONCENTRATION (µg/L) AND RADIUM-226N ACTIVITY (mBq/L) MEASURED BETWEEN 2009 AND 2016 IN THE LA COMMANDERIE STREAM AND IN THE OPEN-PIT MINE**



Regulatory monitoring data

La Commanderie stream

- RUCDRA (La Commanderie stream - upstream)
- RUCDRO (canal feeding the open-pit mine)
- RUCDR (La Commanderie stream - downstream)

Other

- Water of the open-pit mine (CDRO)

Spot measurements (random checks 2009, 2010 and MIMAUSA)

La Commanderie stream

- At point RUCDRA (La Commanderie stream - upstream)
- At point RUCDRO (canal feeding the open-pit mine)
- At point RUCDR (La Commanderie stream - downstream)

Other

- Water of the open-pit mine (CDRO)

Food chain

Part of the food chain around the La Commanderie site is subject to monitoring of the foodstuffs irrigated by the water from the mine. For this, measurements are made in:

- the irrigation water (during the pumping periods);
- the irrigated soils along with the associated crops (maize and potatoes);
- the beef (from cattle fed with the maize).

Furthermore, the water from the open-pit mines used for irrigation must comply with the following values:

- The pH must be between 5.5 and 8.5.
- The uranium and the radium-226 must, respectively, be less than 1800 µg/L (in soluble form) and 370 mBq/L (in soluble form).

The measurements in the irrigation water show uranium concentration between 7 and 39 µg/L and radium-226 activity between 80 and 270 mBq/L (cf. figure 5). These values are consistent with those deriving from the monitoring of the open-pit mine water, with its average uranium concentration of 27.6 µg/L and average radium-226 activity of 145.7 mBq/L (Point CDRO, cf. figure 4).

The activity per unit mass of the radionuclides measured in the soils of the maize fields both irrigated and not irrigated with the water from the open-pit mine are of the same order of magnitude, except for the year 2016, when the irrigated soil presented an activity per unit mass of ^{234}Th (corresponding to the ^{238}U) considerably higher than in previous years (cf. figure 6), despite no significant increase in the uranium content of the open-pit mine waters being observed that year.

The radium-226 and thorium-234 activity levels measured in the maize are low (cf. figure 7):

- for radium-226, between 0.003 (decision threshold) and 0.024 Bq/kg fresh for non-irrigated maize and < 0.25 (decision threshold) and 0.58 Bq/kg fresh for irrigated maize;
- for thorium-234, the measurements are all below the decision threshold (< 0.02 Bq/kg fresh) for non-irrigated maize, and the irrigated maize presents a single significant measurement equal to 0.004 Bq/kg fresh.

The activity per unit mass of the radionuclides measured in the beef of cattle fed with maize irrigated with the water from the open-pit mine are for the most part below the decision threshold (cf. figure 8).

FIGURE 5 / **URANIUM CONCENTRATION (µg/L, left axis) AND RADIUM-226 ACTIVITY (mBq/L, right axis) MEASURED IN THE WATER OF THE OPEN-PIT MINE USED FOR IRRIGATION BETWEEN 2009 IN 2016**

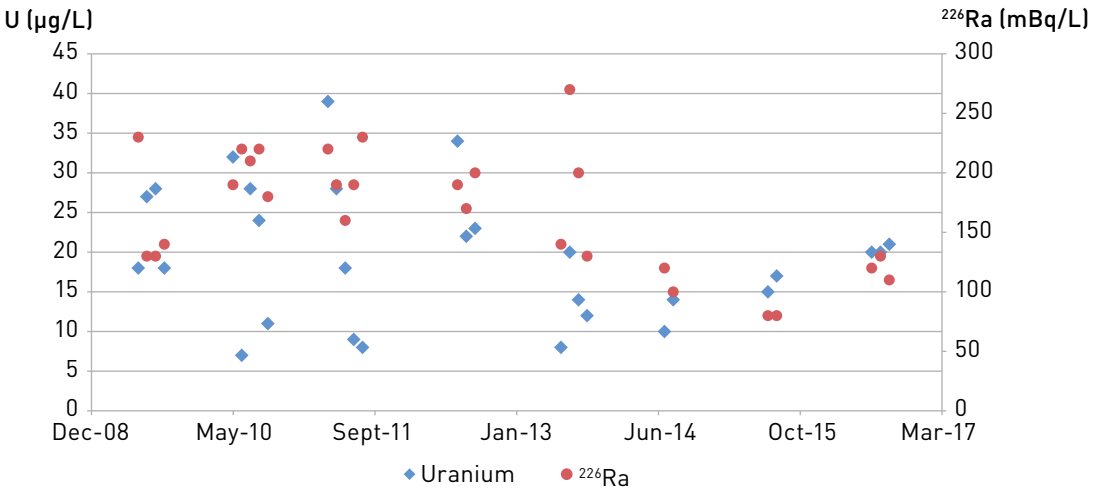


FIGURE 6 / **ACTIVITY PER UNIT MASS OF ^{234}Th (corresponding to the ^{238}U) AND OF ^{226}Ra MEASURED IN THE IRRIGATED SOILS (maize crop) AND NON-IRRIGATED SOILS (maize crop) WITH THE WATER FROM THE OPEN-PIT MINE BETWEEN 2009 AND 2016 (Bq/kg dry)**

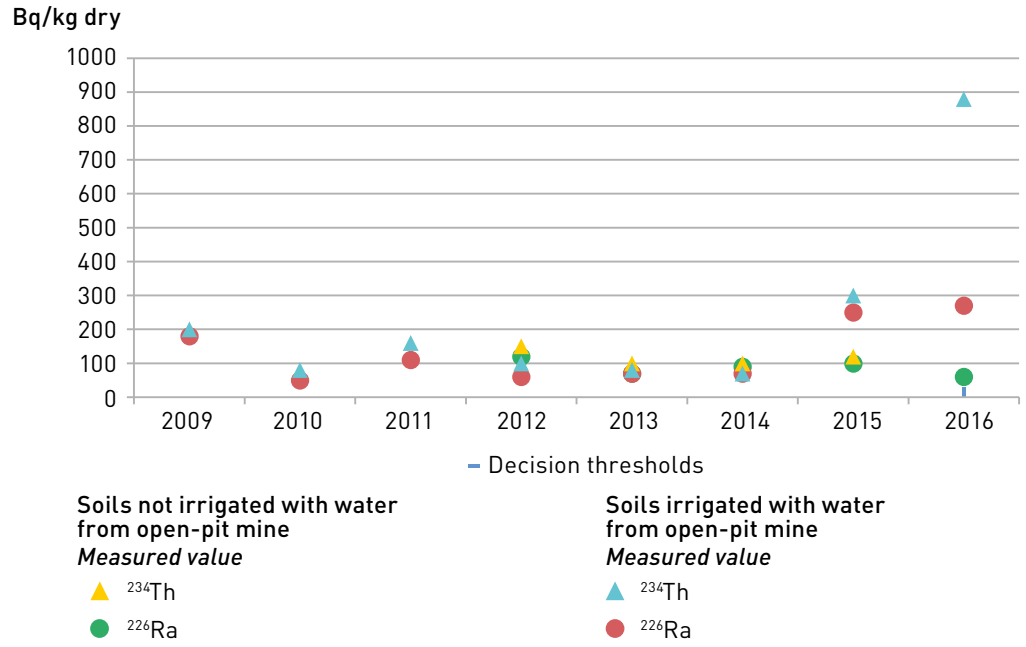


FIGURE 7 / **ACTIVITY PER UNIT MASS OF ^{234}Th (corresponding to the ^{238}U) AND OF ^{226}Ra MEASURED IN THE IRRIGATED SOILS (available data: 2009-2016) AND NON-IRRIGATED SOILS (available data: 2012-2016) WITH THE WATER FROM THE OPEN-PIT MINE (Bq/kg fresh)**

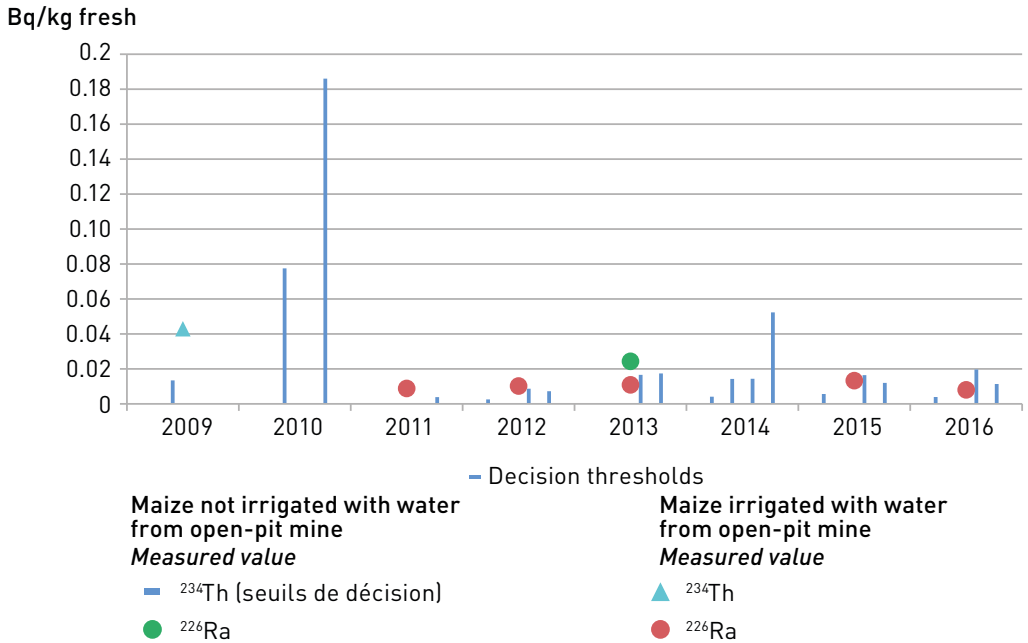
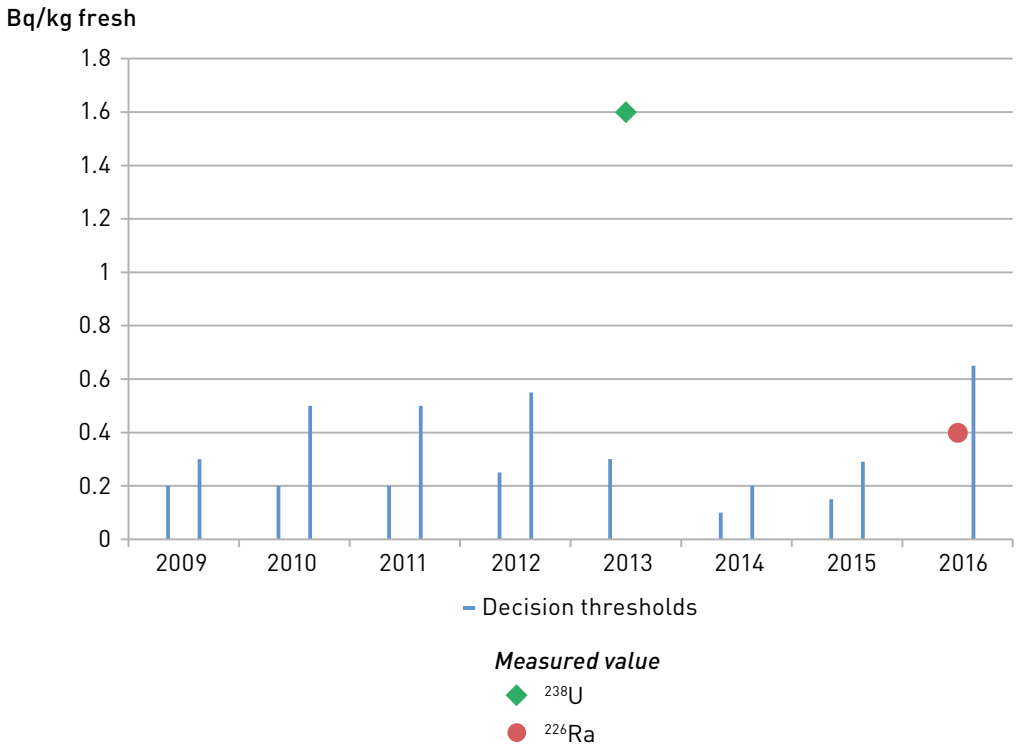


FIGURE 8 / **ACTIVITY PER UNIT MASS OF ^{238}U AND OF ^{226}Ra MEASURED IN BEEF BETWEEN 2009 AND 2016 (Bq/kg fresh)**



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La Porte former open-pit mine

La Porte site

The La Porte site is situated in the municipality of Saint-Julien-aux-Bois in Corrèze. It is located along the Riou-Tort river, downstream of several other mining sites (the main ones being Galerie des Biaurottes, Le Jaladis, La Clare and La Besse, cf. figure 1). This site, which covers an area of 6.5 ha and is located on granitic terrain, was operated between 1982 in 1984 for open-pit mining and produced 29.6 tonnes of uranium. The site was redeveloped in the mid-1990s, and the flooded open-pit mine, property of Orano, is not used and access to it is prohibited. The rest of the site belongs to private landowners and is used for pasturing.

Monitoring plan

The La Porte site is subject to regulatory monitoring. The Orano monitoring plan is presented below (cf. table 1 and figure 1), involving the monitoring of the following:

- the waters of the open-pit mine;
- gamma radiation on the site and in La Porte village;
- air quality on the site and in La Porte village (radon and dust);
- the aquatic environment around the site (the Riou Tort river).

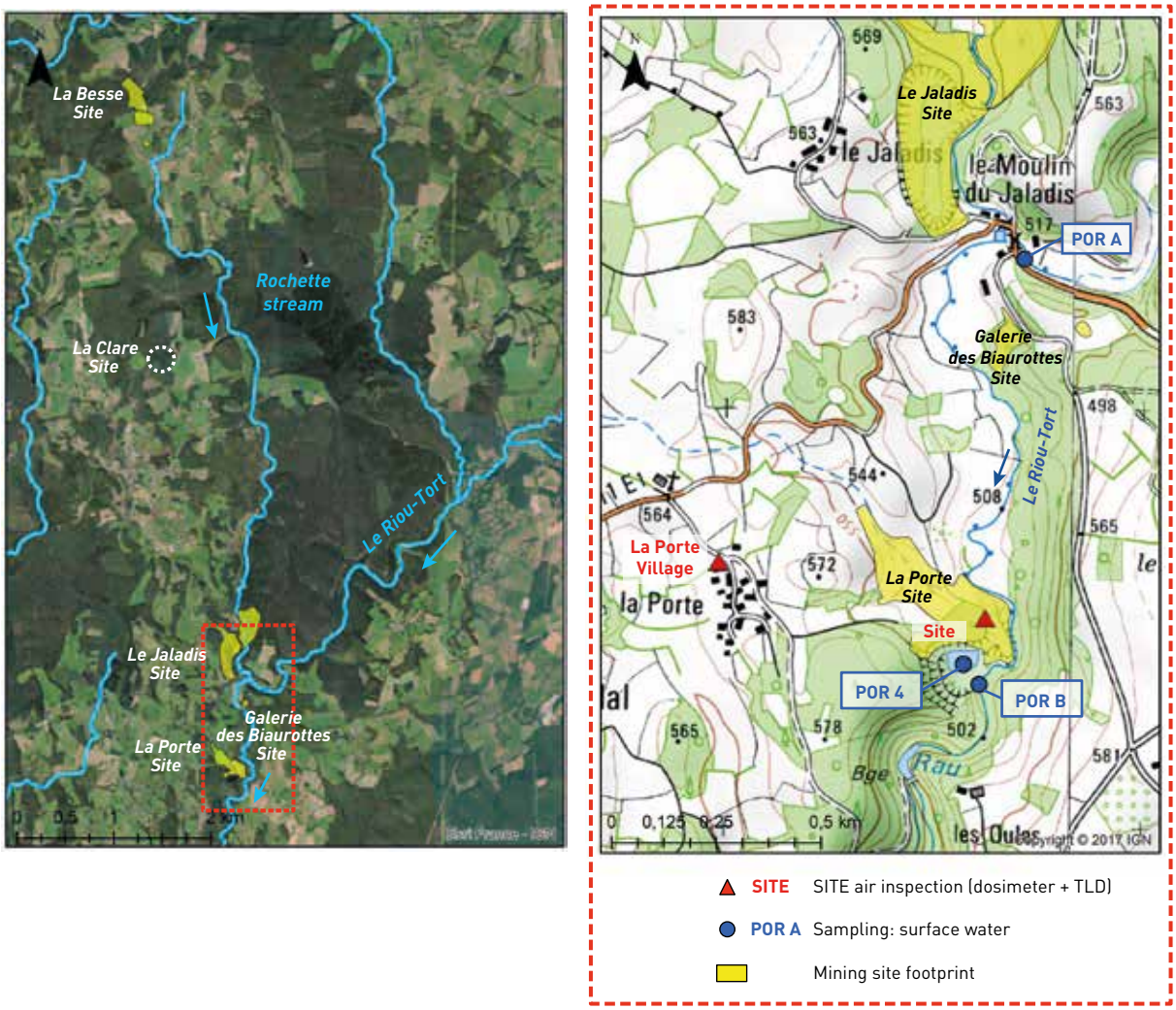
In addition, spot analyses were also conducted, in particular in the framework of random checks or the MIMAUSA programme.

TABLE 1 / **MEASUREMENTS MADE ON AND AROUND THE LA PORTE SITE**

Monitored environment or nature of inspection	Orano	IRSN	DREAL
Site water	• **Regulatory monitoring** in the open-pit mine (point POR4): Quarterly measurements of uranium, ^{226}Ra and pH	• **MIMAUSA programme in 2011:** in the open-pit mine (at point POR4): spot measurements of uranium, ^{226}Ra and physical-chemical parameters	• **Random checks in 2012:** in the open-pit mine (at point POR4): spot measurements of uranium and ^{226}Ra
Gamma radiation	• **Regulatory monitoring:** 2 measurement stations: 1 in La Porte village and 1 on the site		
Air (radon-222 and radon-220)	• **Regulatory monitoring:** 2 measurement stations: 1 in La Porte village and 1 on the site Monthly measurements of the ^{222}Rn PAEC, the ^{220}Rn PAEC and the dust		
Continental aquatic environment	• **Regulatory monitoring:** Water: 2 sampling points (POR A and POR B) Monthly measurements of the uranium, ^{226}Ra and pH	• **MIMAUSA programme in 2011:** Water: 2 points (at the open-pit mine, alongside point POR B and upstream of the La Porte site but downstream of the Galerie des Biaurottes site), spot measurements of uranium, ^{226}Ra and physical-chemical parameters	• **Random checks in 2012:** Water (at point POR B): 1 point, spot measurement of uranium and ^{226}Ra

FIGURE 1 / **SURFACE WATERWAYS NETWORK IN THE PROXIMITY OF THE LA BESSE, LA CLARE, LE JALADIS, GALERIE DES BIAUROTTES AND LA PORTE FORMER MINING SITES - SAMPLING LOCATIONS LINKED TO THE REGULATORY MONITORING OF THE LA PORTE SITE**

Mining site footprint: Source Orano



Influence of the La Porte site on its environment

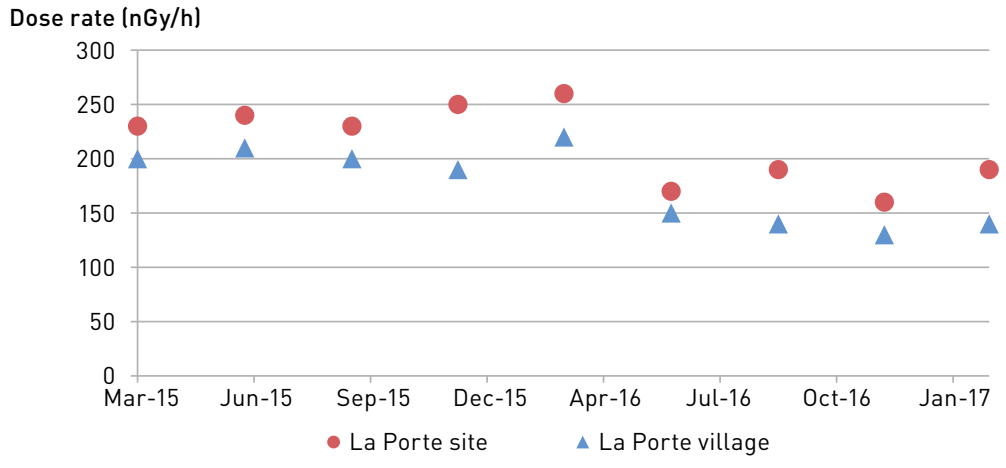
Air quality and gamma radiation

For the period 2015-2017, the dose rate varied between 160 and 260 nGy/h on the La Porte mining site, and between 130 and 220 nGy/h at La Porte village (cf. figure 2). These values are consistent with the values generally observed on former mining sites and in their granitic environment. The average value for the dose rate for this measurement period is higher on the La Porte site (average: 213 nGy/h) than in La Porte village (average: 176 nGy/h). The average value observed on the site is probably due to the location of the dosimeter directly above a redeveloped mining waste pile.

In the absence of a station measuring the immediate natural environment of the site, Orano has chosen to compare the potential alpha energy concentration (PAEC) of the ^{222}Rn measured as part of the monitoring with the values defined in the framework of the third-party expert assessment conducted by IRSN for the 10-year environmental report on the sites of the La Crouzille mining division, for the three wind exposure situations[3]. Thus, the values measured on the La Porte site, described with a "valley bottom"-type topographic condition, were compared with the reference value of 178 nJ/m^3, and those of La Porte village, described with a "hillside"-type topographic condition, with the reference value of 154 nJ/m^3 (cf. figure 3). The results of the measurements for 2015-2017 on the La Porte site indicate an average value of 336 nJ/m^3 for the PAEC of ^{222}Rn.

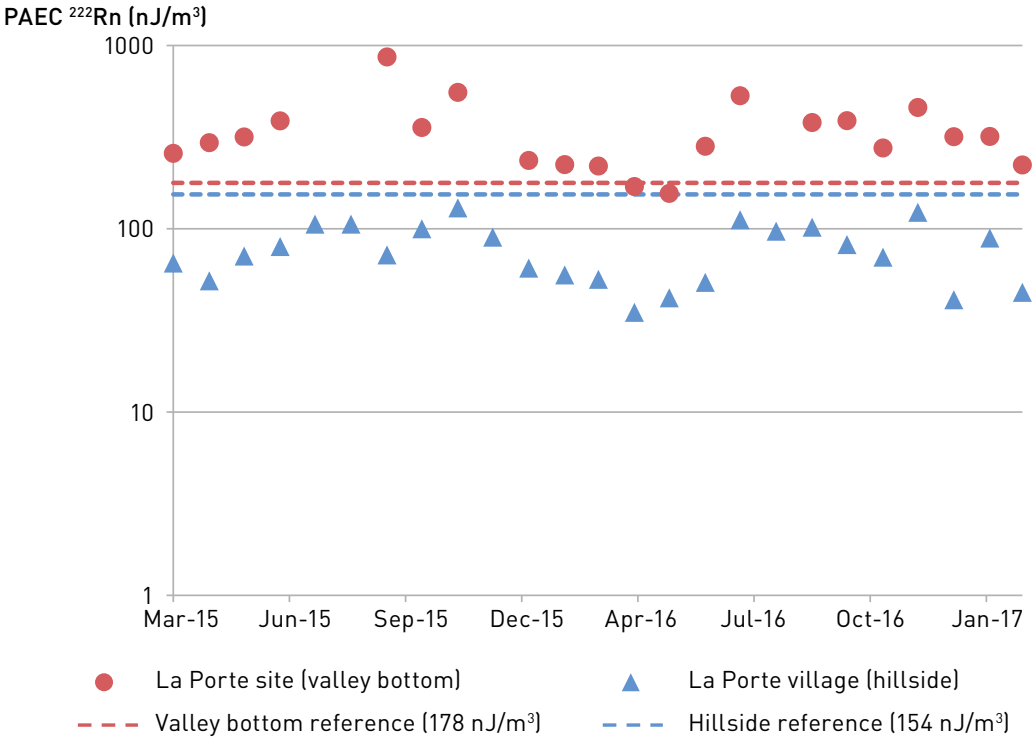
These measurements highlight the impact of the mining operation on the PAEC of ^{222}Rn at the La Porte site, with the position of the site in the valley bottom and the presence of mining waste on the site favouring the accumulation of radon-222 at the La Porte site. For La Porte village, the PAEC of radon-222 is on average 77 nJ/m^3 for the period 2015-2017. This value is below the chosen reference value of 154 nJ/m^3.

FIGURE 2 / **LOG OF DOSE RATE MEASUREMENTS MADE BETWEEN 2015 AND Q1 2017 ON THE LA PORTE SITE AND IN LA PORTE VILLAGE (nGy/h)**



3. 2007, IRSN, Expertise globale du bilan décennal environnemental d'AREVA NC (Global 10-year environmental expert study of AREVA NC), Part 2, ref.: DEI/SARG/2007-042.

FIGURE 3 / **TIMELINE OF ^{222}RN PAEC MEASUREMENTS MADE BETWEEN 2015 AND Q1 2017 ON THE LA PORTE SITE AND IN LA PORTE VILLAGE (nJ/m^3)**



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Old mining waste pile

Surface water

The measurements made since 2010 at the point located on the Riou-Tort river, upstream of the mining sites and therefore outside of their influence (point POR A, cf. figure 1), reveal an average uranium concentration of 1.4 µg/L and average radium-226 activity of 18.3 mBq/L (cf. figures 4 and 5). These values are of the same order of magnitude as those usually encountered in a natural environment with the same geological context.

The highest radionuclide values in the waters are measured in the open-pit mine of the site with, on average, a uranium concentration of 76.7 µg/L and radium-226 activity of 109.3 mBq/L (cf. figures 4 and 5). These high values, compared to the background radiation, probably derive from the leaching by the water of the granitic rock in which the open-pit mine was excavated.

FIGURE 4 / **TIMELINE OF URANIUM MEASUREMENTS MADE ON AND AROUND THE LA PORTE SITE (µg/L)**

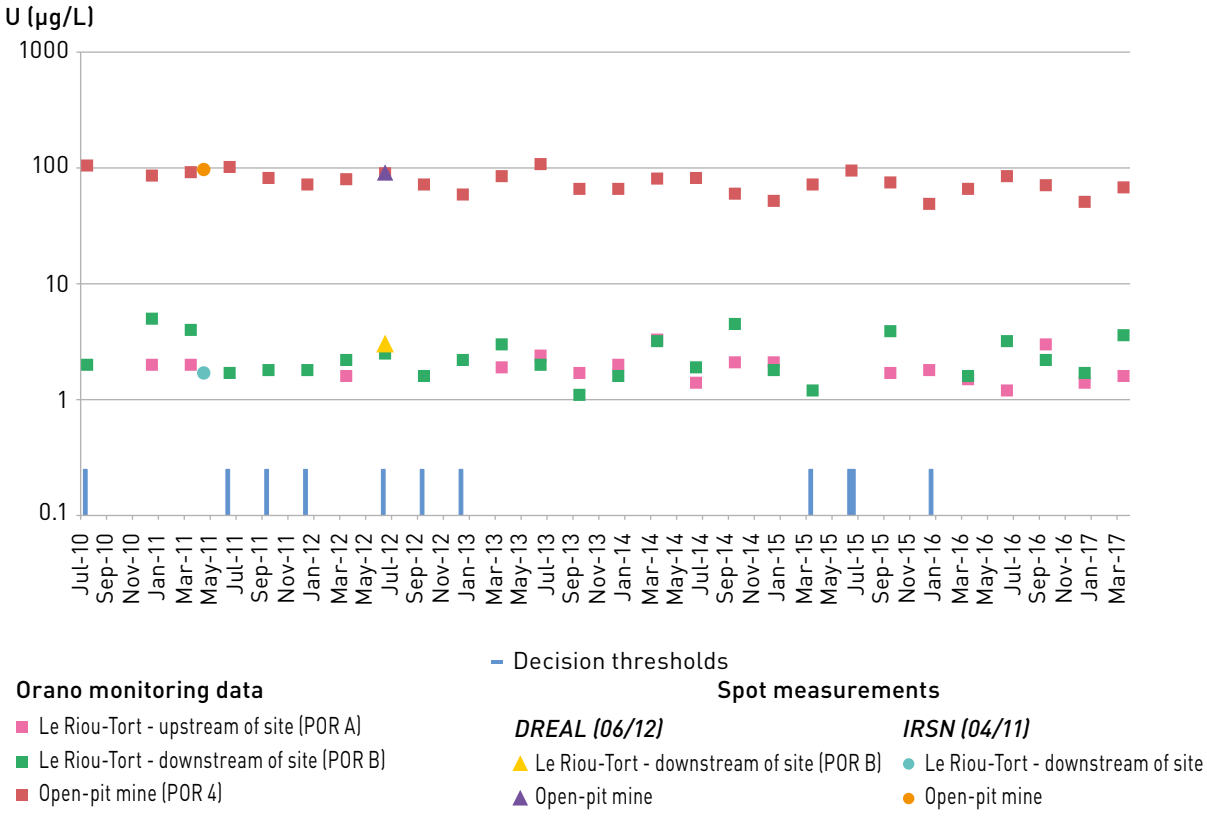
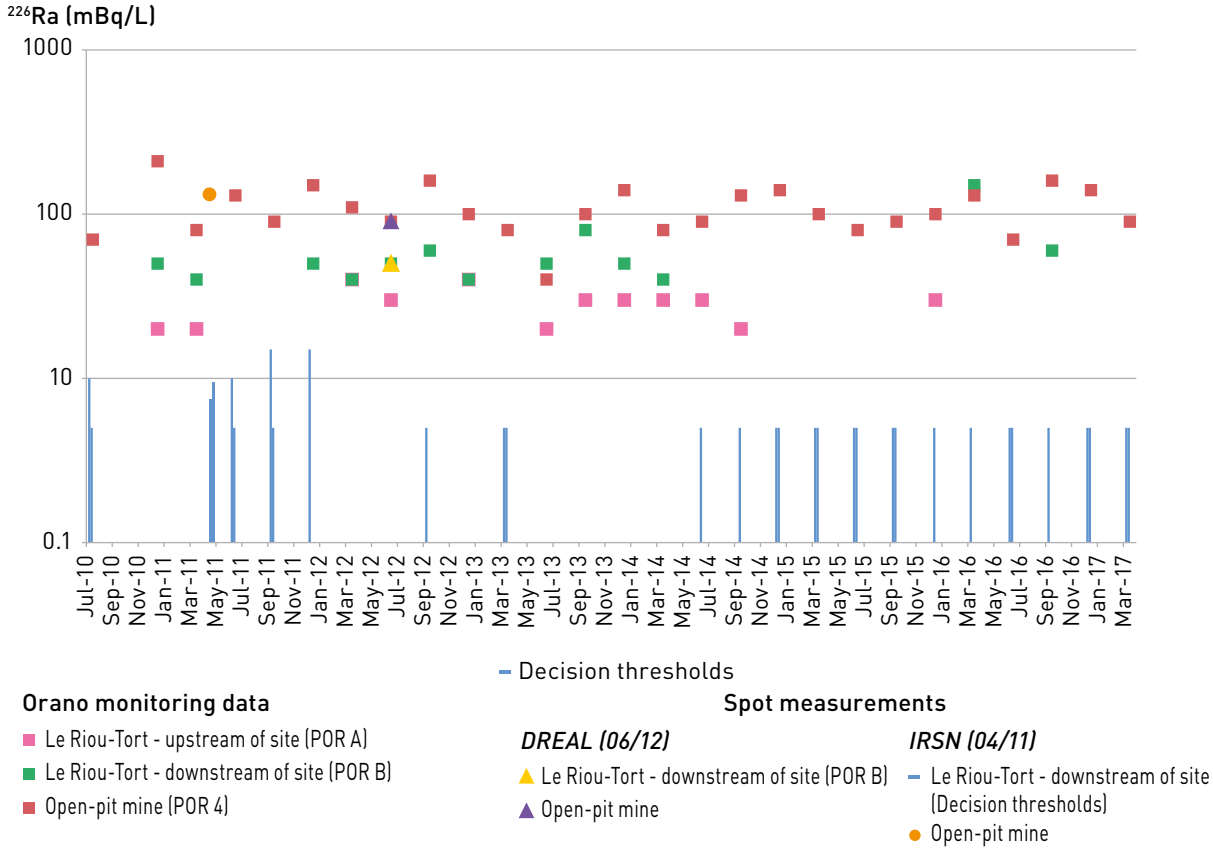


FIGURE 5 / **TIMELINE OF RADIUM-226 MEASUREMENTS MADE ON AND AROUND THE LA PORTE SITE (mBq/L)**

NB: 51.9% of the samples present radium activity below the decision threshold



The monitoring conducted since 2010 at point POR B, located immediately downstream of the La Porte site, reveals an average uranium concentration of 2.3 µg/L, similar to that measured at point POR A. The measurements of radium-226 activity show greater variability, with values between 10 mBq/L and 150 mBq/L. The fact that this variation is not observed at point POR A probably testifies to the influence of the past mining activities. However, on account of the absence of a monitoring point immediately upstream of the La Porte site, the current monitoring does not permit these variations to be attributed to the La Porte site alone, considering the presence of other uranium mines also located in the Riou-Tort drainage basin.

© IRSN

Sampling sediments

Atmospheric aerosols sampling station OPERA-AIR TGD 700 m³/h

© IRSN

05

DOSIMETRIC SUMMARY AND NEWS ITEMS FOR THE PERIOD 2015-2017

05
DOSIMETRIC SUMMARY AND NEWS ITEMS FOR THE PERIOD 2015-2017

5.1. SUMMARY OF DOSIMETRIC ASSESSMENTS

On the thirty-six mainland French sites where basic nuclear facilities (INB) are operated, twenty-eight were able to undergo dosimetric assessments based on radiological measurement results in their environment. These measurements were undertaken over the period 2015-2017, either by the nuclear operators as part of regulatory monitoring or in supplementary studies ordered by them, or by IRSN in the framework of its environmental radiological monitoring mission. Table 1 presents in summary form the estimated doses due to the discharges from nuclear facilities and to which the populations residing around the sites are exposed, and which are estimated based on environmental measurements. This table can also be used to compare these doses with those estimated in the previous *Radiological Report* which covered the period 2011-2014. These estimations are presented per radionuclide and per route of exposure.

Persons living close to one of these nuclear sites are likely to be concerned by exposure to the radionuclides measured in the air and issuing from atmospheric pollution: external exposure to krypton-85 for persons residing around La Hague, inhalation of uranium dust for the sites of Malvési, Tricastin or Romans-sur-Isère, inhalation or cutaneous transfer of tritium around the sites of Valduc, Grenoble or Creys-Malville. This exposure varies according to the scenarios and the distance from the site; the stated doses often correspond to the most conservative scenario (immediate proximity).

However, the doses linked to the incorporation of radionuclides by ingestion of foodstuffs presenting a measurable level of radionuclides (^{14}C, ^{129}I, ^{60}Co, plutonium and americium around La Hague, ^{14}C and ^{3}H around the nuclear power plants, ^{3}H around Valduc, Grenoble or Creys-Malville, for example) can only be received by persons likely to consume the foodstuffs concerned. These estimated doses are therefore proportional to the quantities consumed.

It should be noted that, in the case of nuclear power plants, the doses by ingestion of water or freshwater fish can only concern persons living close to a nuclear power plant situated on the bank of a river. Conversely, the nuclear power plants of the Manche department are the only ones concerned by the consumption of seafoods fished locally. In the particular case of the Flamanville nuclear power plant, a person consuming seafoods issuing from local fishing would also be exposed to the liquid discharges from the La Hague site, on account of its proximity. Lastly, a person consuming water or fish from the major rivers receiving the discharges from several basic nuclear facilities (INBs) (Rhone, Garonne, Loire, Meuse, Seine, Rhine and Moselle) may be concerned to a lesser degree, even if the person is situated far downstream of one or more INBs.

The doses likely to be received by the population residing around French nuclear installations and estimated based on measurement results are very low. Thus, any person residing in the vicinity of a nuclear power plant, and who may be prone to all the routes of exposure (regularly consuming locally produced food, consuming 2 L/day of water from the river and several kg/year of fish taken downstream of the site discharges), would receive a dose of less than 1 µSv/year, i.e.: less than 1000th of the public exposure limit set at 1 mSv/year (1000 µSv/year). The same accumulated routes of exposure would lead, around La Hague, to a maximum dose of 8 µSv/year: the highest level estimated in this report but which is almost 400 times lower than

TABLE 1 / **DOSES IN µSV/YEAR POTENTIALLY RECEIVED BY THE POPULATION RESIDING CLOSE TO THE NUCLEAR SITES, ASSESSED ON THE BASIS OF ENVIRONMENTAL MEASUREMENT RESULTS ACQUIRED AROUND EACH OF THESE SITES. DOSES DUE TO NATURAL RADIOACTIVITY IN FRANCE.**

Sites	Dose (µSv/year)		Radionuclide and route of exposure
	RR 2011-2014	RR 2015-2017	
La Hague	0.6 to 3.5	1.6 to 5.4[1]; 3.3[2]	^{85}Kr – external exposure
	0.7	0.4	^{14}C – ingestion of land-grown food and seafood
	1.1	0.2	^{129}I – ingestion of land-grown food and seafood
	–	< 0.002	^{14}C – inhalation
	–	0.05	^{90}Sr – ingestion of milk
	0.62	0.02[3]	^{60}Co, plutonium and ^{241}Am – ingestion of seafood
	-	< 0.03	^{3}H – inhalation, skin absorption and ingestion of food
Malvési	2	–	Uranium – inhalation
	0.4	–	Uranium – ingestion of vegetables
	–	0.002	Uranium – occasional ingestion of 1 L of water
	–	0.01	Uranium – occasional ingestion of 1 kg of wheat
Tricastin	0.05	0.06	Uranium – inhalation
	0.003	0.003	Uranium – occasional ingestion of 1 L of water
Romans-sur-Isère	0.5	0.15	Uranium – inhalation
Marcoule	0.28	–	^{3}H – inhalation, skin absorption
	0.12	–	^{3}H – ingestion of food
	–	0.07	^{14}C – ingestion of land-grown food
Saclay	0.28	0.15	^{3}H – ingestion of food (and particularly water)
	1.4	1.4	^{14}C – ingestion of lake fish
Grenoble (ILL)	0.14	0.05	^{3}H – inhalation, skin absorption
	–	0.03	^{3}H – ingestion of food
Bruyères-le-Châtel	0.14	–	^{3}H – inhalation, skin absorption
Valduc	0.39	1.0	• 0.14 to 0.22: ^{3}H – inhalation / skin absorption • 0.10 to 0.15: ^{3}H – ingestion of food • 0.7: ^{3}H – ingestion of water
Nuclear power plant sites	0.1	0.05 to 0.075	^{14}C – ingestion of land-grown food
	0.12	0.007 to 0.2	^{14}C – ingestion of river fish
	0.01 to 0.7	0.04 to 0.5	^{3}H – ingestion of water
	–	0.003	^{3}H – ingestion of land-grown food
	–	< 0.001	^{14}C – ingestion of river fish
	0.08	< 0.02	^{110m}Ag – ingestion of sea fish
	0.0004	< 0.001	^{60}Co, ^{58}Co, ^{110m}Ag... – exposure to the air: external and inhalation
Creys-Malville	< 0.07	0.06	^{3}H – inhalation, skin absorption
Downstream Rhone (all Rhone valley nuclear installations)	0.06		Miscellaneous radionuclides[4] – ingestion of water from the Rhone
	0.4		^{14}C – ingestion of fish from the downstream Rhone
Natural radioactivity	310		Exposure to cosmic radiation
	550		Frequent flyer
	360 – 1100		Exposure to terrestrial radiation
	380 – 2500		Ingestion of natural radionuclides (maximum: heavy consumers of seafood)
	10		Consumption of 200 g of mussels (^{210}Po essentially)
	540 – 3150		Inhalation of radon (max = Lozère, Cantal...)
	300		Heavy smokers

(1) Based on the measured ^{85}Kr activity levels. (2) Based on the dose rate measurements. (3) Shellfish only.

(4) This dose is calculated on the basis of the activity levels of all artificial radionuclides present in the water of the Rhone in dissolved form and measured by IRSN's SORA (Rhone observation station at Arles), after deduction of the background radiation. 80% of this dose is due to the tritiated discharges from Rhone valley nuclear facilities, 17% from strontium-90 discharges and less than 3% from other radionuclides (mainly iodine-131 from hospital discharges and cobalt-60).

the average dose received annually by the French population outside of any influence from a nuclear facility, on account of the background radiation present throughout France. These doses match those estimated by calculation (modelling the dispersion and transfer of radionuclides in the various components of the environment, through to Man) by the operators of the nuclear sites, based on the actual discharge radioactivity (a summary of these dosimetric impact calculations based on the actual discharges from nuclear facilities is presented in the annual report of the ASN on the state of nuclear safety and radiation protection in France, available from www.asn.fr).

Unlike the calculation estimations conducted by the operators, which make it possible to take into account all routes of exposure for the public and all discharged radionuclides, the environmental measurements only enable assessment of the preponderant exposure resulting from measurable radiological marking in the environment. For certain sites such as Valduc, Grenoble or Creys-Malville, the doses due to tritium alone, estimated on the basis of measurements conducted in the environment, represent the majority of the total calculated dose for these sites, taking all routes of exposure and all radionuclides into consideration. In the case of La Hague or the nuclear power plants, the doses presented in table 1 represent more than 70% of the total dose that can be potentially attributed to the site. Lastly, in the case of Tricastin, inhalation of uranium dust represents almost 60% of the dose calculated by the operator (which takes account of all potential exposure to radionuclides discharged by the site's installations).

Knowledge of the radioactivity in the environment, based on the various environmental monitoring programmes of the French nuclear sites, therefore makes it possible to estimate the main doses likely to be received by the neighbouring population. It also feeds into the validation of the calculations conducted by the operators. This knowledge does not, however, derive solely from regulatory monitoring. Supplementary studies conducted at the initiative of IRSN or certain operators also contribute to this.

The report shows that the doses estimated for the period 2015-2017 are for the most part entirely concordant with those presented in the previous Radiological Report, for the period 2011-2014. This is the case in particular for the potential doses around the nuclear power plants, around the sites of Creys-Malville, Valduc, Saclay and Tricastin, and for the doses due to carbon-14 and krypton-85 around the La Hague site. In the case of the sites of Grenoble and Romans-sur-Isère, the reduction in the doses between the two periods 2011-2014 and 2015-2017 is due to the drop in discharges. In the case of Marcoule or Bruyères-le-Châtel, the reduction in discharges was such that the environmental radiation cannot for the most part be measured (below the decision thresholds), so that it is no longer possible to calculate any doses. Around Malvési, the doses linked to the inhalation of uranium dust were able to be calculated for the previous report based on measurements made during the specific study conducted by IRSN. Since this study has not been repeated, and pending the upcoming installation of a permanent sampling station close to this site, this dose could not be assessed. However, the activity levels in the plants, of the same order of magnitude as in the previous period, testify to the fact that the activity levels in the air and therefore the associated doses have also been of the same order of magnitude. Furthermore, certain data that were not used in the dosimetric evaluations for the previous report did get used in this one. Lastly, some deviations can be explained by changes to the usable set of data or the way in which this data set is used. Hence, for the La Hague site, only the ingestion of molluscs could be taken into consideration with regard to the incorporation of certain radionuclides, the activity levels of which could only rarely be measured in the other seafoods.

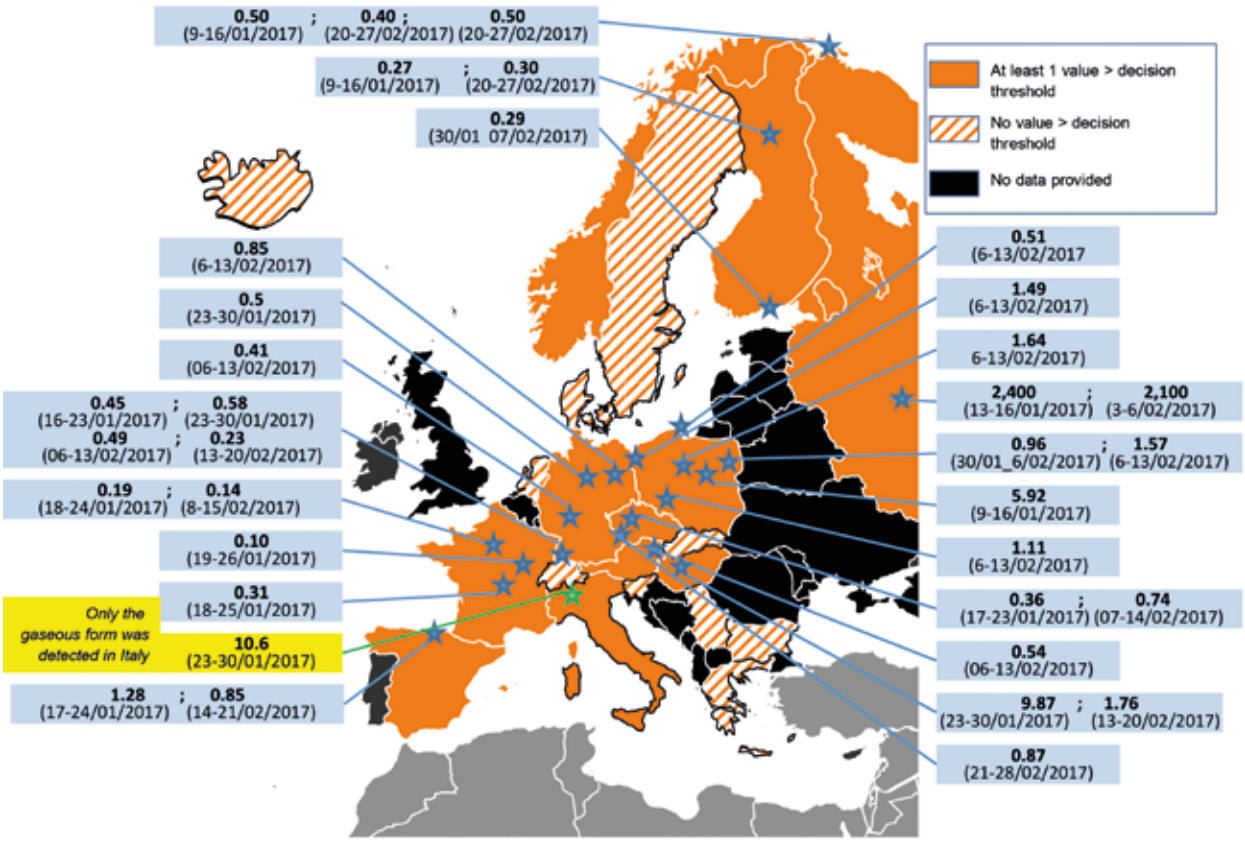
Just as with the previous *Radiological Report*, the doses could not be estimated around certain sites whose discharges had too insignificant an influence on the environment to be quantifiable by measurement. This concerns the sites of the French Navy (Cherbourg, Toulon, Brest), Fontenay-aux-Roses, Cadarache and Brennilis, and CSA-Cires, to which has also been recently added the site of Bruyères-le-Châtel. For these sites, the doses estimated by the operators for calculation on the basis of radiation from discharges, taking into account all routes of exposure and radionuclides, are lower - in some cases far lower - than 0.1 µSv/year (with the exception of the Cadarache site, for which the dose of 1.5 µSv/year, estimated by the CEA, is mainly due to the additional emanation of radon, for which the measurements are not available in the RNM (national network for radioactivity measurement in the environment)).

Lastly, the chapter relating to the former mining sites is not subject to dosimetric assessments in the framework of this report. There are three main reasons for this choice: (1) the radioactivity levels measured in the environment around these sites relate for the most part to the background radiation, which may potentially be locally reinforced; (2) the available measurement results, in particular for dose rate and radon, are not for the most part discernible in this background radiation on account, in part, of the relatively imprecise knowledge we have of its variability (summarily illustrated in chapter 2); (3) in the case of surface waters and fish, the analysis results available from monitoring would only enable very partial doses to be estimated.

5.2. DETECTION OF IODINE-131 IN THE AIR IN JANUARY AND FEBRUARY 2017

Traces of particulate radioactive iodine[1] (^{131}I) were detected in the atmosphere of a dozen or so European countries between mid-January and the end of February 2017. In all, around 40 detections were signalled over a period of eight weeks by 20 monitoring stations spread around Europe. The concentrations of this nuclear fission product remained very low (between 0.1 and 10 µBq/m^3) and did not lead to any significant health impact (cf. figure 1). Nevertheless, IRSN has looked into the various reasons that enabled these detections to be made. One reason is the

FIGURE 1 / **COMPILATION OF IODINE-131 LEVELS IN THE FORM OF AEROSOLS IN THE AIR (value in µBq/m^3 and dates)**
Source: IRSN



1. *Adsorbed on aerosols or present in the form of nanoparticles.*

considerable improvement in the performance of the atmospheric dust collection stations (in terms of sampling rate) and of the metrology. It is likely that, considering the levels observed, this episode would have gone undetected only a decade ago. IRSN also reviewed the different types of facility authorised to discharge this radionuclide, and classified them according to their expected contribution in a situation of normal operation. These are the discharges of the radiopharmaceuticals industry, and in particular those of an institute situated at Obninsk, around 200 km south-south-west of Moscow, which appear to be the most likely contributors to the activity levels measured across Europe, far ahead of the incinerators of the wastewater purification stations situated downstream of the nuclear medicine services, and in last place the discharges from nuclear power plants[2].

Reconstitution of the air mass trajectories associated with these detections also indicate a source of radiopharmaceuticals iodine (used in particular for diagnosing and treating thyroid cancers) as being the most probable and most significant source. The poor conditions of atmospheric dispersion that prevailed at this period of the year over Europe contributed significantly to the increase in the concentrations in the air by a factor of 4 to 5 for the daily average of particulate matter in the air (PM_{10}[3] and $PM_{2.5}$[4]) and the radionuclides of natural origin (^{7}Be, ^{210}Pb, ^{40}K), and facilitated the detection of the iodine-131. The winter weather conditions characterised by strong inversions of the vertical temperature gradient in the lower layers of the atmosphere are known for generating episodes of atmospheric pollution.

Iodine is a volatile species whose presence in the atmosphere is divided into gaseous form (around ¾) and particulate form (around ¼) through adsorption of part of the gaseous species on aerosols. Except for a station in Italy equipped with a high flow-rate iodine sink, no other gaseous iodine value higher than the detection limits was measured for the gaseous fraction, despite its predominance. The reason for this derives from the far higher flow rate of the aerosol samplers, enabling far lower detection limits for the iodine-131 in particulate form.

Despite being of shorter duration, simultaneous detections of this radionuclide on the European continent had already occurred between September and October 2011, originating from the Isotopes Institute in Hungary responsible for the radiopharmaceutical production of iodine-131. Other episodes affecting several European countries are to be signalled in February 2012, December 2013, March and May 2015 and, more recently, in January and February 2018. Besides improvements in the conditions of sampling and measurement, radiopharmaceutical industry production is increasing to face a growing demand in the number of diagnostics and treatments using iodine-131. This has resulted in an increase in the emissions and detections.

5.3. DETECTION OF RUTHENIUM-106 IN THE AIR FROM LATE SEPTEMBER TO EARLY OCTOBER 2017

Between late September and early October 2017, around 250 monitoring stations conducting aerosols collection and spread around most of Europe signalled the detection of ruthenium-106 in the atmosphere. The map at the top of figure 2 indicates the activity concentration ranges (a circle may represent several stations). This radionuclide of artificial origin had never been observed on a continental scale since the Chernobyl disaster. In France, 9 of the 45 aerosol collection stations of the IRSN OPERA-AIR network recorded activity by unit volume levels for ruthenium-106 of between 0.17 and 46 µBq/m^3. These very low activity by unit volume levels generated no health concerns. Depending on the country, the sampling period ranged from less than one day to one week, or even one month in certain cases. The shortest periods were able to demonstrate that in a given location the plume had remained for between one and three days on average. The shortest periods of presence were observed in eastern Europe and the longest in western Europe. These extended to up to 6 days in Italy on account of local stagnation of the air masses. The highest value (176 mBq/m^3), not

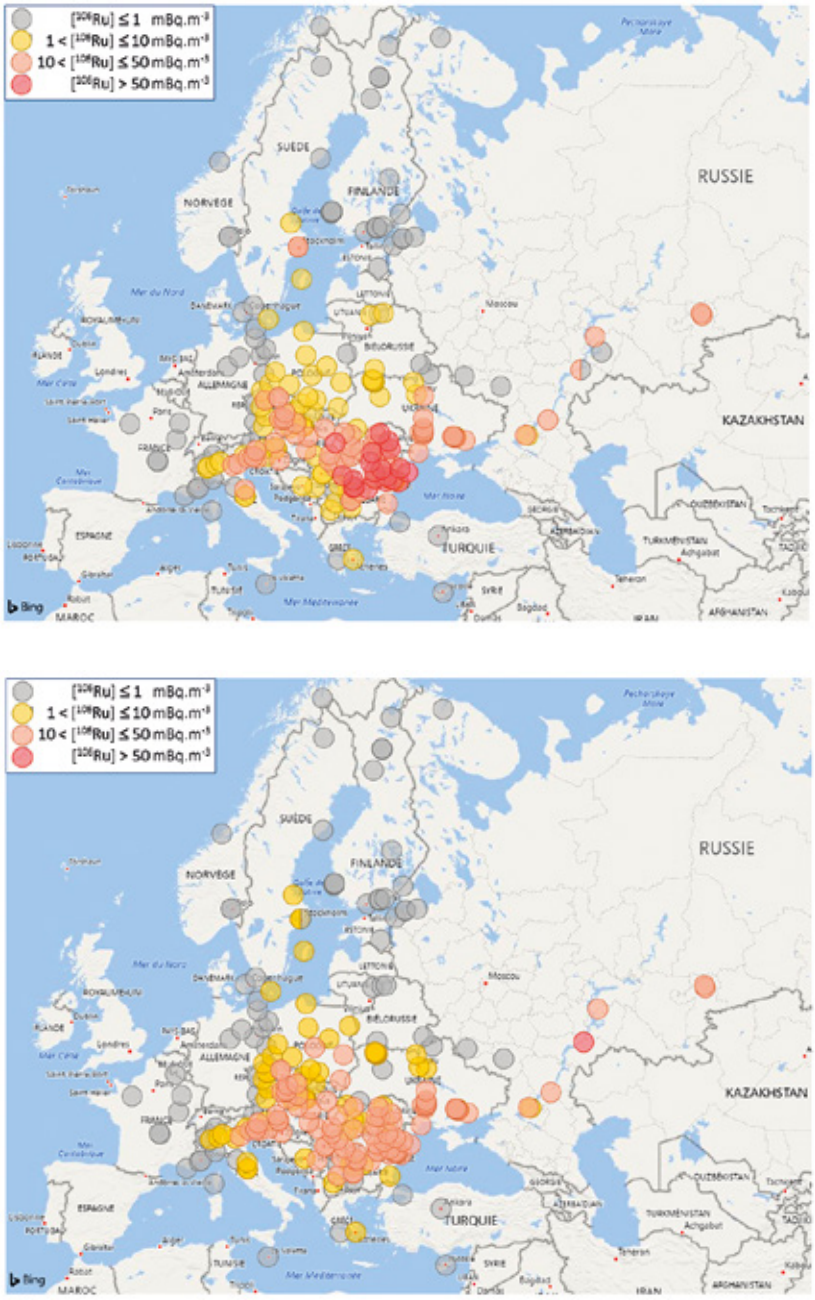
2. Masson et al. (2018) Potential source apportionment and meteorological conditions involved in airborne ^{131}I detections in January/February 2017 in Europe. Environ. Sci. Technol. 2018, 52, 8488–8500.

3. Particles in suspension in the air, with an aerodynamic diameter of less than 10 µm.

4. Particles in suspension in the air, with an aerodynamic diameter of less than 2.5 µm.

FIGURE 2 / **ACTIVITY BY UNIT VOLUME OF RUTHENIUM-106, RAW (left map) AND CORRECTED FOR AN AVERAGE 7-DAY PRESENCE PERIOD FOR THE PLUME (right map)**

Source: IRSN.



corrected for the period of the plume's presence, was recorded in just one day at a station in southern Romania. To be able to compare these results obtained over variable sampling periods, all the levels were averaged over seven days. The data corrected in this way (cf. figure 2, bottom map) show that the highest ruthenium-106 activity levels were distributed randomly between the countries of central Europe (Romania, Hungary, Serbia, Bulgaria) and eastern Europe (southern Ukraine and southern Russia). According to the Russian weather agency, the situation in southern Ural during the period from 25 September to 6 October was due to a vast anticyclone centred around the White Sea (to the south of the Kola Peninsula), almost closed in by the anticyclone in the central part of western Siberia. The conditions for an active transfer of air masses and pollutants from the territory of the southern Urals and southern Siberia to the Mediterranean region then to northern Europe began in the southern part of western Siberia, then the Caspian Sea plain and the northern Caucasus.

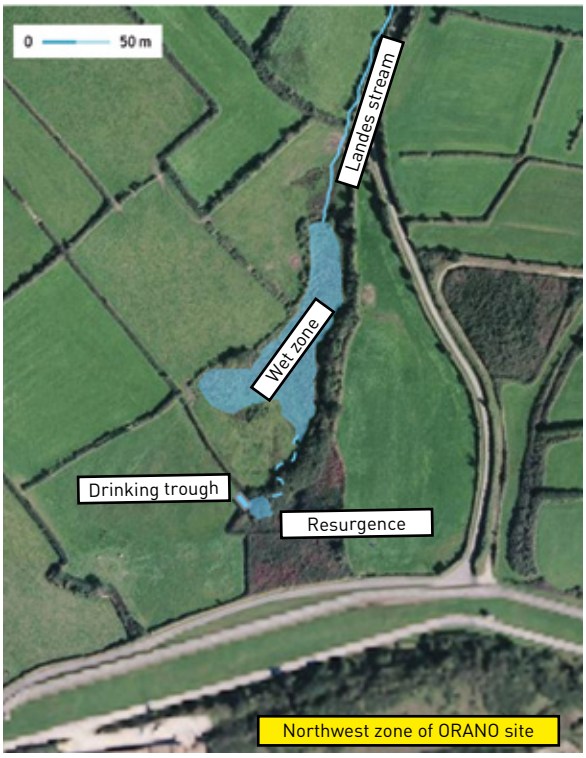
Detection on a continental scale, and at these levels, suggests that the source term was significant. IRSN estimated the discharge at between 100 and 300 TBq, which cannot correspond to a discharge from an installation in normal operation. Only ruthenium was detected, which also makes it possible to exclude an accident in a nuclear power plant. The exact location of the discharge is unknown, but the various trajectories of air masses in the days preceding the detections in the various European stations suggest that the emission location would be between the Ural and the Volga. To date, no IAEA Member State has declared any accident on its territory.

5.4. OVERVIEW OF THE RADIOLOGICAL MARKING OF THE RU DES LANDES ZONE

On 10 October 2016, ACRO (Association for the inspection of radioactivity in western France) published a press release reporting on the presence of americium-241, caesium-137, cobalt-60 and iodine-129 in the sediments and aquatic mosses sampled at the Ru des Landes ("Landes stream") source situated to the north-west of the Orano establishment at La Hague.

The radiological marking of the Ru des Landes goes back some years: it is known to the ASN and the CLI (first exchanges of correspondence in 1995 between CSPI [CLI] and DSIN [ASN today]). It is subject to regulatory radiological monitoring conducted by Orano, which has since been reinforced. Nevertheless, the operator on the one hand and IRSN on the other conducted a new study in 2016 and 2017 aimed at better characterising the radionuclides and the radiological activity encountered, and determining the origin and extent of the contamination observed. These sampling and

FIGURE 3 / **NORTH-WEST ZONE OF THE ORANO SITE AT LA HAGUE**



measurement campaigns also made it possible to provide supporting information for the IRSN act of referral from the French Nuclear Safety Authority (ASN) concerning the technical note requested of Orano by the ASN in December 2016 (IRSN/2017-00136 notice of 20/04/2017), and the zone rehabilitation report filed by the operator in July 2017 (notice 2017-00376 of 04/12/2017).

In the framework of this report, IRSN on the one hand and Orano on the other conducted a large number of additional samples and analyses. IRSN carried out, in particular, five missions involving six laboratories, running between October 2016 and July 2017. These campaigns involved the use of varied and complementary resources: on-board (car-mounted) and in-situ gamma spectrometry, sampling of the water, the soil, the grasses, the sediments and the aquatic plants (representing more than 120 analysed samples and more than 200 measurements). Together, they enabled the entire zone to be covered.

By analysing the data obtained, and in particular the spatial distribution of the activity levels over the zone, it is possible to observe how different radionuclides behave differently.

The caesium-137 is distributed relatively homogeneously and uniformly over the entire zone, with values nevertheless higher close to the drinking trough. Marking is also to be noted however further away, to the north of the wet zone and on the edge of a field to the west of the zone, with single points also observed using mobile and in-situ gamma spectrometry. Concerning the aquatic environment, the levels of caesium-137 observed in the sediments are lower, and all the measurements in the waters of the Ru are below the decision thresholds. IRSN estimates for its part that these characteristic elements tend to point toward an old atmospheric origin of the deposit, linked to leaks observed in 1974 from blocks of concreted waste stored in the open air to the north-west of the site and deriving from the activities of the Elan IIb workshop (production of ^{90}Sr and ^{137}Cs sources, which ceased in 1973).

FIGURE 4 / **SAMPLING DONE BY ACRO, IRSN AND ORANO FOR THE ZONE**

These cesium-137 activity levels should be placed in the context of those observed in the soils: in the order of 6 Bq/kg dry in the Omonville zone and 2 to 6 Bq/kg dry in the Manche department.

The markings observed in plutonium are significantly more localised and observed almost exclusively in the aquatic environment, in particular in the sediments, with values higher than the local background radiation, including around the site (in the order of 0 to 2 Bq/kg dry in the sediments). The only significant value observed for plutonium-238 and plutonium-239+240 in the soils is situated in the immediate proximity of the drinking trough, and could therefore be explained by a direct transfer from this trough to the surrounding soil. It may also be noted that the sediments (point to the north of the drinking trough) and the grass (point to the south-west) sampled at a distance from the flow do not present a significant plutonium value. Based on these supplementary elements and analyses, IRSN concluded, as did the operator, that the water table was marked with alpha emitters (plutonium and americium).

For the sedimentary component, the study of the observed levels of americium and plutonium in the sediments show a correlation between the two radionuclides, and therefore a common source. The reports on the isotopic activity levels assessed by the various parties who have conducted measurements in the zone (ACRO, IRSN and ORANO) show that these levels derive from historic activities for reprocessing spent fuels from the old natural uranium / graphite / gas (UNGG) reactor system.

FIGURE 5 / **ACTIVITY RANGES OF CAESIUM-137 AND AMERICIUM-241 MEASURED IN THE SOILS (Bq/kg dry)**

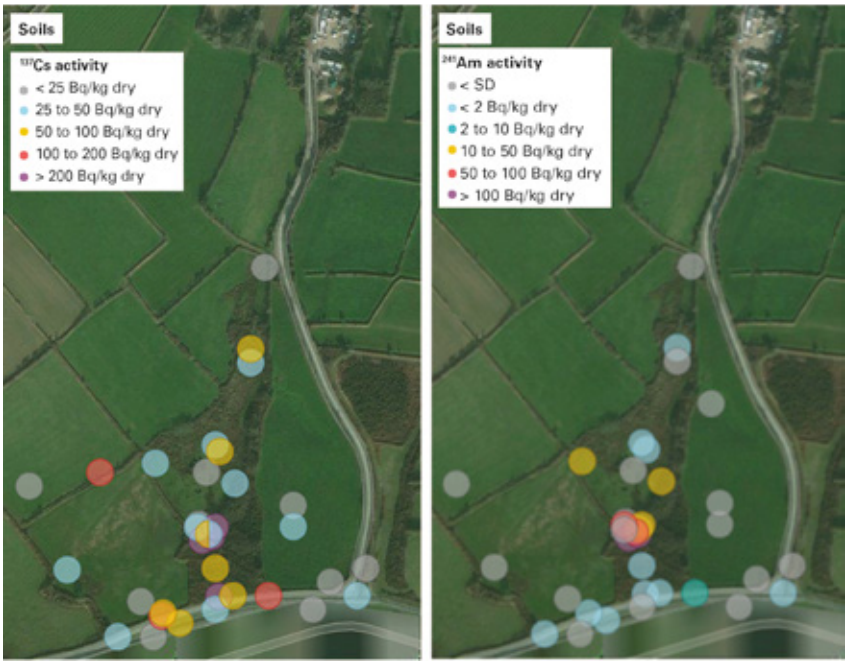


FIGURE 6 / **ACTIVITY RANGES OF PLUTONIUM-239+240, AMERICIUM-241 AND STRONTIUM-90 MEASURED IN THE SEDIMENTS(Bq/kg dry)**

Concerning americium-241, a dual geographical coincidence is observed with, on the one hand, plutonium in the aquatic environment and, on the other, the highest values of caesium in the soils. Input *via* two distinct channels is therefore to be envisaged:

- airborne, in similar fashion to caesium but *via* different types of waste (blocks issuing for example from AT1 on which cracks had been detected in 1979), or else, under certain conditions, *via* run-off from the plots situated to the east;
- aquatic, such as for plutonium, with very high localised values (in the sediments, for example, with more than 10 times the activity levels observed elsewhere around the establishment and less than 5 Bq/kg dry).

The levels observed in the water and sediments and the distribution of the strontium-90 show that this is the primary input channel, with levels higher by a factor of 2 to 3 in the water and by more than 10 in the sediments, compared to those usually observed in the environment, including around La Hague. Furthermore, bioaccumulation in the mosses of the drinking trough and the aquatic plants of the wet zone, associated with the high mobility of strontium in this type of matrix, were observed. However, the presence of strontium in the grass sampled to the south of the plot adjacent to the site and to the drinking trough could have the same origin as that of the caesium.

TABLE 2 / **SUMMARY OF THE MEASUREMENT RESULTS ACQUIRED FOR THE RADIOLOGICAL CHARACTERISATION OF THE RU DES LANDES AND AVAILABLE IN THE RNM**

		Fresh water (Bq/L)	Grasses (Bq/kg dry)	Mosses (Bq/kg dry)	Aquatic plants (Bq/kg dry)	Sediments (Bq/kg dry)	Soils (Bq/kg dry)
^{137}Cs	Number of values < DT	35	0	2	1	0	6
	Number of significant values	0	1	2	8	16	142
	Minimum value		0.598	2.10	0.648	1.29	0.584
	Maximum value		0.598	51.6	7.50	45.2	550
	Mean value		0.598	26.9	4.30	3.85	27.8
^{238}Pu	Number of values < DT	4	1	0	1	10	0
	Number of significant values	1	0	1	1	4	4
	Minimum value	0.001		0.381	0.286	0.464	1.15
	Maximum value	0.001		0.381	0.286	15.6	3.57
	Mean value	0.001		0.381	0.286	2.84	2.26
$^{239+240}$Pu	Number of values < DT	3	1	0	0	6	0
	Number of significant values	2	0	1	2	8	4
	Minimum value	0.001		4.00	0.013	0.857	14.4
	Maximum value	0.004		4.00	3.31	174	40.2
	Mean value	0.002		4.00	1.66	3.98	26.2
^{241}Am	Number of values < DT	28	2	0	2	12	77
	Number of significant values	1	0	4	8	8	58
	Minimum value	0.001		8.92	8.80	0.356	0.40
	Maximum value	0.001		28.0	25.0	97.8	198
	Mean value	0.001		11.5	14.0	17.4	1.90
^{90}Sr	Number of values < SD	0	0	0	0	0	0
	Number of significant values	35	1	1	2	6	0
	Minimum value	0.008	10.3	221	29.4	1.45	
	Maximum value	3.13	10.3	221	963	323	
	Mean value	0.77	10.3	221	497	107	

All these elements led IRSN to identify at least three potential modes of transport in its notice 2017-00136 of 20/04/2017:

- transfer through the water table *via* its resurgence, possibly resulting from a phenomenon of water-borne pollutants (plutonium and americium in particular) at very low concentrations and progressive fixation of these pollutants in the soils traversed;
- airborne transfer, explaining a more generalised and homogeneous distribution, for example of caesium-137;
- transfer by run-off, in particular in the event of strong rainfall, from the land situated in immediate proximity to the source of the Ru des Landes, and presenting marking of the soils, in particular with caesium-137 and americium-241.

In order to obtain additional information and be capable of assessing the impact on foodstuffs that may come from the zone in question (with certain fields open to livestock in the immediate proximity of the drinking trough), a milk sample was taken by the French General Department of Food (Direction générale de l'alimentation - DGAL) and analysed by IRSN. All the measurements made using gamma spectrometry on this sample

were below the decision threshold, and the ^{90}Sr activity was 0.135 ± 0.017 Bq/L, within the high bracket of the analyses conducted on the milk of the establishment at La Hague. This activity would lead to an effective dose for an adult consuming this milk of 0.1 µSv/year.

Orano decided to withdraw the most marked land at the level of the resurgence deriving from the Ru des Landes, and to lower the water table upstream of the site by means of two boreholes so as to avoid any fresh input of artificial radionuclides as the source of this marking, and implement a programme of additional reinforced monitoring as presented in the figure and table below. These investigations are intended in particular to guarantee and confirm the absence of any changes to the marking for this zone. This monitoring programme has already been running for approximately one year. The report associated with these investigations is currently being drawn up by the ASN.

FIGURE 7 / **NEW MONITORING PLAN IMPLEMENTED BY ORANO**

© IRSN

Drinking trough

© DR

06

UNDERSTANDING RADIOACTIVITY AND THE POSSIBLE EFFECTS OF EXPOSURE ON THE HUMAN BODY

06
UNDERSTANDING RADIOACTIVITY AND THE POSSIBLE EFFECTS OF EXPOSURE ON THE HUMAN BODY

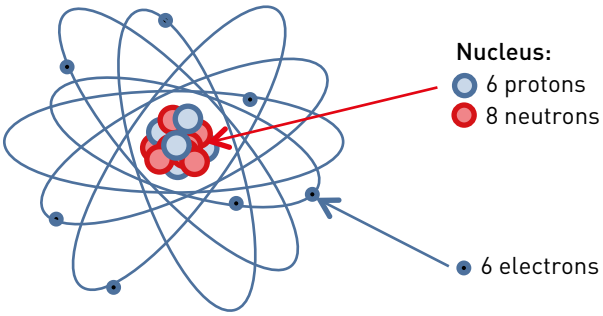
6.1. RADIONUCLIDES

Matter consists of molecules, which are combinations of the atoms of different chemical elements: atoms of carbon, hydrogen, potassium, calcium, iron, lead, uranium, etc. An atom is composed of a central nucleus consisting essentially of protons and neutrons, with a surrounding cloud of electrons (cf. figure 1).

Certain atomic nuclei are unstable - radioactive - , and transform spontaneously into other nuclei: we call this decay or disintegration.

Each of the chemical elements may present different nuclei, some of which are radioactive. These are radionuclides (or radioactive isotopes). Hydrogen has one radionuclide: tritium. The radionuclides of carbon include in particular carbon-14. Caesium-134 and caesium-137 are two of the 15 known isotopes of caesium. Certain very heavy chemical elements such as uranium or plutonium do not have any stable nucleus, only radioactive nuclei.

FIGURE 1 / **SCHEMATIC REPRESENTATION OF A CARBON-14 ATOM**



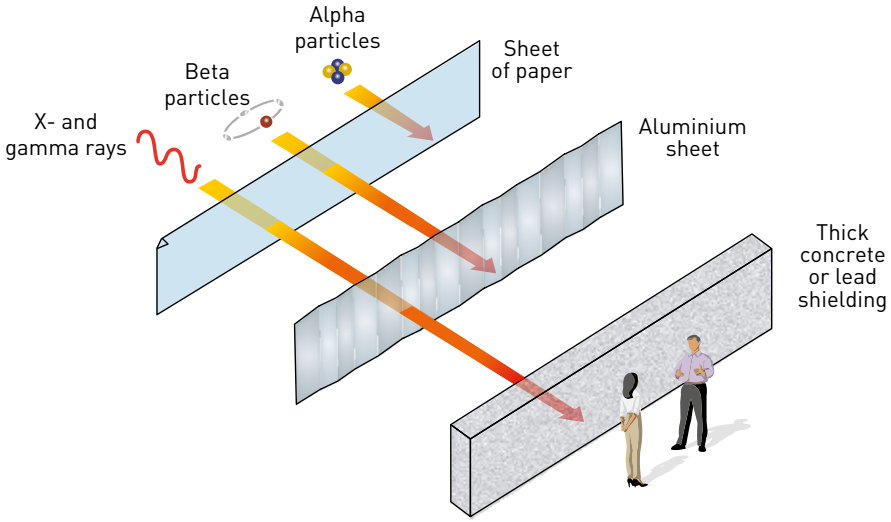
6.2. RADIATION

When an atom disintegrates it can emit different types of radiation. This radiation may strip electrons from the atoms of the matter receiving it, and in this way ionise this matter. This is why this radiation is called "ionising".

The main types of ionising radiation deriving from the disintegration of radionuclides are as follows (cf. figure 2 and table 1):

- alpha radiation consisting of a stream of helium nuclei (formed by two protons and two neutrons); they can be stopped by a simple sheet of paper;
- beta radiation, consisting of a stream of electrons; they can be stopped by a sheet of aluminium foil;
- X and gamma electromagnetic waves; the most energetic can only be stopped by extreme thicknesses of lead or concrete.

FIGURE 2 / **PATH OF DIFFERENT TYPES OF RADIATION**



6.3. ACTIVITY: THE BECQUEREL (Bq)

The activity of a radionuclide is the number of nucleus decays it produces per second (1 Bq = 1 decay per second). Since the number of decays per second is proportional to the number of radioactive atoms, the activity of a radionuclide corresponds to a quantity of this radionuclide. To quantify the radioactive discharges from a nuclear facility, since the becquerel is a very small unit, multiples are used: kilo-becquerel kBq (= 1000 Bq), mega-becquerel MBq (= 1,000,000 Bq), giga-becquerel GBq (= 1000 MBq), tera-becquerel TBq (= 1000 GBq).

In the environment, activity is often stated in relation to a mass or volume. Activity per unit volume (Bq/L or Bq/m^3) (activity concentration) or activity per unit mass (Bq/kg) (specific activity) of a radionuclide in a sample of material is a means of expressing the radionuclide content of the sample. Activity levels in the environment are often very low, and we use sub-multiples: for example, milli-becquerel per kilogram mBq/kg (= 0.001 Bq/kg), micro-becquerel per cubic meter µBq/m^3 (0.000001 Bq/m^3).

By measuring the activity of radionuclides *via* the radiation that they emit it is possible to detect tiny quantities (masses) of radioactive matter. Hence, a specific activity of 600 becquerels of caesium-137 per kilogram corresponds to a caesium content of 0.00000086 gram (0.86 micrograms) of caesium-137 per tonne.

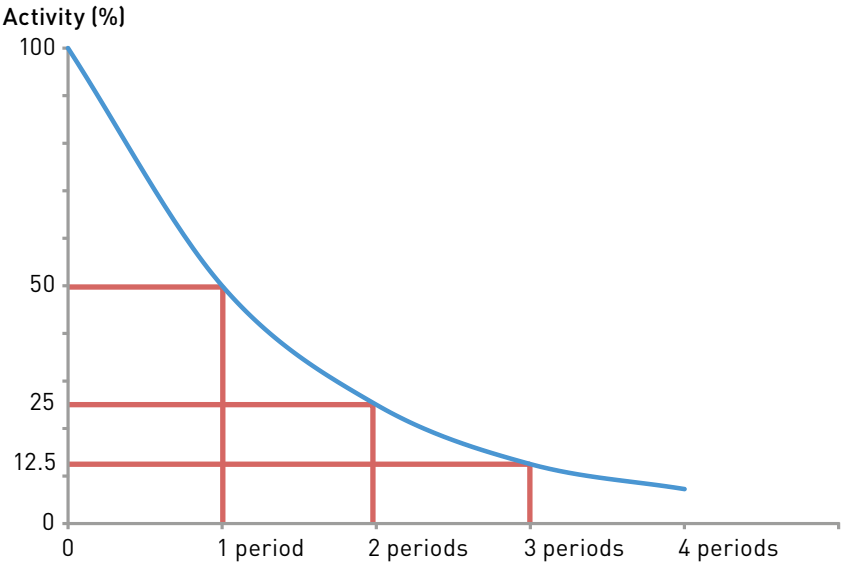
6.4. HALF-LIFE

The disintegration of an atom generates either the formation of another radioactive atom (another radionuclide), or the production of a stable atom (non-radioactive). This therefore generates a reduction in the activity of the radionuclide in question.

The radioactive period, or half-life, of a radionuclide is the time required for the activity (number of becquerels) of a radionuclide to be reduced by half (cf. figure 3 and table 1).

This varies according to the radionuclide from a fraction of a second to billions of years. Uranium-238 has a half-life of nearly 4.5 billion years. It is this long half-life which explains why it can still be found on Earth in its natural condition. The half-life of uranium-235 is almost 700 million years; this explains why, compared to uranium-238, relatively little is still found in nature (it only constitutes 0.7% of natural uranium).

FIGURE 3 / **GRAPHIC REPRESENTATION OF RADIOACTIVE DECAY**



6.5. MODES OF EXPOSURE TO ENVIRONMENTAL RADIOACTIVITY

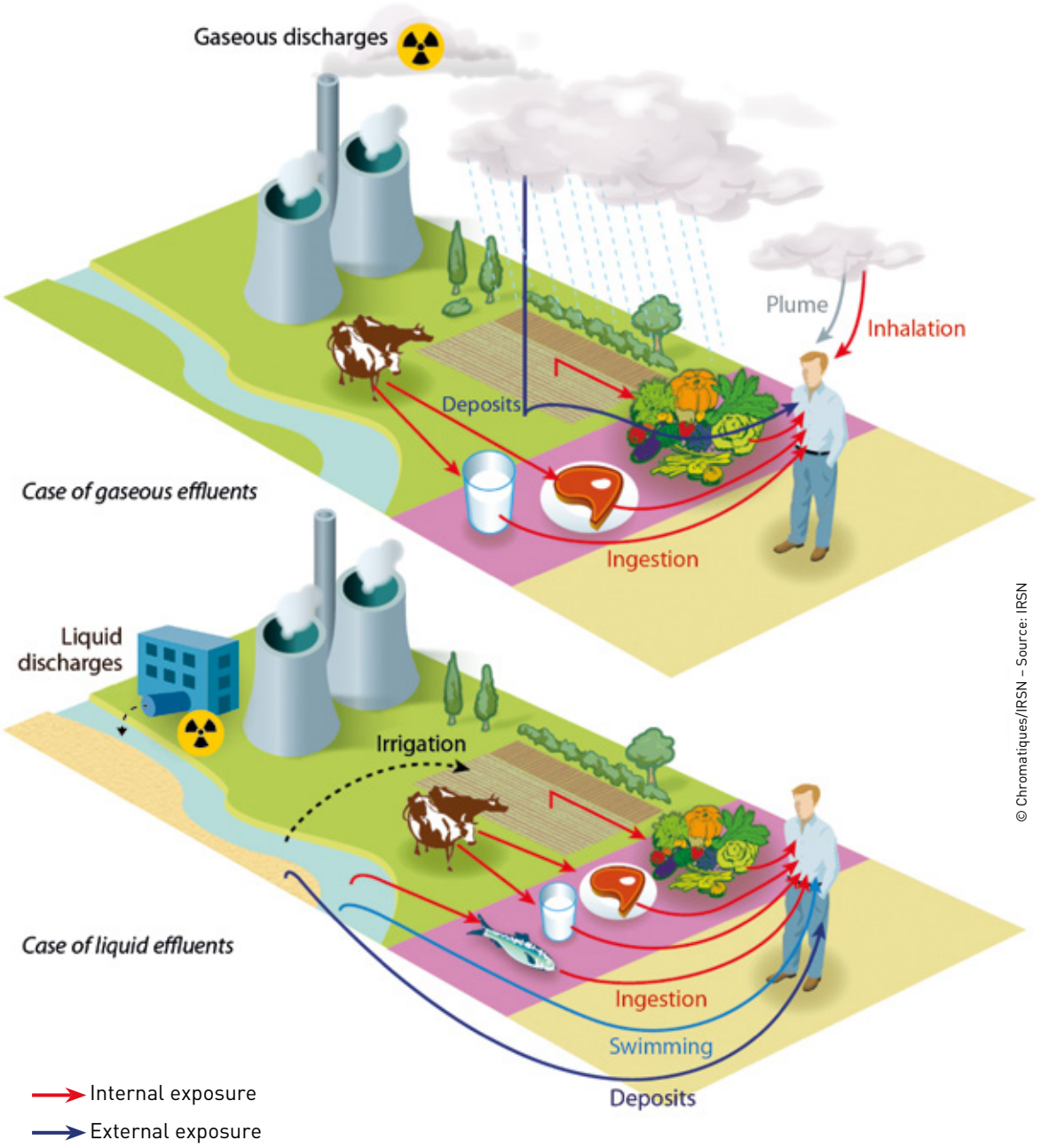
A person can be exposed in several ways to the radioactivity present in the environment.

If the person is exposed to a radiation source external to them, the air or the soil for example, the exposure is external. This exposure essentially concerns X or gamma-ray emitter radionuclides, as this kind of radiation travels far through the air and can penetrate deep into the body (cf. figure 2). Exposure is low for pure alpha emitting radionuclides (without gamma emission, such as ^{238}Pu or $^{239+240}$Pu for example) or for pure, low-energy beta emitters (such as tritium and carbon-14) which are stopped by the skin. External exposure diminishes very quickly as the distance increases from the source, and ceases if you are far enough away.

If the radionuclide penetrates the body through inhalation or ingestion, exposure is internal. This exposure will persist until the radionuclide

disappears through radioactive decay or is eliminated from the body. This elimination can be very rapid (as with tritium eliminated with water) or very long (as with plutonium, which settles in particular in the bones). This exposure is particularly damaging from alpha emitters, whose very energetic radiation strikes the cells of living tissues situated in the immediate proximity of the place in the body where they have settled.

FIGURE 4 / **HOW A PERSON IS EXPOSED TO ENVIRONMENTAL RADIOACTIVITY**



6.6. DOSE : THE SIEVERT (Sv)

By transferring its energy to them, ionising radiation can damage the body's tissues. This damage and its consequences depend on the nature of the radiation, its energy and what becomes of the radionuclide when it is ingested or inhaled.

Furthermore, the different organs differ in terms of their sensitivity to radiation. What is more, the effects will differ depending on which parts of the body are struck by the radiation. Estimation of the effective dose makes it possible to quantify and compare the different types of exposure to which a person can be subjected, taking account of the specific characteristics of the radionuclides, their radiation and the organs exposed. The effective dose is expressed in sieverts (Sv). For exposure resulting from environmental radioactivity, this unit is very large, and we use sub-multiples: the millisievert (1 mSv = 0.001 Sv) or the microsievert (1 µSv = 0.000001 Sv). In this radiological report, the effective doses are estimated for an adult individual and for an exposure period of one year (mSv/year or µSv/year).

The dose factor can be used to estimate the dose in sieverts based on the measured environmental activity levels (Bq/kg in food, Bq/m^2 in soils and Bq/m^3 in the air, in particular). The dose factor for estimating the dose following ingestion of a radionuclide is expressed as ingested Sv/Bq; for estimating the dose through inhalation as inhaled Sv/Bq; and the external exposure in Sv/h per Bq/m^3 if the radionuclide is in the air or in Sv/h per Bq/m^2 if it is on or in the soil. Figure 5 shows that the dose factors differ widely according to radionuclide and exposure mode.

FOCUS
THE EFFECTS OF RADIATION ON HEALTH

Radiation can generate damage in the cells of the organs exposed to it. In the event of intense exposure, massive cell death can lead to rapid and certain effects: various degrees of burning, necrosis, reduction in white cells, nausea and, in extreme cases, the death of the individual. Radioactivity in the environment can never under any circumstances lead to this kind of consequence. Exposure to environmental radioactivity is in the order of a thousand to a million times lower than the exposure likely to produce the aforementioned effects. This exposure can be the source, on a random basis, of pathologies that may appear years, even decades later: essentially, cancers.
These consequences are akin to those that can result from smoking or the appearance of skin cancer following repeated exposure to the sun.

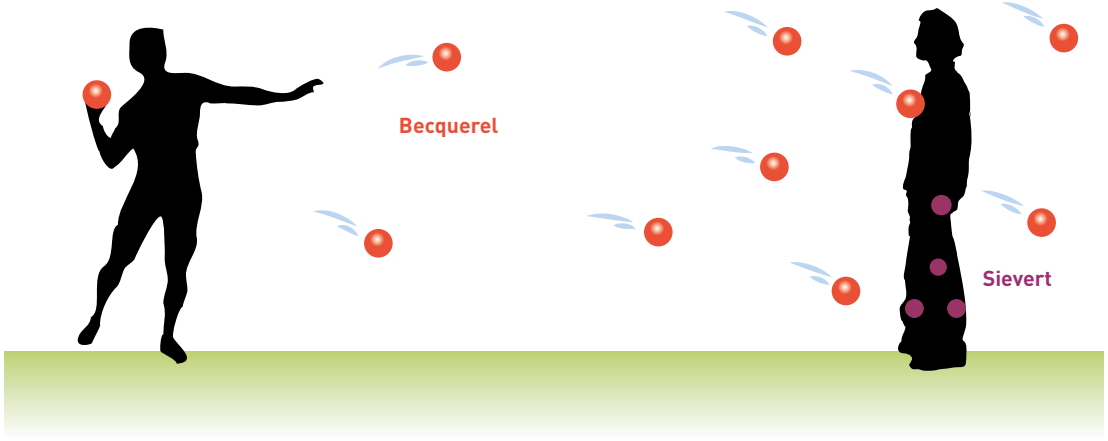


TABLE 1 / **CHARACTERISTICS OF THE MAIN RADIONUCLIDES MEASURED IN THE ENVIRONMENT**

Radionuclide	Half-life (years)	Radiation		Source
		Type	Energy	
^{3}H	12.3	Beta	Very low energy	1, 2 and 3
^{14}C	5730	Beta	Very low energy	1, 2 and 3
^{90}Sr-Y	28	Beta	High energy	2 and 3
^{40}K	1,260,000,000	Beta and gamma	High energy	1
^{110m}Ag	0.68	Beta and gamma	High energy	2
^{134}Cs	2.1	Beta and gamma	High energy	2
^{60}Co	5.3	Beta and gamma	High energy	2
^{137}Cs-^{m}Ba	30	Beta and gamma	High energy	2, 3 and 4
^{106}Ru-Rh	1	Beta and gamma	High energy	2
^{129}I	15,700,000	Beta and gamma	Low to average energy	1 and 2
^{226}Ra	1600	Alpha and gamma	High energy	1
^{210}Po	0.38	Alpha	High energy	1
^{238}U	4,500,000,000	Alpha	High energy	1 and 2
^{238}Pu	88	Alpha	High energy	2 and 3
^{239}Pu	24,000	Alpha	High energy	2 and 3

1: natural* / 2: nuclear facility discharges / 3: persistence from nuclear weapons testing* / 4: persistence from the Chernobyl disaster*

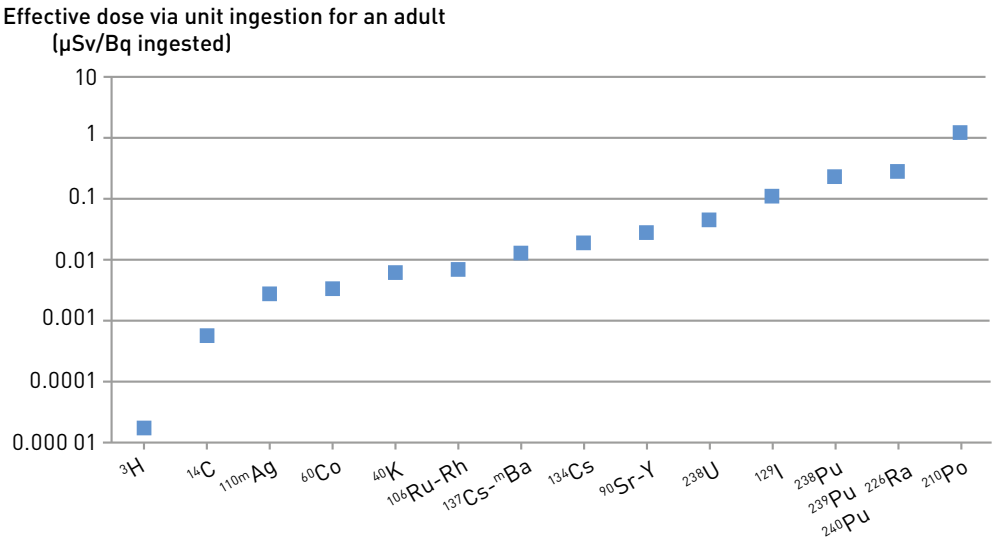
* Cf. chapter 2.

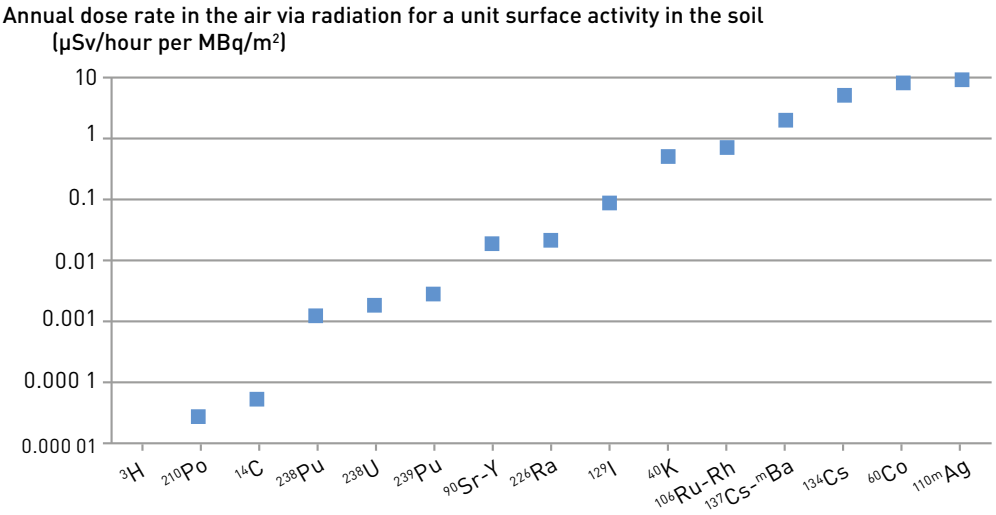
TABLE 2 / **DOSE CALCULATION MODE FOR EXTERNAL AND INTERNAL EXPOSURE BASED ON ENVIRONMENTAL RADIOACTIVITY**

External exposure	=	Surface activity or activity per unit volume in Bq/m^2 or Bq/m^3	X	Exposure time in h	X	Dose coefficient in Sv/h per Bq/m^2 or Sv/h per Bq/m^3
Internal exposure	=	Activity per unit mass or activity per unit volume (air, food) in Bq/kg or Bq/L for food and Bq/m^3 for air	X	Quantity of air inhaled or food ingested m^3 of air, L or kg of food	X	Dose coefficient in Sv/Bq inhaled or ingested

FIGURE 5 / **EFFECTIVE DOSE FOR UNIT INGESTION (µSv/Bq) AND DOSE RATE IN THE AIR BY IRRADIATION FOR A UNIT SURFACE ACTIVITY (µSv/hour per MBq/m²) FOR THE MAIN RADIONUCLIDES MEASURED IN THE FRENCH ENVIRONMENT**

For the same radioactivity ingested or the same radioactivity deposited on the soil, the doses generated by the radionuclide are very different. They depend on the nature of the radiation and on its energy, along with what happens to the radionuclide in the body in the case of ingestion. On account, in particular, of its very low-energy beta radiation, tritium is almost 10 million times less radiotoxic through ingestion than polonium-210. It does not produce, moreover, any external irradiation. Generally speaking, alpha-emitter radionuclides (plutonium, radium, polonium and uranium) are the most radiotoxic through ingestion.
On account of their high-energy gamma radiation, silver-110m, cobalt-60, and caesium deposited on the surface of the soil produce most irradiation in the air.





To assess the potential annual effective dose resulting from ingestion, it is necessary to estimate the quantity of food concerned ingested per year (cf. table 2). Since the influence of nuclear facilities is essentially limited to the immediate neighbourhood, this involves estimating the proportion of local food consumed. Food studies conducted in France show that the share of local fruit and vegetables can be very high (greater than 70%). However, the consumption of cereal derivatives (bread, pasta, rice, etc.) produced locally is most frequently nil. By multiplying the quantity of each local foodstuff consumed annually (kg/year) by the activity of each radionuclide measured in each of them (Bq/kg) we obtain the annually incorporated radioactivity (Bq/year) for each radionuclide. The dose factor then enables estimation of the effective dose by ingestion (Sv/year) based on this incorporated activity.

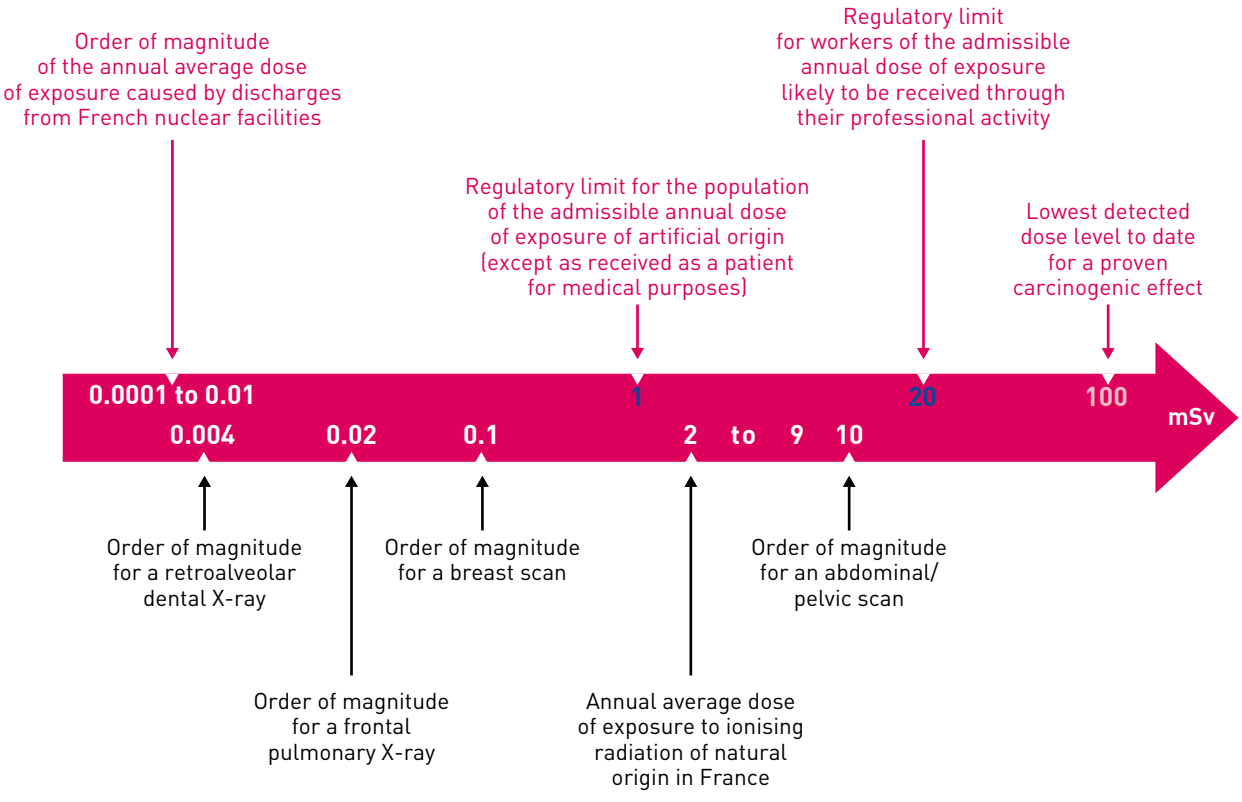
In the case of inhalation, this involves estimating the activity inhaled by the person (Bq/an) based on the activity measured in the air (Bq/m^3) and factoring in an average breathing rate (m^3/h).

The method used for calculating doses is detailed in chapter 8.

6.7. RADIATION PROTECTION

The purpose of radiation protection is to reduce the risks linked to ionising radiation by limiting, in particular, the doses linked to individual exposure. For the population, the annual exposure limit of 1 mSv applies to the total sum of doses received excluding natural radioactivity and the medical use of ionising radiation. The doses calculated in this report based on activity levels measured in the environment are in the order of between 100 and more than 10,000 times lower than this limit.

FIGURE 6 / **REGULATORY EXPOSURE LIMITS AND EXAMPLES OF EFFECTIVE DOSES RECEIVED DURING MEDICAL EXAMINATIONS (mSv)**



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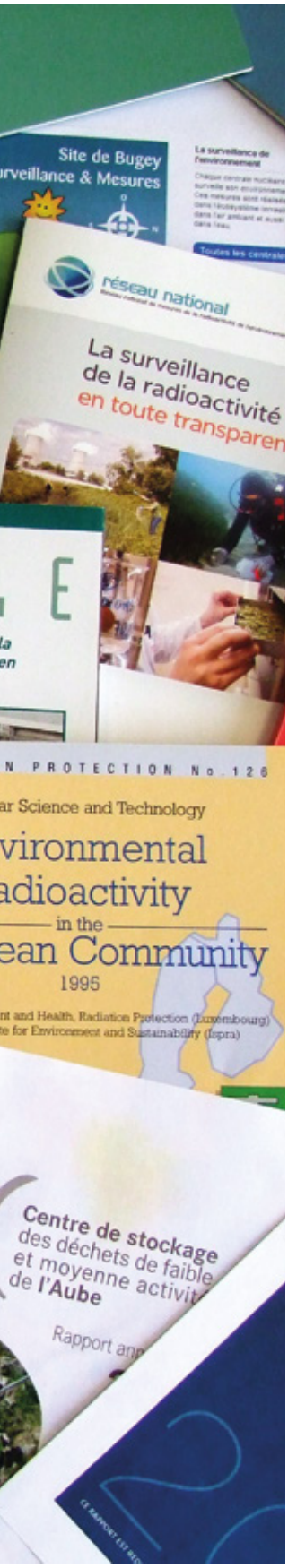


07

INFORMATION SOURCES ON THE MONITORING OF RADIOACTIVITY AND THE DISTRIBUTION OF DATA

07
INFORMATION SOURCES ON THE MONITORING OF RADIOACTIVITY AND THE DISTRIBUTION OF DATA

Informing the public about radioactivity in the environment is an essential element in guaranteeing the transparency of nuclear activities. The TSN Act of 13 June 2006, incorporated in the French Code of the Environment, states that: "transparency in nuclear matters consists of all the measures taken to guarantee the public's right to reliable and accessible information...".

The ASN, IRSN and the nuclear industry stakeholders in France propose many information resources to meet legal obligations on the one hand and public expectations on the other.

The distribution of environmental radiation monitoring data extends beyond national boundaries. In application of the Euratom treaty and in the context of the work of the OSPAR commission, IRSN passes on to the commission every year the results of the monitoring it conducts as part of its mission. Likewise, the nuclear operators also provide OSPAR with their data concerning liquid radioactive discharges. These data are then used in studies and publications available to the public *via* various information resources.

7.1. WEBSITES AND PUBLIC INFORMATION RESOURCES

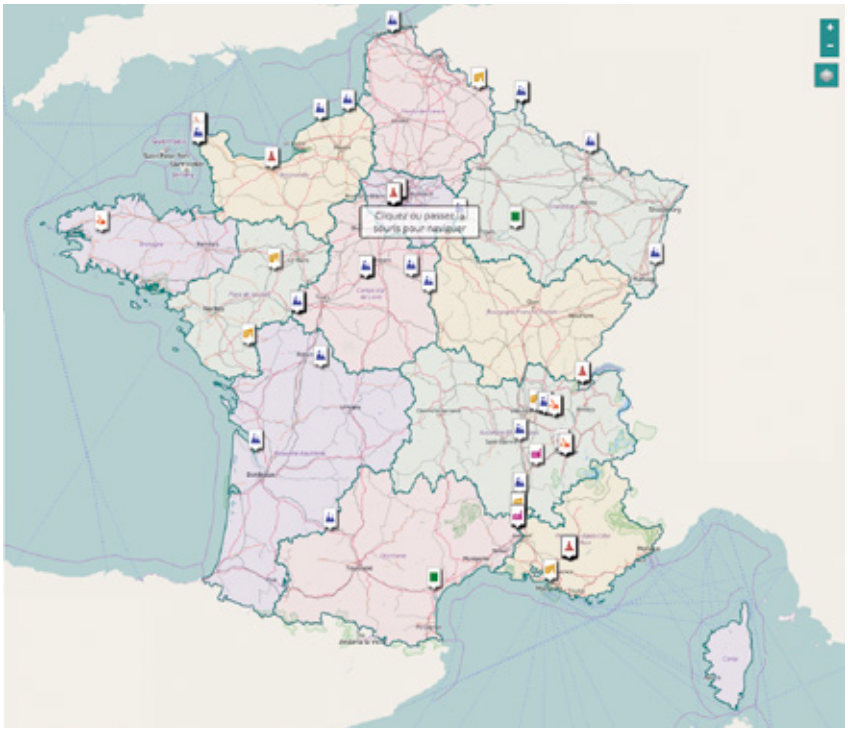
Web portal of the national network for radioactivity measurement in the environment (RNM)

The website of the RNM, launched on 2 February 2010 (cf. chapter 1), is the main French reference for the monitoring of environmental radioactivity, offering in particular centralised access to all the environmental monitoring results conducted by all data producers throughout France.

The RNM database can be accessed by means of an information system that enables all information to be retrieved by the general public and by experts, in particular by means of a cartographic web portal: www.mesure-radioactivite.fr.

On average, more than 25,000 new measurement results are added every month. The RNM therefore offers the most global vision possible of all radioactivity measurements made in the environment by the various stakeholders concerned.

FIGURE 1 / **INTERACTIVE MAP OF FRANCE OF THE INSTALLATIONS INSPECTED BY THE ASN**



Websites of the main data producers and interested parties

All those involved in measuring radioactivity in the environment have websites enabling the public to obtain additional information about their activities, and their inspection, monitoring or occasional expert assessment programmes. Certain websites also enable consultation of the annual information report for the public as stipulated by the Code of the Environment, which contains a section relating to the nature and results of the measurements of radioactive and non-radioactive discharges from nuclear facilities into the environment.

Information documentation of the ASN (French nuclear safety authority)

The ASN has put in place an information policy based on supplementary resources for making information accessible to its various audiences. The www.asn.fr website is the main public information tool. It presents the latest news on nuclear safety and radiation protection in France, and the positions adopted by the ASN across its fields of competence. Furthermore, the site provides access to a documentation base on the life-cycle of installations *via* simplified navigation, improved access to data and optimised downloading of selected information or publications. Since 2012, the ASN has developed on its website a TV page (http://tv.asn.fr/Environnement) dedicated to topics associated with environment monitoring.

The ASN has provided online since 2017 an interactive map of France with the facilities it inspects (cf. figure 1), and which enables general information to be obtained about these facilities (description of the facility, applicable regulations, etc.), as well as more detailed information about incidents that have occurred, inspection follow-up letters, and letters stating the position of the ASN.

The ASN Report on the state of nuclear safety and radiation protection in France, published annually, constitutes a reference document providing information about the state of the activities inspected by the ASN in these two areas. The ASN publishes four times a year the periodical: *Contrôle* ("Inspection"), distributed to more than 10,000 readers in France and abroad.

These publications, along with the other information resources of the ASN (*Lettre de l'ASN* ("ASN newsletter"), brochures and news sheets for the general public) can be consulted and downloaded at www.asn.fr. They are also available from the ASN's public information and documentation centre.

The High Committee for transparency and information on nuclear safety (HCTISN)

Created out of the French Environment Code (article L.125-34), the High Committee for transparency and information on nuclear safety is an information, consultation and debating body on the risks associated with nuclear activities and the impact of these activities on the health of people, the environment, and nuclear safety. To this end, the High Committee can issue a notice concerning any question in these areas and on the inspections and information relating to them. It can also deliberate on any question relating to accessibility of information concerning nuclear safety and propose any measure for guaranteeing or improving transparency as defined in article L. 125-12 of the Environment Code.

The committee may also be convened by:

- the minister responsible for nuclear safety;
- the presidents of the competent commissions of the Assemblée Nationale and the Senate;
- the president of the Parliamentary Office for assessment of scientific and technological choices;
- the presidents of the local information commissions;
- the operators of basic nuclear facilities for any questions relating to information on nuclear safety and its inspection.

The HCTISN is composed of members appointed for six years by decree, of whom there are four for the Members of Parliament and six for each of the other categories, distributed thus:

- two MPs designated by the Assemblée Nationale and two senators designated by the Senate;
- representatives of the local information commissions;
- representatives of environmental protection associations and associations mentioned in article L.1114-1 of the French Public Health Code;
- representatives of entities responsible for nuclear activities;
- employee union representatives;
- persons chosen on account of their scientific, technical, economic or social skills, or information and communication skills, with three designated by the Parliamentary Office for assessment of scientific and technological choices, one by the Academy of Sciences and one by the Academy of Moral and Political Sciences;
- representatives of the ASN, of the State services concerned and of IRSN.

The president of the High Committee is appointed by decree out of its member parliamentarians, representatives of the local information commissions and persons chosen for their skills.

"Environment" reports of the nuclear facilities

The operators are subject to legal information obligations: either general (such as the environment report stipulated by the Code of Commerce for joint-stock companies) or specific to the nuclear field.

The Environment Code obliges all nuclear facility operators to draw up every year a report on their situation and the actions they undertake, in particular in terms of the radiological monitoring of their facility's environment. In parallel, the regulations also oblige operators to publish an annual monitoring report in application of the general rules relating to basic nuclear facilities (Order of 7 February 2012): "The operator shall draw up annually a report presenting the impact of its facility during the past calendar year. This report shall characterise the water samples, the effluent discharges, the environmental monitoring and the impacts of the pollution generated. The report shall be transmitted to the nuclear safety authority (ASN), to the DREAL (Regional department for the environment, development and housing), to the regional health agency, to the service responsible for water policing and to the local information commission."

Every year the ASN conducts an analysis of these documents and publishes in its annual report the main conclusions relating to the treatment of the topics subject to legislation, to the strategic aspects and to the instructional aspects regarding transparency and the right to access nuclear information.

7.2. DISTRIBUTING INFORMATION IN THE FRAMEWORK OF INTERNATIONAL TREATIES OR CONVENTIONS

IRSN action with regard to information about the monitoring of radioactivity in the environment is also conducted internationally, in particular in the framework of the Euratom treaty and the OSPAR convention (Convention for the Protection of the Marine Environment of the North-East Atlantic).

Distribution of French data in the framework of the Euratom treaty

Every year, IRSN transmits to the European Commission, in the name of the French State, several thousand environmental radioactivity measurement results relating to aerosol particles, water and milk, to satisfy the requirements of articles 35 and 36 of the Euratom treaty. This submission is complemented by the automatic release of the hourly ambient dose rate averages measured by the sensors of the Téléray network on the EURDEP platform *(EUropean Radiological Data Exchange Platform)*. The European Commission regularly publishes a summary report at European level deriving from the processing of data transmitted by the Member States. A public web portal http://rem.jrc.ec.europa.eu enables connection to the various databases of the European Commission to view the results.

Data transmitted to the OSPAR commission

The mission of the OSPAR Convention is to protect the marine environment of the North-East Atlantic by preventing and eliminating pollution, protecting the marine environment against the harmful effects of human activities, and contributing to the sustainable use of the seas.

This commission is composed of representatives from the governments of the 15 contracting parties (Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK) and the European Commission, and from non-governmental organisations.

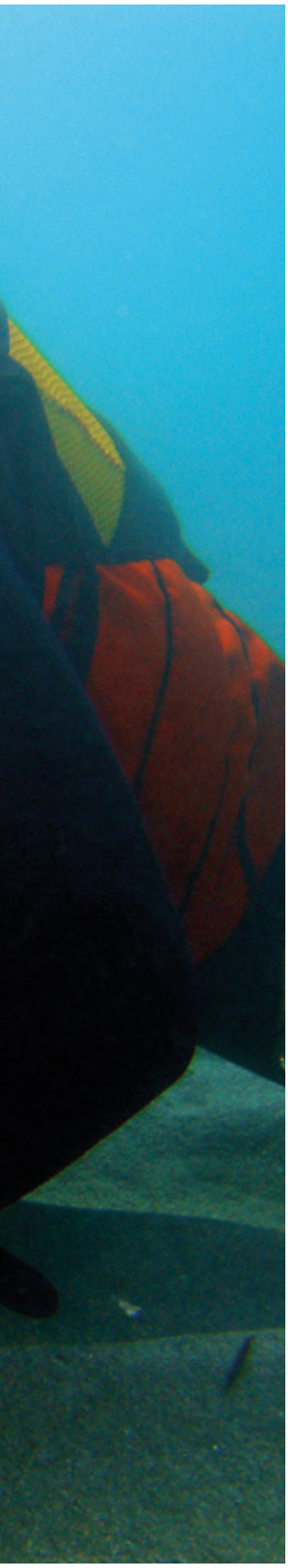
"The strategic objective of the OSPAR Commission with regard to radioactive substances consists in preventing pollution of the maritime zone from ionising radiation, through the progressive and substantial reduction of waste, emissions and losses from radioactive substances, with the ultimate objective of achieving concentrations in the environment that are close to the ambient values in the case of radioactive substances present in nature, and close to zero in the case of synthetic radioactive substances."

IRSN is involved in the work of the OSPAR Commission and passes on to it radioactivity data relating to the marine samples taken on the Atlantic - Manche department seaboard (water, sediments, fauna and flora), which have been used for establishing a "baseline", or reference point, for regularly assessing the progress made since 1998 in reducing the environmental marking attributable to human activities. These transmissions of annual data are likely to continue into the future.

Lastly, France periodically produces a report also including information relating to the environmental monitoring conducted by the operators of basic nuclear facilities (INBs) (PARCOM 91/4 recommendation).

Sampling underwater sediments

© Marine nationale



08
APPENDICES

08 APPENDICES

8.1. CALCULATING THE MEAN AND TAKING ACCOUNT OF NON-SIGNIFICANT VALUES

Since the activity levels of certain radionuclides in the environment are very low, the series of measurement results frequently include results below the decision threshold (DT, cf. chapters 1.4 and 7). The best-known and most-used statistical indicator, the arithmetic mean (sum of the values of a series divided by the number of values), does not on its own allow these results to be taken into account. However, they must not be disregarded, and when their proportion is too high, it is relevant to consider them in the statistical calculations. For the previous Radiological Review, this integration was done by calculating an average weighted against uncertainty or the decision threshold value. Application of this method to the series of measurement results led to the estimation of low averages vis-a-vis the series they were supposed to represent and, in particular, vis-a-vis the arithmetic mean. This method has been abandoned.

The indicator proposed for the present report is an arithmetic mean calculated on the basis of, firstly, the significant measurements (i.e.: where the value is >DT) and, secondly, the non-significant measurements (i.e.: where the value is <DT) to which are attributed the DT value when certain conditions are fulfilled. The different possible scenarios and the method used for each of these are explained below.

This method was chosen taking account of recognised statistical methods. This choice reflects the intention never to underestimate the value of the calculated mean without, nonetheless, being too conservative or, indeed, issuing non-verifiable hypotheses about the measurement distribution laws. Two parameters determine the mode of calculation for the mean:

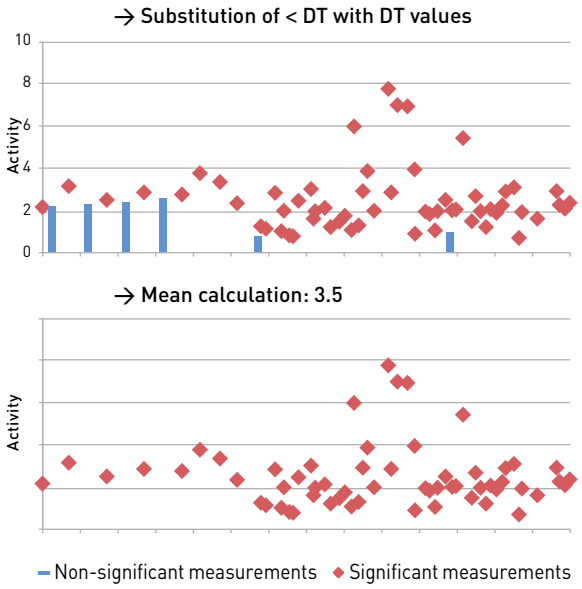
- the number of measurements below the decision threshold (DT) with respect to the total number of measurements: the literature is unanimous on the fact that beyond a certain percentage of non-significant measurements (around 80%) there is no reliable method for estimating the mean of a sample (there would be too high an error level). In the case of this report, we considered that the chosen method was no longer satisfactory beyond 50% of non-significant measurement results (below the decision threshold);
- the presence, for the same set of data, of heterogeneous measurements (measurements obtained with very different precision instruments) and mixing significantly different decision thresholds (see below, example of case No. 2).

Ultimately, three different possible cases were identified, with a calculation type specific to each of them.

Case No. 1: Few measurements below the decision threshold and homogeneous data

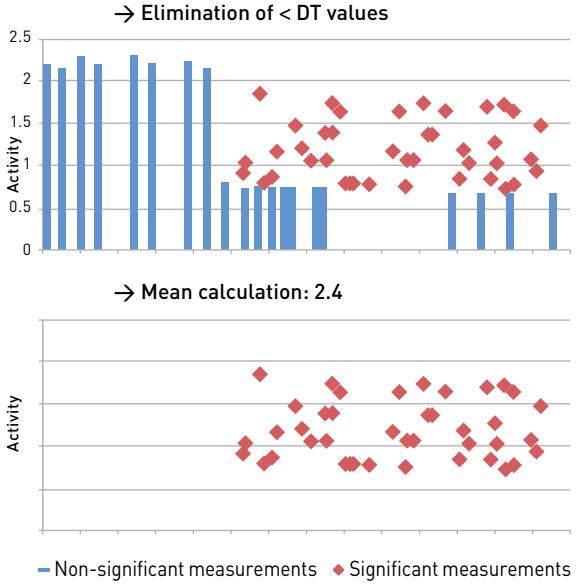
In case No. 1, the percentage of non-significant measurements is below 50% [3], and the data set is homogeneous.

The non-significant measurements (expressed as <DT) are replaced with the DT value and the indicators are calculated on the basis of this new data set. This case can be illustrated by the example opposite.



Case No. 2: Few non-significant measurements but heterogeneous data set

Case No. 2 is characterised by a percentage of non-significant measurements of less than 50%, but also by the presence of heterogeneous results. In this case, the measurements below the decision threshold are eliminated and the calculation of the mean is done on the basis of this new set of data (with fewer data). This case can be illustrated by the graph opposite.

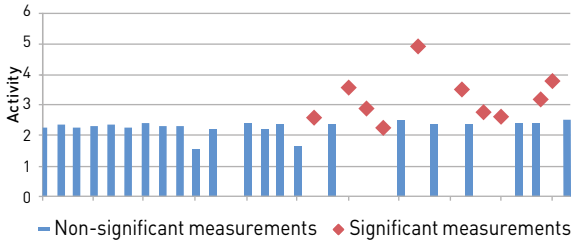


Case No. 3: High percentage of non-significant measurements

The percentage of non-significant measurements is higher than 50%.

In this case, the calculation of the mean is no longer carried out. The information that will be provided on this set of measurements will be:

- the range of values actually measured (min, max);
- the percentage of measurements below the decision threshold.



→ Only possible conclusions:
- 71% non-significant measurements
- Measured min.: 2.2
- Measured max.: 4.9

8.2. REPRESENTATION OF INDICATORS IN THE FORM OF A BOX-AND-WHISKER PLOT

To describe a series of measurement results, and in particular its dispersion, it is possible to supply the lower and upper bounds, thus determining the full range of values. However, it so happens that the upper and lower bounds correspond to extreme values which give too wide a vision of the range of values most frequently encountered. To determine this range, it is possible to calculate percentiles. Thus, 90% of the data fall between percentile 5% and percentile 95%; or else 95% of the results are less than this 95th percentile.

The box-and-whisker plot can be used to represent simultaneously several indicators and obtain a summary and complete view of the distribution of the measurement results. Usually, the box-and-whisker plot provides percentiles and, in particular, a median (50th percentile) to indicate the centre of distribution (50% of the values are below this median). This choice of representation was used in particular in chapter 2 in relation to the reference environmental background radiation values (in the particular case of chapter 2, the values below the decision threshold are not taken into account). The arithmetic mean as presented previously is added to these "box-and-whisker" representations.

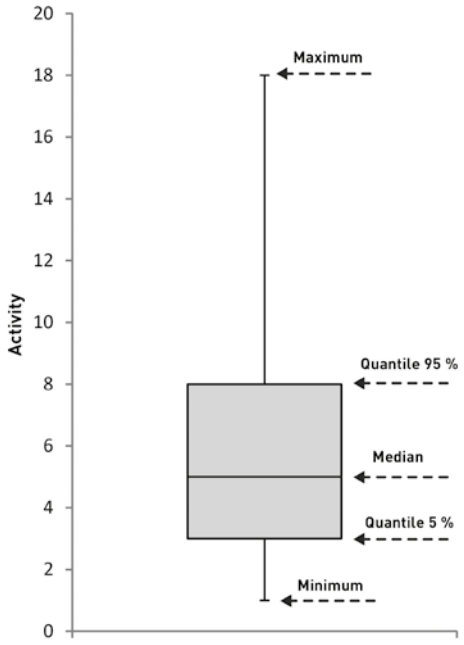
References

[1] Helsel D, *Nondetects and Data Analysis: Statistics for Censored Environmental Data*, Whiley.

[2] Antweiler RC and Taylor HE, *Evaluation of statistical treatments of left-censored environmental data using coincident uncensored data sets: Summary statistics*, Environmental science & technology, 2008.

[3] IRSN 2018 internal report *"Méthodes statistiques pour le traitement de données censurées - Choix d'indicateur(s) applicables à la surveillance de l'environnement" ("Statistical methods for the processing of censored data - Choice of indicator(s) applicable to environmental monitoring")*.

FIGURE 1 / **EXAMPLE OF A BOX-AND-WHISKERS PLOT**



8.3. METHOD USED FOR ESTIMATING DOSES

Data used for calculating doses

The measurement results on which the dose calculations are based are the activity per unit volume in the air, water and milk, and the activity per unit mass in solid foodstuffs (plant production [leafy vegetable, fruit, etc.]), animal production [meat, eggs, etc.], and sea or river produce (fish, crustaceans, molluscs, etc.). For the radiological report, the activity levels are averaged out per radionuclide, per matrix (for example, measurement of the activity per unit volume in the air), and for the entire stated period. For foodstuffs, these activity levels are expressed as Bq/kg of fresh foodstuff.

In the case of carbon-14, when the activities added locally around a nuclear facility are too low to be distinguished from the background radiation *via* activity per unit mass measurements expressed as Bq/kg fresh, specific activity measurements expressed as Bq/kg of carbon enable added activity levels in the order of several percent of this background radiation to be quantified. Based on these added specific activities, it is possible to deduce the activity per unit mass by means of the measured or theoretical content of elemental carbon in the food:

$$A_{mC14,food\ (i)} = A_{spec.C14,food\ (i)} \cdot C_{totfood\ (i)} \quad \textbf{[1]}$$

In the case of tritium, three types of measurement in foodstuffs are used in this radiological report: measurements of total tritium, expressed as Bq/kg fresh, measurements of organically bound tritium (OBT) expressed as Bq/kg fresh OBT or as Bq/L of combustion water, and free tritium (HTO) activities expressed as Bq/kg fresh of free tritium or as Bq/L of dehydration water (cf. focus in chapter 1). Since the dose coefficients are different for the OBT and the HTO, it is necessary in all cases to have separate information concerning the activity per unit mass of the bound fractions (OBT) and free fractions (HTO) for each foodstuff. The relations between these various activities are as follows:

$$A_{mH3total,food\ (i)} = A_{mOBT,food\ (i)} + A_{mHTO,food\ (i)} \quad \textbf{[2]}$$

where:

$$A_{mTOL,food\ (i)} = A_{v,combwater\ (i)} \cdot WE_{(i)}$$

$$A_{mHTO,food\ (i)} = A_{v,dryingwater\ (i)} \cdot WC_{(i)}$$

TABLE 1 / **PHYSICAL QUANTITIES USED IN CALCULATING THE ACTIVITY LEVELS OF CARBON-14 IN FOODSTUFFS**

Physical quantity	Unit	Retained value	Reference or explanation
$A_{m,food\ (i)}$ **Activity per unit of mass of foodstuff i**	Bq/kg fresh	/	
$A_{spec.food(i)}$ **Specific activity of foodstuff i**	Bq/kg of carbon	Measurement in the environment	/
$C_{totfood\ (i)}$ **Total elemental carbon content of foodstuff i**	kg of C/kg fresh		IAEA [10] or IRSN data

TABLE 2 / **PHYSICAL QUANTITIES USED IN CALCULATING THE ACTIVITY LEVELS OF TRITIUM IN FOODSTUFFS**

Physical quantity	Unit	Retained value	Reference or explanation
$A_{mH3total,food\ (i)}$ **Activity per unit of mass of total tritium in foodstuff i**	Bq/kg fresh	/	
$A_{mOBT,food\ (i)}$ **Activity per unit of mass of bound tritium in foodstuff i**	Bq/kg fresh OBT	/	/
$A_{mHTO,food\ (i)}$ **Activity per unit of mass of free tritium in foodstuff i**	Bq/kg fresh HTO	/	/
$A_{v,combwater\ (i)}$ **Activity per unit of volume of combustion water for foodstuff i**	Bq/L	Measurement	See Focus chapter 1.
$A_{v,dehydwater\ (i)}$ **Activity per unit of volume of dehydration water for foodstuff i**	Bq/L	Measurement	See Focus chapter 1.
$WE_{food\ (i)}$ **Water equivalent content of dry matter in foodstuff i**	L/kg fresh	0.6	IAEA [10] and IRSN data
$WC_{foodstuff\ (i)}$ **Water content of foodstuff i**	L/kg fresh	Measurement or reference	IAEA or IRSN data

Integration of background radiation

Added doses attributable to installation discharges are estimated in the radiological report. When a radionuclide is present in the environment beyond the influence of the nuclear facility (natural radionuclides or residual radionuclides from old fallout, cf. chapter 2), this environmental background radiation is subtracted from the measurements before estimating these added doses. Lastly, in the absence of a background value, the "raw" activities measured are directly used for estimating the doses, which are therefore overestimated.

Furthermore, the background radiation activity levels of the carbon-14 that are subtracted from the activity per mass unit measured around a site, before estimating the doses, are calculated according to relation 1 with a specific activity value of the background radiation equal to 227 Bq/kg of carbon (cf. chapter 2).

Lastly, the background radiation activity levels of the tritium that are subtracted from the activity per mass unit measured around a site, before estimating the doses, are calculated according to the previous relation 2 with a background radiation activity value equal to 1.3 Bq/L of combustion or dehydration water (cf. chapter 2).

Radionuclides and decay series

For each quantified radionuclide, it is also necessary to consider the daughter isotopes if they have been quantified (case in particular of natural families of uranium).

The radionuclides likely to exceed the background radiation and give rise to the calculation of doses are listed below:

- radionuclides measured in the air: ^{3}H, ^{14}C, ^{51}Cr, ^{54}Mn, ^{57}Co, ^{58}Co, ^{60}Co, ^{110m}Ag, ^{124}Sb, ^{129}I, ^{131}I, ^{137}Cs, ^{230}Th, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{238}Pu, $^{239+240}Pu$;
- radionuclides measured in food or water: ^{3}H, ^{14}C, ^{58}Co, ^{60}Co, ^{90}Sr, ^{110m}Ag, ^{129}I, ^{137}Cs, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{238}Pu, $^{239+240}Pu$.

The question of decay series progeny applies to a limited number of radionuclides, to be considered on a case-by-case basis:

- for ^{90}Sr, the de facto equilibrium with its daughter isotope (^{90}Y) is assumed;
- for uranium (234, 235 and 238), it depends on its age according to the type of industry of each site (case of fuel manufacturing sites: Malvési, Romans-sur-Isère and Tricastin).

In the case of the state of equilibrium with the daughter isotopes not being known, only the quantified radionuclide will be taken into account in the dose calculation.

Calculated value

To conduct the dosimetric impact calculations for the population on the basis of the measurements made in the environment, we opted to calculate the effective doses. Each dose is expressed as Sv/year then converted into sub-multiples, mainly the µSv/year. The doses are calculated for adults.

Routes of exposure

The main routes of exposure to added radioactivity when a person resides close to a nuclear site are:

- internal exposure by inhalation of aerosols or radioactive gas,
- internal exposure *via* skin absorption for tritium in the air (in HTO form),
- external exposure by immersion in a plume of noble gases (case of ^{85}Kr at La Hague),
- and, lastly, internal exposure by ingestion of food and/or water for persons consuming produce of local origin.

Presentation of exposure scenarios and calculations

Calculation of the internal dose received by inhalation of radioactive aerosols or gas

The conservative scenario is considered of a person breathing the external air with no protection for the habitat. Such persons are exposed 100% of the time, or 8760 hours per year.

The annual dose received by inhalation of substance i is calculated based on the following formula [3]:

$$E_{inh}(i) = A_v(i) \cdot f_r \cdot t \cdot e_{inh}(i) \cdot 10^6 \quad \textbf{[3]}$$

TABLE 3 / **PHYSICAL QUANTITIES USED IN CALCULATING THE INTERNAL DOSE RECEIVED BY INHALATION**

Physical quantity	Unit	Retained value	Reference or explanation
E_{inh} (i) **Annual dose received by inhalation of substance i**	µSv/year	/	/
A_v(i) **Average activity concentration measured in the air**	Bq/m³	Measurement in the environment	/
t **Exposure duration per year**	h/year	8760	Exposure 100% of the time with no protection factor for the habitat
f_r **Respiratory flow rate**	m³/h	0.96	Respiratory flow rate for an average activity for an adult *(taken from publication 66 of the CIPR)*
e_{inh}(i) **Effective dose per unit intake by inhalation of substance i**	Sv/Bq	According to radionuclide	Values taken from table 1.2 of the Order of 1 September 2003 [2]*

* Since no information is available about the form of the aerosols measured in the environment, the type of pulmonary absorption (fast (F), medium (M), slow (S), gas and vapour (V)) used in the calculations has been chosen in accordance with the recommendations in table 1.3 of the Order [2]. In the case of the Order not providing for any particular form, the form leading to the worst-case effective dose dose intake is chosen.

Calculation of the internal dose received via skin absorption (case of ^{3}H in HTO form)

The conservative hypothesis is chosen whereby the annual dose received by skin absorption from the tritium present in the air in HTO form is equal to the annual dose received by inhalation of tritium in HTO form.

$$E_{skin\_absorption\_3H(HTO)}(i) = E_{inh\_3H(HTO)} \quad \textbf{[4]}$$

TABLE 4 / **PHYSICAL QUANTITIES USED IN CALCULATING THE INTERNAL DOSE RECEIVED BY SKIN ABSORPTION FOR TRITIUM IN HTO FORM**

Physical quantity	Unit
$E_{skin\_absorption\_3H(HTO)}$ **Annual dose received by skin absorption**	µSv/year
$E_{inh(i)}$ **Annual dose received by inhalation of tritium HTO**	µSv/year

Calculation of the external dose received by immersion in an atmosphere where there is a noble gas present (case of ^{85}Kr in La Hague)

The conservative scenario is considered of a person exposed 100% of the time to a noble gas with no protection for the habitat. In this case, only external exposure *via* immersion is to be considered. The annual dose received by external exposure through immersion in substance i is:

$$E_{ext_{immersion}}(i) = A_v(i) \cdot t \cdot e_{immersion}(i) \cdot 10^6 \quad \textbf{[5]}$$

TABLE 5 / **PHYSICAL QUANTITIES USED IN CALCULATING THE EXTERNAL DOSE RECEIVED BY IMMERSION IN A NOBLE GAS**

Physical quantity	Unit	Retained value	Reference or explanation
$E_{ext\_immersion}$ (i) **Annual dose received by immersion in substance i**	µSv/year	/	/
A_v(i) **Average activity concentration measured in the air**	Bq/m^3	Measurement in the environment	/
t **Exposure duration per year**	d/year	365	Exposure 100% of the time with no protection factor for the habitat
$e_{immersion}$(i) **Effective dose coefficient of substance i**	(Sv/d)/ (Bq/m^3)	According to radionuclide	Values taken from table 2.2 of *the Order of 1 September 2003* [2]

Calculation of internal dose received by ingestion of foodstuffs

For this exposure scenario, only adults will be studied.

Diets may vary according to geographical zone. In light of the dosimetric assessments conducted in the previous radiological report, three types of diet were used. The first derived from the food survey conducted by CREDOC [8] in North Cotentin and would be used for the La Hague site. The second derived from the food survey for the Marcoule [7] site and would be used for the Marcoule site. For the other sites, we proposed to use an average diet for the whole of France based on data deriving from the INCA 3 food survey [3]. By way of a sensitivity analysis, other diets might be taken into account to assess doses due to particular practices (heavy consumers of fish, etc.).

For the calculation, the proportion of food produced locally is also taken into account, with the notion of self-consumption rate. This rate varies according to the food in question and the survey carried out. For the first two studies (CREDOC [8] and Marcoule [7]), the self-consumption rate value was available. However, for the INCA 3 survey, no data were supplied. The values available in the INSEE [5] study for the agricultural population living in rural communities would be applied.

The annual effective dose received by ingestion of foodstuffs for substance i is calculated based on the following formula:

$$E_{ing\_food}(i) = e_{ing}(i) \sum_{food\_j} (A_{m,\,food\_j}(i) \cdot q_{food\_j} \cdot R_{sc_{food\_j}}) \cdot 10^6 \quad \textbf{[6]}$$

Furthermore, to estimate as fully as possible the doses due to tritium, the tritium activity levels for food around the site can also be deduced from those of the HTO measured in the air, based on the previous formulations. This calculation, based on the assertion of tritium equilibrium in all components of the overground environment, can lead for different reasons to a potential overestimation of the doses for the population. In particular, the tritium activity for a foodstuff of animal origin (milk, meat or egg) is linked to the average activity of the feed consumed by the animal. This feed may only be partially of local origin.

TABLE 6 / **PHYSICAL QUANTITIES USED IN CALCULATING THE INTERNAL DOSE RECEIVED BY INGESTION OF FOODSTUFFS**

Physical quantity	Unit	Retained value	Reference or explanation
$E_{ing\_foodstuffs}$ (i) **Annual dose received by ingestion of foodstuffs for substance i**	µSv/year	/	/
$A_{s,\,foodstuff\_j}$(i) **Specific activity of substance i in foodstuff j**	Bq/kg fresh	Measurement in the environment	/
$q_{foodstuff\_j}$ **Quantity of foodstuff ingested per year**	kg fresh weight/year	Depends on the foodstuff and the chosen food survey	Diet associated with the studied siter (La Hague or Marcoule) or diet for the whole of France for the other sites
e_{ing}(i) **Effective dose per unit intake by ingestion of substance i**	Sv/Bq	According to radionuclide	Values taken from table 1.1 of the Order of 1 September 2003
$R_{s\text{-}c\_foodstuff\_j}$ **Self-consumption rate of foodstuff in question**	-	Depends on the foodstuff and the chosen food survey	This concerns the percentage of locally-produced foodstuff. This value depends on the study in question. For the INCA 3 study these are the data of the INSEE 1991 study

TABLE 7 / **QUANTITIES CONSUMED ANNUALLY FOR EACH TYPE OF FOODSTUFF AND SELF-CONSUMPTION RATE (FRACTION OF FOODSTUFFS OF LOCAL ORIGIN) USED TO ESTIMATE THE DOSES *VIA* INGESTION**

	La Hague site		Marcoule site		Other site	
	Diet[1] (kg fresh weight/year or L/year)	Self-consumption rate	Diet[2] (kg fresh weight/year or L/year)	Self-consumption rate[3]	Diet[4] (kg fresh weight/year or L/year)	Self-consumption rate[5]
Milk (cow)	54.2	0.148	60.51	0	21.99	0.43
Milk (goat)	-	-	0	0	5.50	0
Milk (sheep)	-	-	0	0	0	0.43
Yoghurt and fromage blanc	37.8	0.182	33.85	0	38.13	0.058
Cow's cheese	9.4	0.242	11.92	0	12.92	0.016
Goat's cheese	-	-	3.62	0.12	1.13	0.05
Animal fats (butter)	2.5	0.440	3.30	0	3.29	0.05
Egg	6.2	0.633	12.65	0.52	4.60	0.63
Root vegetables	39.3	0.540	40.56	0.75	37.96	0.75
Leafy vegetables	3.4	0.574	28.00	0.75	24.01	0.71
Fruiting vegetables	-	-	120.03	0.89	60.28	0.35
Honey	2.4	0.100	0.53	0.64	2.37	0.11
Fruits	25.6	0.112	93.40	0.76	52.37	0.21
Jams	4.8	0.100	4.60	0.42	4.75	0.52
Sea fish	16.8	0.354	14.66	0	10.88	0.16
Freshwater fish	-	-	1.37	0.63	0.59	0.16
Crustaceans	3.3	0.54	2.02	0	0.76	0
Shellfish/molluscs	3.6	0.75	2.02	0	0.93	0
Meat (beef)	-	-	16.90	0.006	12.99	0.38
Meat (poultry)	8.8	0.37	14.37	0.16	16.30	0.74
Meat (lamb)	1.5	0.40	5.56	0.028	7.79	0.49
Meat (rabbit)	2.5	0.37	1.50	0.19	2.20	0.93
Meat (pork)	-	-	26.16	0.008	29.5	0.24
Game	-	-	9.87	0.954	0.4	0.89
Wheat (cereals)	-	-	18.8	0	30.96	0.015
Wine	-	-	51.87	0.94	26.71	0.23
Wild mushrooms	-	-	3.10	0.69	2.5	0.97

1: diet for a person residing in North Cotentin and whose main breadwinner is a fisherman.
2: average diet for someone living around the Marcoule site (between 5 and 10 km away).
3: average self-consumption rate.
4: average diet for mainland France.
5: self-consumption rate representative of an agricultural population living in a rural community.

Calculation of internal dose received by ingestion of drinking water

To assess the impact of the presence of radionuclides in certain watercourses or underground water, the conservative hypothesis is chosen whereby the water is used as drinking water. Consequently, certain hypotheses considered for calculating the indicative dose (ID) (formerly total indicative dose (TID)) are used, as presented in the Order of 12 May 2004 [5]. We therefore consider a regular consumption by adults of 2 L of water per day, i.e.: 730 L of water per year. The chosen activities per unit volume are the values measured in filtered water.

The annual dose received by ingestion of water for substance i is calculated as follows:

$$E_{ing\_water}(i) = A_v(i) \cdot q_{ing\text{-}water} \cdot e_{ing}(i) \cdot 10^6 \quad \textbf{[7]}$$

In the case of the water analysed not being destined for consumption (e.g., water from a canal or a stream), and you wish to assess its impact on health, we propose calculating a unit dose through ingestion of a litre of water. Depending on the available data, the calculation will be made based on measurement results for unfiltered or filtered water. In this case, the calculation should be based on unfiltered water to be representative of water that would be drunk by immersing a water bottle directly in the watercourse. However, most of the time analyses of water samples are made on filtered water.

In all cases, the calculation is identical to the formula [5], with only the quantity of consumed water being rounded to 1 L and the unit expressed as µSv/L.

TABLE 8 / **PHYSICAL QUANTITIES USED IN CALCULATING THE INTERNAL DOSE RECEIVED BY INGESTION OF WATER**

Physical quantity	Unit	Retained value	Reference or explanation
E_{ing_water} (i) **Annual dose received by ingestion of water for substance i**	µSv/year	/	/
A_v(i) **Activity by unit of volume measured in filtered water for radionuclide i**	Bq/L	Measurement in the environment	/
$q_{ing\text{-}water}$ **Quantity of water consumed per year**	L/year	730	Order of 12 May 2004
e_{ing}(i) **Effective dose per unit intake by ingestion of substance i**	Sv/Bq	According to radionuclide	Values taken from table 1.1 of the Order of 1 September 2003

List of references

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8.4. GLOSSARY

A

AASQA
Association agréée de surveillance de la qualité de l'air (Certified air quality monitoring association).

ACRO
Association pour le contrôle de la radioactivité dans l'Ouest (Association for the inspection of radioactivity in the west of France).

Actinide
Family of chemical elements with an atomic number equal to or greater than actinium (atomic number 89). Four actinides exist in the natural state: actinium (89), thorium (90), protactinium (91) and uranium (92). There are also artificial actinides: these are the transuranic elements (plutonium, americium, neptunium and curium).

Activation
Process whereby atomic nuclei are made radioactive under the action of a flow of neutrons or other particles.

Activation product
Artificial radionuclide produced by capturing a neutron from a stable or unstable atom.

Activity
Number of spontaneous disintegrations of atomic nuclei per unit of time. The unit of activity is the becquerel (Bq). See chapter 6.

Aerosol
Suspension, in a gaseous medium, of solid or liquid particles, or both, with a slow settling speed. In the air and under normal conditions, this corresponds to particles with diameters of less than 100 micrometres, with the finest measuring only several fractions of a nanometre.

AFCN
Agence fédérale de contrôle nucléaire (Belgian federal nuclear inspection agency).

AFNOR
Association française de normalisation (French standardisation association).

Alpha (α symbol)
Radiation composed of helium-4 nuclei, strongly ionising but with low penetration. A simple sheet of paper is enough to halt its propagation. See chapter 6.

α global (alpha global)
Radioactivity index representative of the activity of alpha emitter radionuclides.

ANCCLI
Association nationale des comités et commissions locales d'information (National association of local information committees and commissions)

ANDRA
Agence nationale pour la gestion des déchets radioactifs (National agency for the management of radioactive waste).

ANSES
Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail (National health and safety agency for food, the environment and the workplace)

ARS
Agence régionale de santé (Regional health agency).

ASN
Autorité de Sûreté Nucléaire (Nuclear Safety Authority)

AS station
Fixed aerosols sampling station.

Atom
Basic constituent of matter. It consists of a nucleus (neutrons + protons) around which electrons orbit. See chapter 6.

B

Becquerel (Bq)
Legal and international unit of measurement used for quantifying radioactivity. The becquerel (Bq) is equal to one disintegration per second. See chapter 6.

Beta (β symbol)
Radiation composed of negative or positive charged electrons. A screen of several metres of air or a single sheet of aluminium is enough to halt it. See chapter 6.

β global (beta global)
Radioactivity index representative of the activity of beta emitter radionuclides.

BNEN
Bureau de normalisation d'équipements nucléaires (Nuclear facilities standardisation bureau). The BNEN is one of 31 sectoral standardisation bureaus making up the national standardisation system run by AFNOR.

C

Caesium (Cs, atomic number 55)
Rare and toxic metal whose chemical characteristics are comparable to those of potassium. Isotopes 134 and 137 are radioactive fission products with a half-life of 2.2 years for the first 30.17 years for the second.

CEA
French Alternative Energies and Atomic Energy Commission

CLI
Commission locale d'information (Local information commission)

CNPE
French abbreviation for a nuclear power plant.

COFRAC
Comité français d'accréditation (French accreditation committee).

Combustion water
Water obtained by burning dry matter in the presence of oxygen and the absence of other sources of water during combustion.

COMURHEX
(Conversion Métal URanium HEXafluorure)
Subsidiary of ORANO, this company operates two industrial sites in France. The COMURHEX Malvési industrial site handles the first stage of conversion of uranium concentrates deriving from the uranium tetrafluoride (UF4) mining sites for electricity companies the world over. This transformation is continued on the industrial site of COMURHEX Pierrelatte (Drôme), which transforms the uranium tetrafluoride into uranium hexafluoride (UF6), the last stage before enrichment.

CRIIRAD
Commission de recherche et d'information indépendantes sur la radioactivité (Independent research and information commission on radioactivity).

CSP
Code de la santé publique français (French code of public health).

D

DDCSPP
Direction départementale de la cohésion sociale et de la protection des populations (Departmental directorate for social cohesion and the protection of the population).

DDPP
Direction départementale de la protection des populations (Departmental directorate for the protection of the population).

Decay or deactivation
Natural diminution of the nuclear activity of a radioactive substance by spontaneous disintegration.

Decision threshold (DT)
The decision threshold is the minimum value that a sample needs to have for the metrologist to be able to "decide" that this activity is present and therefore measured. Below this value, the activity of the sample is therefore too low to be assessed. This decision threshold depends on the performance of the metrological resources used and the ambient radiation. See chapter 1.4.

Decline
Sloping path *via* which you descend to access a mineral zone for mining extraction.

Decommissioning
Comprises the operations aimed at evacuating radioactive materials and waste, removing the equipment present, cleaning up and disassembling the buildings of a nuclear facility at end-of-life or upon definitive shutdown. It is a industrial project extending over a very long duration, with a security examination for each stage, to ensure effective risk management of the operations.

Dehydration water
Water obtained after drying the sample (most often by freeze-drying) for analysing the free tritium.

DGAL
Direction générale de l'alimentation (Directorate general for food).

DGCCRF
Direction générale de la concurrence, de la consommation et de la répression des fraudes (Directorate general for competition, consumption and the repression of fraud).

DGPR
Direction générale de la prévention des risques (Directorate general for risk prevention). The DGPR consists of a technological risks department (in charge in particular of radiological risks), a pollution prevention and environmental quality department, and a natural and water-related risks department.

DGS
Direction générale de la santé (Directorate general for health).

Discharge authorisation ("Autorisation de Rejet")
This determines, for each nuclear facility, the discharge limits for liquid and/or gaseous effluents and their monitoring conditions. This authorisation is granted by Interministerial Order, upon submission of a file to the Ministries for industry, health and the environment.

Dose coefficient
See chapter 6.

Dose rate
Intensity of exposure to ionising radiation (energy absorbed by matter per unit of mass and time). The legal unit is the Gray per second (Gy/s).

DREAL
Direction régionale de l'environnement, de l'aménagement et du logement (Regional directorate for the environment, development and housing).

E

EDF
Électricité de France.

Effective dose
See chapter 5.

Effluent
Any gas or liquid, which may or may not be radioactive, issuing from nuclear facilities.

Electron
Elementary particle charged with negative electricity. It is part of the composition of atoms. See chapter 6.

EMM
Staff office of the French Navy.

Environmental background radiation
See chapter 2.

Euratom
This treaty, signed in Rome in 1957, established the European Atomic Energy Community, whose mission consists in contributing, through the development of nuclear energy, to the pooling of know-how, infrastructures and financing, and ensuring secure supply in the framework of centralised control.

EURODIF
European gaseous diffusion uranium enrichment plant.

Exposure
Exposure is the condition of being exposed to ionising radiation (external exposure if the source is situated outside the body, internal exposure if the source is situated inside the body, etc.). See chapter 6.

F

FBFC
Société Franco-Belge de Fabrication de Combustibles (Franco-Belgian fuel manufacturing company).

Fissile
Refers to an atomic nucleus in which fission can be induced by capturing a single neutron. Fissile nuclei have an energy configuration very close to spontaneous fission.

Fission
Splitting of an atom's nucleus under the action of neutrons. This reaction is accompanied by the emission of neutrons, ionising radiation and a powerful release of heat. It is the latter this is used to create electrical power in a nuclear power plant.

Fission product
Radionuclide produced by the nuclear fission of a heavy nucleus or by the radioactive decay of a nuclide formed by this process.

FNR
Fast-neutron reactor.

Fruiting vegetables
Vegetables whose fruiting parts are consumed (tomato, aubergine, bell pepper, pea, bean, etc.).

Fuel cycle
All industrial operations to which the nuclear fuel is subject. These operations include in particular the extraction and treatment of the uranium ore, conversion, enrichment of uranium, manufacturing fuel, processing used fuels, recycling fissile materials recovered for manufacturing new fuels and management of radioactive waste.

Fusion
Formation of a heavy nucleus from two light nuclei. This reaction is accompanied by a release of energy. Research is underway into using the energy released by fusion for producing electricity.

G

Gamma (γ symbole)
Electromagnetic radiation that is very penetrative but weakly ionising, emitted by the disintegration of radioactive elements. Shields of concrete or lead offer protection from it. See chapter 6.

Gray (Gy)
Unit of energy transmitted to matter per unit of mass (joules per kg) during absorption of the radiation dose.

GSIEN
Groupement de scientifiques pour l'information sur l'énergie nucléaire (Association of Scientists for Information on Nuclear Energy)

H

Half-life (radioactive period)
Time at the end of which the activity of the radionuclide has diminished by half. The half-life varies from one radionuclide to the next. See chapter 6.

Helium 4
Nucleus formed by two protons and two neutrons. Constituting a particularly stable arrangement, it can be emitted by heavy nuclei seeking stability. It is then called an alpha ray.

I

ICPE
Installation classée pour la protection de l'environnement (Installation classified for the protection of the environment).

ILL
Laue – Langevin Institute. International research body based in Grenoble. It possesses a research reactor, the high-flux reactor (RHF, INB No. 67) with thermal power of 58 MW, used for producing neutron beams.

INB
Installation nucléaire de base (Basic nuclear facility).

INBS
Installation nucléaire de base secrète (Secret basic nuclear facility).

Incline
Sloping path *via* which you ascend to access a mineral zone for mining extraction.

InVS
Institut de veille sanitaire (Health monitoring institute).

Iodine (I, atomic number 53)
A simple structure whose radioactive isotopes are present in fission products. All radioactive iodine (129, 131, 132, 133, etc.) has a short half-life (e.g., isotope 131 has a half-life of 8.02 days), except for iodine-129 whose half-life is nearly 16 million years.

Ionising radiation
Radiation with the propensity to strip electrons from matter. See chapter 6.

IRSN
Institut de radioprotection et de sûreté nucléaire (Institute of radiation protection and nuclear safety).

Isotopes
Elements whose atoms possess the same number of electrons and protons but a different number of neutrons. They have the same name and the same chemical properties. We currently know of around 325 natural isotopes and 1200 artificially-created isotopes.

K

K
Symbol of the element potassium. It is expressed generally as mg/L or mg/kg (milligrams per litre or per kilogram). 1 gram of natural potassium has an activity (β/γ) of 31 Bq due to the decay of the natural radioactive isotope of mass 40 (^{40}K).

L

Leafy vegetables
Vegetables of which we consume all of part of the leaves and stems (lettuce, spinach, cabbage, leek, etc.).

M

Matrix
Sub-part of a compartment (atmospheric, overground, continental aquatic or marine). Examples: rainwater, soil, plant produce, sediments, molluscs, etc.

Measurement uncertainty
Margin of inaccuracy for the measurement value of a physical quantity.

Metrological background radiation
See chapter 1.3.

Mining residues
Designates the products remaining after extraction of the uranium contained in ore *via* static or dynamic processing. They contain the daughter isotopes of uranium-238, in particular radium-226.

MOX (Mixed Oxide)
Mixture of uranium and plutonium oxides used in the manufacturing of certain nuclear fuels.

MW
Megawatt.

N

Neutrinos
Elementary particles with no known electrical charge or mass emitted during weak interactions.

Neutron
Electrically neutral fundamental particle making up, with protons, the composition of an atom's nucleus. It is the neutron that generates the fission reaction in nuclei whose energy is used in nuclear reactors.

Noble gases
Gases with no chemical affinity and producing no compounds. These are argon, helium, krypton, neon, xenon and radon. Certain noble gas isotopes are products of fission and are therefore radioactive.

Nuclear fuel
Fissile material constituting the active part of a reactor's core. For a fission chain reaction to be possible, the natural uranium, a mixture comprising 0.7% uranium-235 – fissile – and 99.3% uranium-238 – non fissile –, must have been previously enriched to 4% uranium-235. This uranium is used in the form of uranium oxide, which is particularly chemically stable.

Nucleus
Central part of the atom, positively charged. 10,000 times smaller than the atom, it accounts nonetheless for practically all the mass. The nucleus is an assembly of protons and neutrons bound by strong interaction.

O

OPERA-AIR
IRSN permanent observatory for monitoring the environmental radioactivity in the air comprising the stations "AS" (80 m^3/h) and "TGD" ("very high volume": 700 m^3/h). See chapter 1.

Orano
French industrial group involved in particular in the fuel cycle and the manufacturing of nuclear facilities, formerly called AREVA.

Ore
A rock containing useful minerals in sufficiently substantial proportions to justify exploitation.

Ores
Rocks containing useful minerals in sufficiently substantial proportions to justify exploitation.

Outfall
Outlet of effluents discharged from a nuclear facility.

P

Photons
Elementary particles with no charge or mass, triggering the electromagnetic interaction.

Pit head
Surface installation of a mine.

Plutonium (Pu, atomic number 94)
Transuranic chemical element; isotope 239 has a half-life of 24,110 years.

Potential alpha energy concentration (PAEC)
The potential alpha energy concentration (PAEC) is a parameter used for physically quantifying the energy that can potentially be deposited in the respiratory tracts by the disintegration of radon progeny (cf. chapter 1.2). It is used for monitoring workers and mining sites. It is expressed as J/m^3 (joules per cubic metre).

Processing of spent fuel
All operations relating to the extraction of fissile and fertile materials (uranium and plutonium) from spent fuels, their reuse, and the packaging of the various types of waste in a form suited to temporary and long-term storage.

Proton
Positively-charged elementary particle, constituting the nucleus with the neutron.

PWR
Pressurised water reactor. Designates a nuclear reactor using uranium or mixed uranium-plutonium oxide as fuel and ordinary water maintained at high pressure (155 bar, to avoid its vaporisation) as coolant. The French fleet of nuclear power plants is based on the use of this reactor system, accounting for the largest number of units in service in the world.

R

Radiation
Transfer of energy in the form of electromagnetic waves (gamma) or particles (alpha, beta, neutrons) emitted during the disintegration of radionuclides.

Radiation protection
A set of measures designed to protect the health of the population and workers against exposure to ionising radiation.

Radioactive waste management
Set of provisions and operations (regulatory or technical) relating to radioactive waste, from production through to and including storage, designed to protect people and the environment.

Radioactivity
Property of certain elements whose nuclei disintegrate spontaneously to form other elements while emitting ionising radiation.

Radionuclide
Radioactive isotope of an element. Examples: ^{3}H: tritium, radioactive isotope of hydrogen; ^{14}C: carbon-14, radioactive isotope of carbon.

Radiotherapy
Use of the destructive power of ionising radiation for destroying sick cells, while minimising damage to the surrounding healthy cells.

Radon (Rn)
Radioactive gas omnipresent on the surface of the Earth. It has three natural isotopes (^{219}Rn, ^{220}Rn, ^{222}Rn), progeny of the radionuclides present in the soil (^{235}U, ^{232}Th and ^{238}U). ^{222}Rn is often the most important one to take into account due to its longer half-life: 3.8 days.

Reactor system / type
Term used for designating a given type of nuclear reactors capable of producing energy. It is defined by a set of common specifications such as the nature of the fuel, the moderator, the coolant, etc. Such types include the UNGG (uranium naturel-graphite-gaz) reactor, light-water reactors, fast-neutron reactors (FNR), etc.

Reference group (of the population)
As defined by the Euratom 96/29 Directive of 13 May 1999: "Group comprising individuals whose exposure to a source is reasonably uniform and representative of that of the individuals in the population who are the more highly exposed to that source." This notion is replaced by the notion of "Representative Person" defined in the Euratom 2013/59 Directive of 5 December 2013: "Individual receiving a dose that is representative of the more highly exposed individuals in the population, excluding those individuals having extreme or rare habits."

RNM
Réseau national de mesures de la radioactivité de l'environnement (National network for radioactivity measurement in the environment).

Root vegetables
Vegetables whose roots, tubers or bulbs are consumed (carrot, potato, onion, radish, etc.).

RPL dosimeter
Passive radio photo luminescent dosimeter

S

SCL
Service commun des laboratoires (Common laboratories service, formerly the laboratories of the DGCCRF). Since 1986, the date of the Chernobyl disaster, the SCL has carried out regular inspections of the radioactivity levels present in consumer products.

SET
Subsidiary of AREVA, Société d'Enrichissement du Tricastin (Tricastin Enrichment Company) is the works contracting authority and operator of the Georges Besse II plant. It is installed on the Tricastin site.

Sievert (Sv)
Legal unit for dose equivalent or effective dose for determining the biological effect produced by a given absorbed dose on a living organism. The dose equivalent is not a measurable physical quantity but is obtained by calculation. It depends on the energy transmitted to the tissues, the type of radiation and the tissue traversed. See chapter 6.

Significant (significant measurement or result)
Measurement result greater than the decision threshold. See "Decision threshold" and chapter 1.4.

SOCATRI
Subsidiary of Orano (ex-AREVA), SOCiété Auxiliaire du TRIcastin (Tricastin auxiliary company) comprises a basic nuclear facility (INB 138) and a uranium decontamination and recovery plant (ARU).

Specific activity
Activity of a radionuclide expressed in Bq/kg for the corresponding chemical element. In this report, it is used for carbon-14, for which the measurement results are expressed in Bq/kg of carbon. See chapter 2.

Spectrometry
Analysis of the intensity of radiation emitted by a source as a function of its energy level. This method enables both identification of the radionuclides and quantification of their "activity".

SPRA
Service de protection radiologique des armées (Radiological protection service of the French Armed Forces). The SPRA operates under the responsibility of the central director of the French Armed Forces health service.

Strontium (Sr, atomic number 38)
Alkaline earth metal, certain isotopes of which are highly abundant in fission products, in particular isotope 90, which is sequestered in bony tissue and has a half-life of 28.15 years.

T

Tailings
Mining waste discarded as unprofitable on account of low ore concentration.

Temporary storage
Provisional storage of radioactive waste.

TGD station
IRSN "very high rate" aerosols sampling station.

TLD dosimeter
Passive thermoluminescent dosimeter

Transuranic elements
Family of chemical elements heavier than uranium (atomic number 92). The main transuranic elements are neptunium (93), plutonium (94), americium (95) and curium (96).

TTS
Total suspended solids.

U

U by weight
Mass content of uranium in a matrix, with no distinction of the isotopic composition. It can be measured or deduced from the activity (expressed as Bq) of each of the isotopes (in which case we refer to "U equivalent by weight").

UNGG
Natural uranium / gas / graphite reactor. This type of reactor has been in operation on the nuclear power plant sites of Bugey, Chinon and Saint-Laurent-des-Eaux. They are currently being decommissioned.

Uranium
Chemical element with atomic number 92 and symbol U, possessing three natural isotopes: uranium-234, uranium-235 and uranium-238. Uranium-235 is the only natural fissile nuclide, a quality that explains its use as an energy source.

W

Waste
Any residue from the process of production, transformation or use; any substance, material, product or, more generally, any goods that are abandoned or that their owner wishes to abandon as they no longer serve any precise purpose.

WHO
World Health Organisation.

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Landscape of the former open-pit uranium mine at Villeret-en-Lozère, now flooded. © IRSN

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