IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Enhancing nuclear safety

Report on the Radiological State of the Environment in France in 2010-2011

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

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TABLE OF CONTENTS

HOW TO READ THIS REPORT

One of the goals of this report on the radiological state of the environment is to facilitate access to information. It has thus been designed to allow quick, simple access to all information regarding the stakeholders involved in monitoring radioactivity in France, and to the results of studies. It also includes an educational section that explains radioactivity, how it is measured, its biological effects and other topics.

In addition, different approaches to reading this report have been designed for the non-specialist public, well-informed readers and experts. They are presented below.

ACCESS BY TYPE OF READER

NON-SPECIALIST PUBLIC

Chapter X	Understanding Radioactivity
Chapter I	Radiological Monitoring of the Environment
Chapter IV	Monitoring in Metropolitan France and the Overseas Territories
Chapter VIII	French Population Exposure to Ionizing Radiation
Chapter IX	Radioactivity Monitoring Information Sources and Data Distribution Networks

WELL-INFORMED PUBLIC

Chapter I	Radiological Monitoring of the Environment
Chapter II	The National Environmental Radioactivity Measurement Network and Stakeholders Involved in Monitoring Radioactivity in France
Chapter IV	Monitoring in Metropolitan France and the Overseas Territories
Chapter V	Monitoring of Nuclear Fuel Cycle Facilities
Chapter VI	Monitoring of Research Centers and Nuclear Naval Bases
Chapter VII	Monitoring of Facilities that Use Sources of Natural or Artificial Radioactivity
Chapter VIII	French Population Exposure to Ionizing Radiation

EXPERTS AND PROFESSIONALS

- Access to all chapters, with a particular focus on those that include monitoring results (Chapters III-VII) and the evaluation of doses received by the population (Chapter VIII).
- To provide direct access to the results, a map showing a summary of those results can be found on the next page.

ACCESS BY SITE: SUMMARY MAP

This summary map is intended for well-informed readers and experts who seek direct access to information and results regarding the main nuclear sites in France (Chapters V, VI and VII).

- Uranium conversion
- Uranium enrichment
- Production of fuel assemblies
- Spent fuel reprocessing and recycling
- Surface disposal of radioactive wastes
- Nuclear power plants
- Nuclear maintenance workshop
- Research centers
- Nuclear naval bases
- Ore processing
- Ionization centers

Map of French mining areas: p. 113

GENERAL ENVIRONMENTAL MONITORING IN FRANCE - ACCESS BY THEME

Note: *The results of marine and coastal environmental monitoring (sea water, sediments and aquatic flora and fauna) near nuclear facilities are presented in Chapter IV.3 (Marine and coastal environment) so that all data available may be used. Similarly, in the atmospheric compartment, the results of active and passive environmental dosimetry measurements are discussed in Chapter IV.*

FOREWORD

The French Institute for Radiological Protection and Nuclear Safety (IRSN) has published an annual Report on the Radiological State of the Environment in France since 2004. Radiological monitoring of the environment in France is one of IRSN's ongoing missions in connection with public policies addressing nuclear safety and radiation protection, and helps to ensure the highest possible level of protection to the population. The objective of this mission is to:

- **verify** that nuclear activities are conducted in compliance with regulations governing discharge;
- **ensure** that all components of the environment remain in a satisfactory radiological state that does not entail excessive exposure of humans and ecosystems;
- **detect** as soon as possible any abnormal elevation in radioactivity that may result from a radiological or nuclear accident in France or abroad.

As announced in the previous report, a new version of the report containing all the data from the National Environmental Radioactivity Measurement Network (RNM) is being issued this year. Since 2003, IRSN's mission has been to develop and manage the RNM, which was established under Articles R. 1333-11 and R. 1333-11-1 of the French Public Health Code.

The main goal of the network, which is described in Chapter 2 of this report, is to gather and make available to the public the information held by public authorities on the radiological state of the various components of the environment. In accordance with regulations, IRSN must now prepare a summary report on the radiological state of the environment based on RNM data, and supplemented by estimates of the radiological impacts of the main nuclear activities.

Publication of this report thus constitutes a major event in France's nuclear energy transparency policy as, for the first time, it incorporates all the data submitted to the RNM by the nuclear stakeholders that are part of the network. With more than 300,000 measurements considered, the report provides the most comprehensive view possible of all the environmental radioactivity measurements taken by the various stakeholders.

In order to incorporate results relating to the Fukushima accident, this report includes the data obtained between January 1, 2010 and June 30, 2011 across the entire country. The monitoring results from French Polynesia are presented in a special report published annually by IRSN, which can be consulted online.

The results are presented thematically:

- **by type of facility that discharges radioactive substances** (for example, nuclear power plants, spent fuel reprocessing facilities, or nuclear research centers) for monitoring results from these sites;
- **by environmental compartment** (atmospheric, continental, marine and coastal) for general monitoring results from across the country.

Each chapter of the report may be read independently of the others. In order to provide the reader with a broader, more representative perspective of environmental radioactivity measurements, IRSN has chosen to express results as a single estimator that takes into account all values measured at a given point over the period in question, including values below decision thresholds. This method avoids over-repetition of individual results in tables or graphs, while remaining scientifically rigorous.

Differences may appear in monitoring plans across sites of a similar nature for geographic or historical reasons or based on a specific study. To find results or obtain access to those that are not included in this report, please consult the RNM website (http://www.mesure-radioactivite.fr) or IRSN's environmental Internet portal (http://environnement.irsn.fr).

The first half of 2011 was marked by the accident at the Fukushima Daiichi nuclear power plant, which occurred in the wake of the March 11, 2011 earthquake and tsunami. This report includes a summary of IRSN's assessment of the impact of that accident in France (both in metropolitan and overseas France), published in early 2012. More than 5,700 measurement results obtained by IRSN and 3,000 results transmitted by operators and the Association for Radioactivity Monitoring in Western France (ACRO) were included in this scientific analysis. More generally, incorporating these results involved a particular approach to managing data analysis and presentation, in that a distinction was made between 'usual' values measured in the environment and those obtained during the period after the accident.

Traces of this event were detected over several weeks. In addition, the results shown in this report reveal the presence of artificial radionuclides in the environment close to known discharge sources (nuclear industry and hospital activities) and outside the areas of influence, due to fallout over the entire country (including from atmospheric nuclear weapons tests conducted from 1945-1980 and the 1986 Chernobyl accident) or former, insufficiently controlled, industrial activities (polluted sites). In general, these traces are evident particularly in soils, continental waters, and the sea (sediment and flora and fauna). From a qualitative perspective, radiation levels measured in 2010 and 2011 remain low and are within the range of values typically seen in recent years.

As it does every year, IRSN has continued to work on improving the content of the report and making it easier to read. This latest report incorporates a number of changes reflecting the integration of data provided by the RNM, and modifications made by IRSN to its national radiological monitoring mission as of 2008 (the introduction of regional radiological reports and redeployment of coastal and food monitoring).

Other novelties in this report include the participation of RNM stakeholders and the Belgian Federal Agency for Nuclear Control (FANC) in special Focus sections that highlight a specific topic or significant event related to environmental radiological monitoring.

I hope you find this report on the radiological state of the environment in 2010-2011 interesting and useful and that it meets your expectations.

Jacques Repussard
Director General

OVERVIEW OF IRSN'S MISSIONS

IRSN, the French Institute for Radiological Protection and Nuclear Safety was set up under Act No. 2001-398 of May 9, 2001. As the public service expert on risks, IRSN contributes to public policy issues relating to nuclear safety and human and environmental protection in the area of ionizing radiation. It interacts with all parties concerned by these policies.

Nuclear risk prevention in France is based on four complementary pillars:

- **Operators** are responsible for the safety of their nuclear facilities. They must demonstrate the appropriateness of the technical and organizational resources implemented to that end (for example, safety analysis reports, and discharge impact studies).
- **Public authorities** determine nuclear and radiation protection policies. They are responsible for the organization and implementation of control.
- **IRSN, the public service expert** in nuclear risks, assesses operator reports and documents on behalf of the relevant authorities. It conducts on-going analysis of feedback on facility operation and human and environmental exposure to radiation. IRSN's expertise is based on its research, designed in an international context, which ensures that it relies on the most effective investigative tools.
- **Local Information Commissions (CLI)** bring together the stakeholders concerned with a given nuclear facility. They provide access to information and exercise vigilance on issues relating to safety and health and environmental protection.

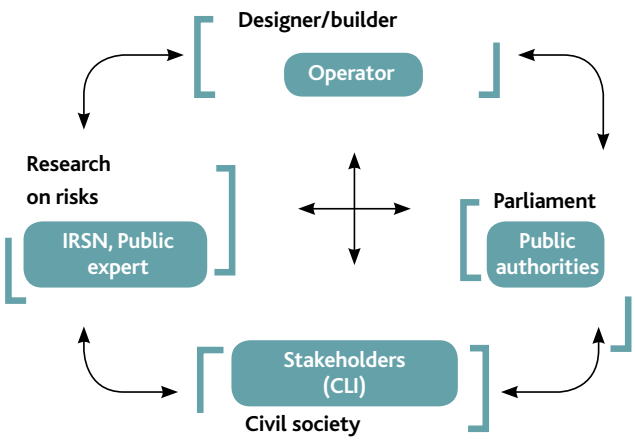

Figure 1 - The four pillars of nuclear risk prevention.

IRSN is a French public authority with industrial and commercial activities placed under the joint authority of:

- the Ministry of Ecology, Sustainable Development and Energy;
- the Ministry of Economic Regeneration;
- the Ministry of Higher Education and Research;
- the Ministry of Defense;
- the Ministry of Social Affairs and Health.

Of its total expenditure (€282 million in 2011), €210.8 million is provided by a grant from the Ministry of Ecology, under the Budget Act's "research and higher education" mission, the "energy, development and sustainable development" research program and the "research in the field of risk" action. This grant is supplemented by national, European and international funding assigned to specific research or assessment programs. IRSN has more than 1,700 employees, including over 1,000 experts and researchers.

Its resources are allocated as follows:

- **40.2%** for research. The largest programs, which require nuclear research reactors or considerable resources (for example, fuel behavior and accident simulations), are pooled at the international level;
- **50.2 %** for technical support to public authorities and government departments and for public service missions;
- **9.6%** for assessments and studies carried out under contract.

IRSN's activities cover the following fields:

- **nuclear safety:** reactors, fuel cycle, waste, medical applications;
- **transportation safety** for radioactive and fissile materials;
- **protection of workers exposed to ionizing radiation:** IRSN manages individual exposure data on approximately 350,000 workers;
- **protection of the population and the environment** against risks associated with ionizing radiation;
- **protection and control** of nuclear materials;
- **protection of nuclear facilities** and radioactive and fissile material shipments against malicious acts.

IRSN promotes nuclear transparency:

- **informing the public** is one of the Institute's missions. Its Internet portal (www.irsn.fr) offers a wide range of information targeting different audiences.
- **IRSN has signed a framework agreement with the ANCCLI, the federation of local information commissions,** to make its expertise accessible to stakeholders and thus contribute to an understanding of technical, often complex, matters;
- **At the request of the public authorities, IRSN leads joint expert groups** on topics that might become the subject of social debate.

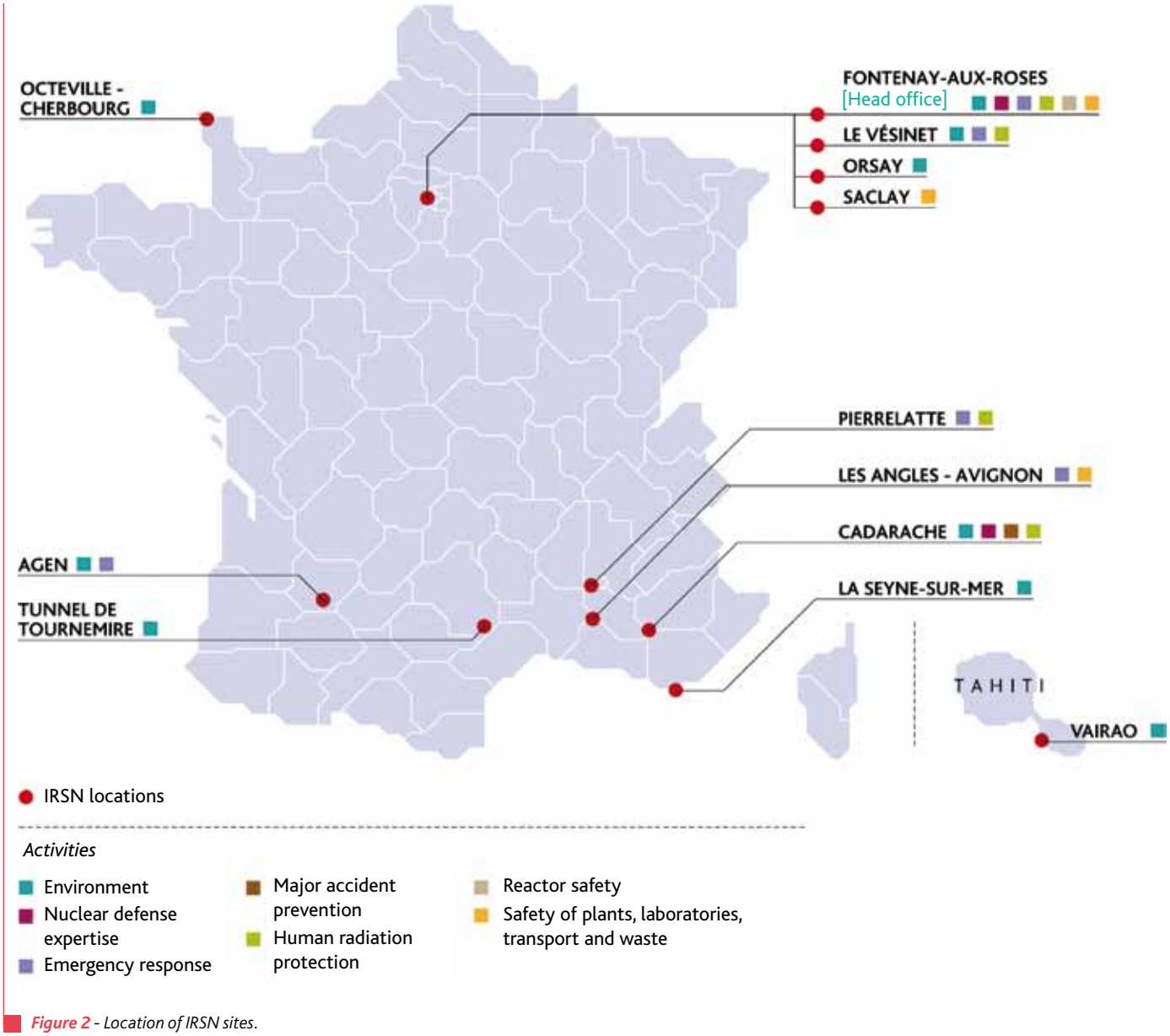

Figure 2 - Location of IRSN sites.

IRSN, an international stakeholder

IRSN is a Technical Safety Organization (TSO), implementing scientific partnerships and overseeing scientific cooperation and nuclear safety, security and radiation protection services in 39 countries under bilateral or multinational consortium agreements, under the auspices of the EU, the NEA or TSO networks (ETSON in Europe), or in cooperation with the IAEA.


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RADIOLOGICAL MONITORING OF THE ENVIRONMENT

Radioactivity in the environment today is due to radionuclides that may be natural, in other words, found on Earth since its very beginnings, or artificial, i.e. introduced by humans as from the mid-20th century. Some radionuclides, such as tritium and carbon-14, are both natural and anthropogenic.

I.1 NATURAL AND ARTIFICIAL RADIATION IN FRANCE

Natural radiation

Radioactivity is part of the universe. It occurs naturally everywhere, without human action. Radioactive elements can be found in the atmosphere and the Earth's crust. From the very beginnings of the Earth, some five billion years ago, matter has been composed of both radioactive and stable elements. Since then, radioactivity has declined steadily as many radioactive atoms have transformed into stable elements.

Sources of natural radiation

- **Cosmic rays** have two components. The first is the product of high-energy ions from the galaxies. The second comes from the sun - solar wind consists primarily of protons. The Earth's magnetic field forms the magnetosphere which, with the atmosphere, acts as a protective screen that prevents all but 0.05% of cosmic radiation from reaching sea level. Conversely, the intensity of cosmic radiation increases with altitude, doubling every 1,500 meters (*Figure I.1*).

- **Radioactivity in the soil** (or terrestrial radiation) is emitted by many radioactive elements found in the Earth's crust, such as uranium and thorium. It varies with the type of soil and is five to twenty times higher in granite massifs, for example, than in sedimentary soils.

- **Radioactivity in water** only partially reflects the geological character of the areas crossed. Everything depends on the chemical nature of the water and the degree of solubility of the radionuclides. Mineral water is more radioactive than surface water and some ground water is rich in dissolved radon gas.

- **Radioactivity in the air** mainly comes from gaseous radon-222, which, in turn, comes from uranium-238. This component is the most significant in terms of natural exposure and varies considerably. It depends on the uranium-238 concentrations in the soil, soil porosity, construction materials and housing ventilation, which concentrates the diffusion of the radon gas by confining it. This gas, together with its derivative products, lodges in the airways.

- **Radioactivity in the human body**, which represents some 120 Bq/kg (8,400 Bq for a person weighing 70 kg), comes from ingesting foods that contain radioactive elements.[1] Once ingested, these radionuclides lodge in tissues and bones. On average, the human organism contains 4,500 Bq of potassium-40 and 3,700 Bq of carbon-14.

1 – Source: La radioactivité naturelle en 10 épisodes, Livret de la SFRP, 1998.

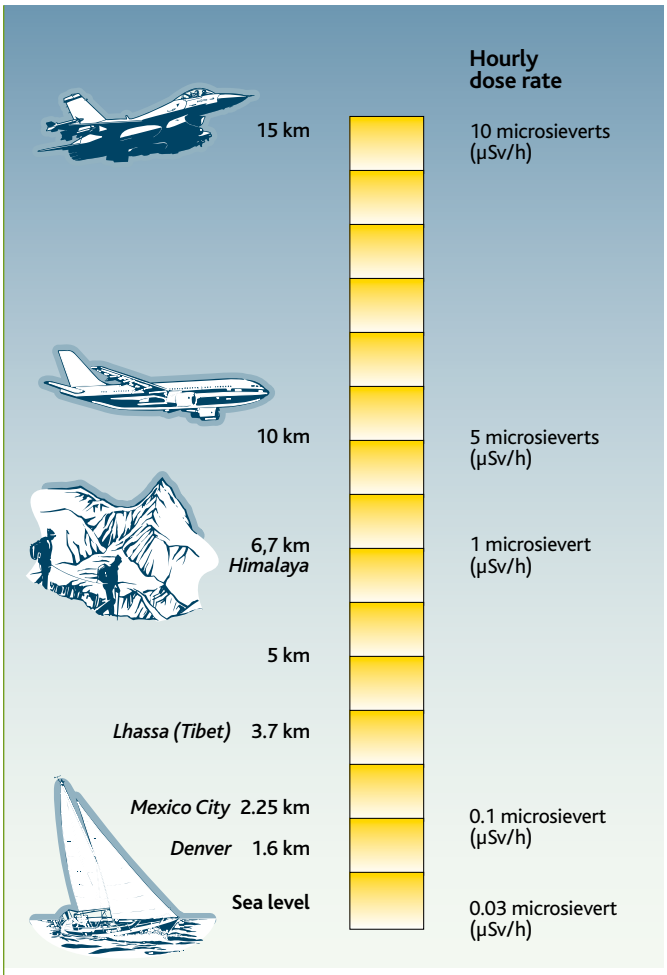


Figure I.1 - The dose due to cosmic rays increases with altitude

Naturally occurring radionuclides

Of the 340 types of atoms that exist in nature, 70 have unstable radioactive nuclei (radionuclides). Only 20 or so of these "primordial" radionuclides still exist today, as the short-lived ones – that is, in relation to the age of the Earth – have disappeared. These naturally occurring radionuclides, which account for most environmental radioactivity, are found in the air, soil, water and living organisms, including humans.

They are either radionuclides with a very long half-life that have been present on Earth since it was formed (potassium-40, uranium-238, uranium-235 and thorium-232), or those created continuously in the upper atmosphere as a result of cosmic radiation, referred to as cosmogenic radionuclides (tritium, carbon-14, krypton-85, beryllium-7 and sodium-22). While most of these radionuclides disintegrate directly into stable, non-radioactive elements, three of them (^{238}U, ^{235}U and ^{232}Th) produce several radioactive decay products, which form families or decay chains, each containing between 10 and 15 different radionuclides (*Figure I.2*).

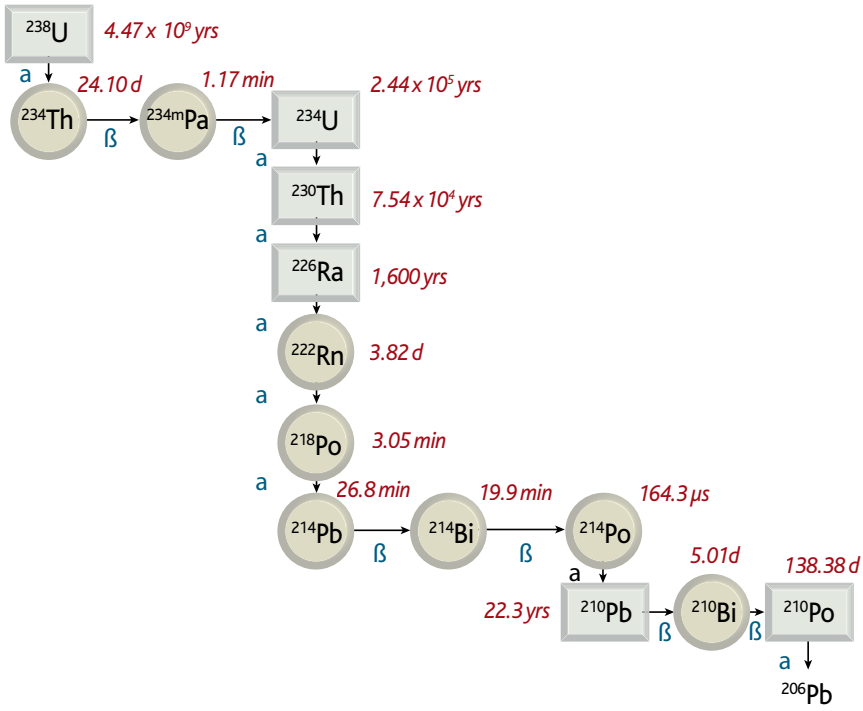


Figure I.2 - Uranium-238 progeny

Special case of radon

Radon (Rn) is a radioactive gas that is found everywhere on the Earth's surface. It has three natural isotopes (^{219}Rn, ^{220}Rn, ^{222}Rn) that are decay products of radioelements in the soil (^{235}U, ^{232}Th and ^{238}U).

Radon-222 in its gaseous form, a decay product of radium (^{226}Ra), which is, in turn, a decay product of uranium-238, is the most common isotope in the atmosphere because its half-life of 3.82 days is long enough to allow it to migrate, from the rock where it was formed to the soil and into the atmosphere (*Figure I.3*). As it decays, radon emits alpha particles and generates solid decay products that are also radioactive (including polonium, bismuth and lead).

It migrates from the soil to the open air through various physical processes, and may accumulate in the more confined atmosphere of buildings. For the French population, inhaling radon and its decay products is the leading cause of exposure to natural sources of ionizing radiation. The increased risk of lung cancer explains heightened vigilance with regard to radon in homes and underground mines.

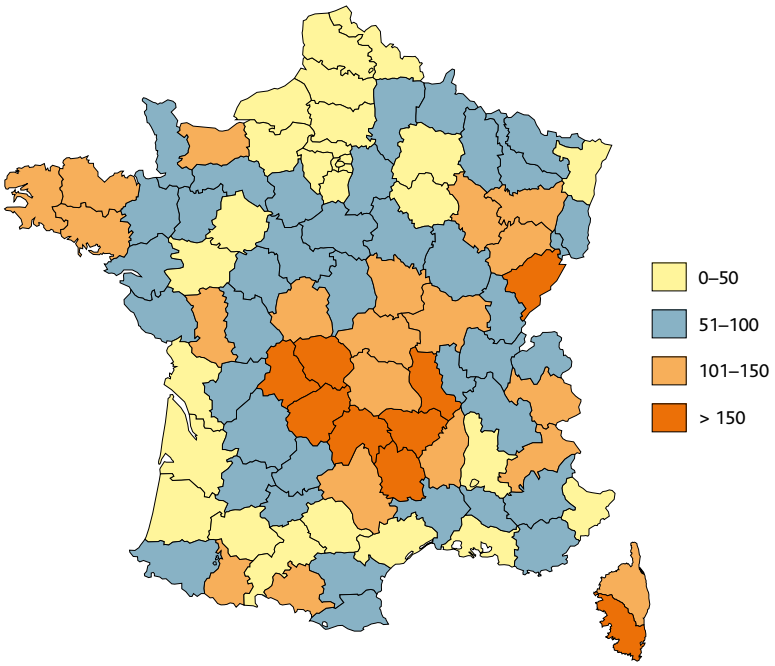


Figure I.3 - Average radon concentration in air in homes by department (Bq/m3)

Technologically enhanced naturally occurring radioactive materials

Natural background radiation has always existed and, on the whole, total human exposure has doubtless changed very little over the centuries. However, lifestyle changes and the introduction of new practices may have changed that situation somewhat.

Certain circumstances may lead to relatively significant exposure to technologically enhanced, naturally occurring radioactive materials:

1 – confinement of radon in housing: the use of certain radon-emitting construction materials, construction that is poorly insulated from uranium-bearing soil and overly confined housing may result in significant exposure;

2 - production processes in certain industrial activities, not related to the nuclear power cycle, may change the physical-chemical equilibria of natural radioactivity contained in the materials used and concentrate it in the generated waste. That is what is meant by technologically enhanced natural radioactivity. It represents a potentially increased risk of radioactive release to the environment and consequently of human exposure, even after industrial activity has ceased.

This unintentionally technologically enhanced, naturally occurring radioactive material comes from ore extraction and geologic resources, as well as from the successive phases of separation, purification, transformation, and use of by-products. It mainly concerns the following activities:

- coal-fired power plants;
- tin, aluminum, copper, titanium, niobium, bismuth and thorium ore processing;
- refractory ceramic production;
- production or use of compounds containing thorium;
- zircon and baddeleyite production;
- phosphate fertilizer production and phosphoric acid manufacturing;
- titanium dioxide processing;
- rare earth processing and production of pigments containing them;
- ground water filtration for drinking water;
- spas.

3– Extraction and processing of uranium ore also generates technologically enhanced, naturally occurring radioactive materials, but, unlike the industrial activities referred to above, the ore is used for its radioactive properties.

Artificial radiation

Sources of artificial radiation

Unlike naturally occurring radionuclides, 'artificial' radionuclides are radioactive elements that are no longer found in nature but recreated artificially. Since the early 20th century, human activity has generated artificial environmental radioactivity.

Artificial radionuclides are produced using particle accelerators or nuclear reactors.

Some radionuclides may be used as an X-ray source or as sources for industrial and medical applications of radiation (radiation therapy for example).

Others are produced in nuclear reactors. Some of these radionuclides, which are highly radioactive and not currently used by humans, form nuclear waste that must be placed under strict surveillance in disposal facilities.

Currently, around ten artificial radionuclides are measured regularly in the environment in France, including strontium-90, cesium-137, iodine-131, plutonium isotopes (^{238}Pu, ^{239}Pu, and ^{240}Pu) and americium-241.

These radionuclides have the following main sources (*Figure I.4*):

- regulated and authorized discharge from nuclear facilities or relating to nuclear medicine activities (radiological tests and medical treatments);
- fallout from atmospheric nuclear weapons testing (1945 to 1980) and the 1986 Chernobyl accident;

Remaining fallout from the Chernobyl accident and atmospheric nuclear tests account for the artificial background radioactivity in France today.

Figure I.4 - Main sources of artificial radiation in the environment in France

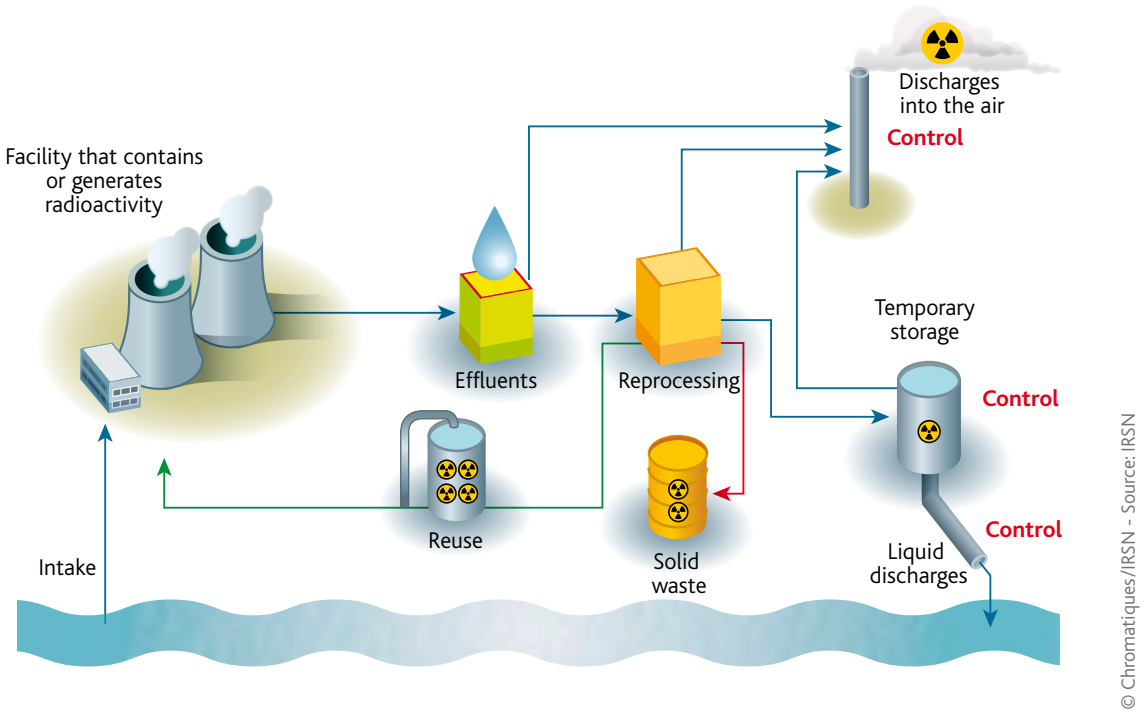


Figure I.5 - Sources and types of effluent from nuclear facilities - a simplified view

Discharge from industrial and nuclear energy research facilities, including nuclear power plants, is regulated. Most nuclear fuel cycle facilities use water drawn from rivers or the ocean (*Figure I.5*). The use of this water is partly responsible for effluent that is treated so that most of it can be retained as solid waste. The remaining effluent is then discharged into the water and air after testing to ensure that it complies with the regulatory requirements laid down by the authorities (rate, discharged activity levels and radionuclides contained).

Nuclear facilities discharge many kinds of radionuclides, depending on the type of facility and operating phase (for example, production, maintenance outage, or dismantling). The activity levels discharged by these facilities in normal operating mode have also changed over time due to increased restrictions on discharge permit renewals issued by the authorities, and as new waste treatment processes are introduced.

Today, three radionuclides make up most of the discharge from French nuclear fuel cycle facilities:

- krypton-85, a chemically inert noble gas with a half-life of 10.7 years, discharged in gaseous form during nuclear fuel reprocessing (Areva NC facility in La Hague);
- tritium;
- carbon-14.

Last, discharge from nuclear medicine activities is characterized by radionuclides with a very short half-life (eight days for iodine-131 and six hours for metastable technetium-99).

The main artificial radionuclides found in the environment in France (*Table I.1*)

Tritium and carbon-14

Also produced naturally in the atmosphere through the interaction of cosmic radiation and matter and as a result of fallout from nuclear testing, tritium (^{3}H) and carbon-14 (^{14}C) are among the radionuclides most frequently discharged by the nuclear industry.

They are quite uniformly distributed across France. The heterogeneity of fallout from nuclear testing is no doubt masked by the prevailing natural component, which is very homogeneous. In the terrestrial environment, in areas unaffected by discharge from nuclear facilities, the specific activity of ^{14}C expressed in becquerels per kilogram of total carbon is in equilibrium with the environmental components and, specifically, with atmospheric CO_2. In 2009, this specific activity was approximately 237 ± 6 Bq/kg of carbon, close to the atmospheric activity prior to atmospheric nuclear tests (226 Bq/kg of carbon). In the aquatic environment, the ^{14}C of freshwater ecosystems is not in equilibrium with atmospheric CO_2. The activity levels there are lower, in the region of 200 Bq/kg of carbon.

With regard to tritium, apart from all anthropogenic sources, activity concentration values range from one to several Bq/L in fresh water or kg wet in foodstuffs, and from 0.01 to 0.05 Bq/m³ in air.

Near some nuclear facilities, however, exposed to prevailing winds or downstream from the outfalls of nuclear facilities, ^{3}H and ^{14}C activity levels can be considerably higher.

While most nuclear facilities have a slight but visible impact on their environment in terms of ^{14}C, ^{3}H activity levels only stand out clearly from the background near certain French nuclear sites such as Valduc, Marcoule, La Hague, Saclay and Bruyères-le-Châtel. Last, ^{3}H was discharged by certain industries that use it for its luminescent properties for watch hands or for signage. For example, the upper reaches of the Rhône are affected by ^{3}H from discharge from the Swiss watchmaking industry.

Cesium-137

Cesium-137 results from nuclear testing and the Chernobyl accident and is also found in discharge from certain nuclear facilities, including nuclear power plants, spent fuel reprocessing facilities and research centers. It is almost impossible, however, to detect what proportion of the discharge from these facilities enters the terrestrial environment because it is masked to a great extent by the persistence of earlier fallout.

After reaching a maximum of 4,000 Bq/m^2 in 1963, soil surface activity in terms of ^{137}Cs then fell slowly after the U.S. and the Soviet Union ended atmospheric nuclear weapons testing and as a result of radioactive decay and dilution and migration processes. The May 1986 Chernobyl accident resulted in additional cesium-137 deposits, distributed irregularly across the country.

Today, cesium-137 soil activity levels may vary by nearly two orders of magnitude depending on initial radioactive deposits. Deposits in the western two-thirds of the country are homogeneous and below 5,000 Bq/m^2, while in the eastern part of the country, deposits are very heterogeneous and up to 40,000 Bq/m^2 (*Figure I.6*).

Cesium-137, still measured in the air in France, is found at an average level of less than 1 µBq/m^3; in rainwater the level ranges from 0.01 to 0.1 mBq/L. In recent years, however, the activity of this radionuclide stopped falling. A balance appears to have been reached between the activity deposited on the surface of the soil and the activity in resuspension from inventory present in the soil and plants. Levels in foodstuffs range from the detection limit to several hundred Bq/kg wet for some mushrooms.

Strontium-90

Strontium-90 comes almost entirely from nuclear testing fallout. Soil surface contamination with ^{90}Sr thus increased gradually as from 1945, reaching a maximum of 2,500 Bq/m^2 in 1963. The halt of nuclear weapons testing then led to a slow reduction as a result of radioactive decay, which continues today. Strontium-90 is still detectable in soil, milk and plant samples. In general, levels found in foodstuffs are around 0.1 Bq/kg wet.

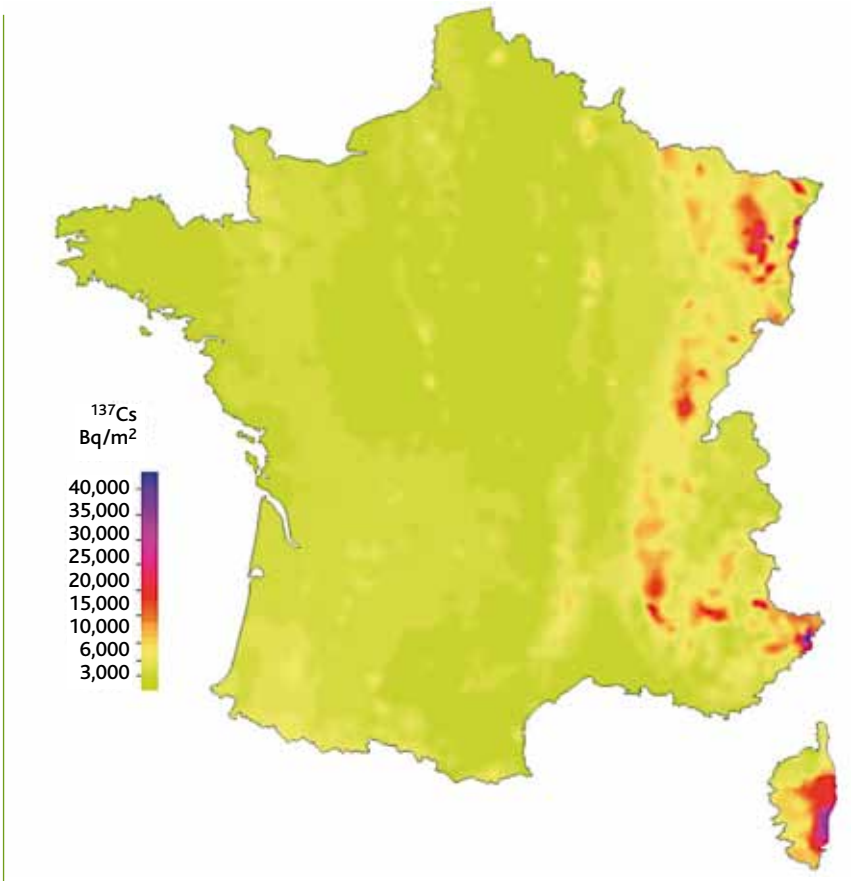


Figure I.6 - Surface activity levels of ^{137}Cs potentially present in French soils in 2007

Transuranium elements (plutonium and americium)

Plutonium isotopes (^{238}Pu, ^{239}Pu, ^{240}Pu and ^{241}Pu) are almost exclusively due to fallout from atmospheric nuclear weapons testing and, in the case of ^{238}Pu, from the disintegration of the US SNAP-9A satellite in 1964, which used a ^{238}Pu-fueled generator. In foodstuffs, the activity levels of ^{239}Pu can reach several mBq/kg wet, but often remain below the detection limit.

Liquid effluent and plutonium discharged into the atmosphere in the past by certain facilities, such as Marcoule and La Hague, have produced concentrations of ^{238}Pu, ^{239}Pu and ^{240}Pu in their immediate environment, relative to the background of earlier fallout.

Americium-241 does not come from fallout, but from ^{241}Pu decay. Thus, its activity increases regularly and will reach its maximum around 2036, when there will no longer be enough ^{241}Pu to allow the production of ^{241}Am to compensate for its slow radioactive decay (half-life of 433 years).

Other artificial radionuclides

Other artificial radionuclides are measured on a more ad hoc basis in continental aquatic and marine environments:

- **in areas impacted by discharge from nuclear facilities,** manganese-54 (^{54}Mn), cobalt-58 and -60 (^{58}Co and ^{60}Co), silver-110 (metastable) (^{110m}mAg), iodine-129 (^{129}I) and, very sporadically, ruthenium-106 (^{106}Ru) and cesium-134 (^{134}Cs);
- **in areas impacted by discharge from hospitals,** iodine-131 (^{131}I) in suspended matter or in aquatic plants.

These radionuclides are very rarely detected in the terrestrial environment and, when they are, only at levels close to the detection limits.

Last, IRSN has begun to monitor the activity concentration of the gaseous radionuclide krypton-85 (^{85}Kr) in the air close to La Hague. An initial assessment was conducted in 2010.

Table I.1 - Main artificial radionuclides in the environment in France

Radionuclide	Radioactive half-life	Main emissions	Main decay product	Main sources
^{3}H	12.32 years	Beta	^{3}He	Cosmic, nuclear tests, discharge from the nuclear and watchmaking industries
^{14}C	5,730 years	Beta	^{14}N	Cosmic, nuclear tests, discharge from the nuclear industry and research
^{60}Co	5.27 years	Beta, gamma	^{60}Ni	Discharge from the nuclear industry
^{90}Sr	28.78 years	Beta	^{90}Y	Nuclear tests, discharge from the nuclear industry
^{131}I	8 days	Beta, gamma	^{131}Xe	Discharge from the nuclear industry and nuclear medicine departments
^{137}Cs	30.07 years	Beta, gamma	^{137}Ba	Nuclear tests, Chernobyl accident, discharge from the nuclear industry
^{238}Pu	87.7 years	Alpha	^{234}U	Nuclear tests, discharge from the nuclear industry
$^{239+240}Pu$	24,100 and 6,560 years	Alpha	$^{235+236}U$	Nuclear tests, discharge from the nuclear industry

I.2 WHY MONITOR ENVIRONMENTAL RADIOACTIVITY?

Industrial and other human activities that use radioactive substances may lead to radionuclides being discharged to the environment, either during normal operation or under emergency conditions.

The following cases are concerned:

- **discharge of radioactive substances into the air or the aquatic and marine environments as a result of nuclear activities.** This is carried out under controlled conditions defined by the discharge permits issued by the authorities. Regulations applicable to discharge have changed over the years, with regular reductions in authorized limits;
- **diffusion** of radionuclides, in particular via seepage water, in residues deposited on soil surfaces or underground, under conditions that do not guarantee total confinement of radionuclides. This particular case arises in connection with former sites that used naturally occurring radionuclides during the first half of the 20th century;
- **accidental release of radioactive substances into the air,** in water, or on the ground, directly or as a result of atmospheric dust fallout (for example, the Chernobyl accident);
- **persistence of long-lived radionuclides in the environment** (radioactive half-life exceeding several years) from discharge into the air or water, accumulating in the soil, sediments or certain living organisms. In France, as in the rest of Europe, radionuclides persist due to atmospheric fallout from nuclear weapons testing and the Chernobyl accident.

In addition, natural sources regularly contribute radionuclides to the environment; for example, carbon-14 (^{14}C), potassium-40 (^{40}K), uranium and thorium and their radioactive decay products.

The presence of these radioactive substances in the environment must be monitored and studied to understand their potential impact on human health, the environment, and economic resources, particularly water and agriculture. Radiological monitoring is therefore carried out in all the environmental compartments: air, water, soils, biological compartments (fauna and flora) and the food chain.

I.3 WHAT ARE THE OBJECTIVES OF RADIOLOGICAL MONITORING OF THE ENVIRONMENT?

Monitoring environmental radioactivity involves many organizations on the French nuclear scene. Based on its missions or regulatory obligations, each stakeholder is positioned in a specific context and responds with its own monitoring strategy.

The radiological monitoring of the environment conducted by these many organizations addresses a variety of objectives:

• protecting human health and the environment against the effects of radiation exposure

Monitoring the environment will help to estimate the impact of ionizing radiation on humans and the environment, whether natural or anthropogenic (including discharge from nuclear facilities).

• knowledge of the radiological state of the environment

This objective involves monitoring spatial and temporal changes in levels of radioactivity found in different environmental compartments across the country, although it focuses particularly on areas surrounding major facilities likely to discharge radionuclides;

• the early detection of any abnormal increase in radioactivity that may result from an incident or accident at a nuclear facility

Radiological monitoring of the environment makes it possible to detect and monitor, as quickly as possible, any abnormal increase in radioactivity, whether due to an accident or incident, or specific natural events - extreme weather situations in particular;

• compliance with regulations by nuclear operators

The impact of nuclear facilities is first evaluated on the basis of discharge, not through direct environmental measurements. However, regardless of the legal status of the facility (basic nuclear installation, environmentally regulated facility, or activity falling under the French Public Health Code), specific monitoring must be put in place to verify that the doses generated by these facilities remain well below the regulatory limits (1 mSv/year for the public) and that the operator complies with the discharge limits set by the authorities;

• informing the public

All monitoring activities must provide for public information on activity levels found in the environment. While each stakeholder has its own communication methods (Internet sites, periodic information brochures and annual reports), since 2009, the National Environmental Radioactivity Measurement Network (RNM) has centralized and reported on these measurements by setting up a single database and an Internet site (www.mesure-radioactivite.fr). One of the main objectives of the RNM is to ensure that the public receives reliable, credible and understandable information.

© Noak/Le Bar Floréal/IRSN

Figure I.7 - Taking water samples from the Donzère-Mondragon canal downstream from the Pierrelatte nuclear site

I.4 HOW IS RADIOACTIVITY MONITORED?

Radiological monitoring of the environment is based on three kinds of sampling systems and/or measurements:

• spot samples taken in the environment for subsequent laboratory measurement

These samples are taken from a variety of matrices: rainwater, surface water (fresh water and sea water), biological indicators (including mosses and algae), soil and sediment, as well as foodstuffs (milk and dairy products, meat, fish, mollusks, crustaceans and cereals);

• continuous sampling procedures with subsequent laboratory measurement of collected samples

This method primarily concerns measurements taken in the atmospheric compartment (aerosols, measurements of specific radionuclides in the air, such as tritium and carbon-14) and in surface water (using water samplers);

• continuous *in situ* measurement systems, possibly associated with a real-time retransmission system. These systems are mainly used for early detection of radiological events. The main continuous measurement networks are the monitors used to measure the ambient gamma dose equivalent rate.

© Caroline Pottier/Le bar Floréal/IRSN

Figure I.8 - Taking filter samples of atmospheric aerosols

© Arnaud Bouisson/MEDDTL/IRSN

Figure I.9 - New-generation IRSN Téléray monitor (for gamma radiation dose rate measurement) installed in Paris (French naval staff headquarters)

I.5 METHODOLOGICAL ASPECTS OF SELECTING MONITORING STATIONS

The general sampling principles are similar to those used to characterize any contamination. They rely on guides and standards (*Table I.2*) developed specifically by the nuclear equipment standardization office (the BNEN, part of the French Standards Association, Afnor). In the field of radiological monitoring of the environment, contamination bioindicators must be used. These help to identify and quantify the concentration in question.

Regarding methodology, the sampling strategy chosen is one of the key elements that defines the representativeness and validity of the measurements. In this document, the environment is presented as a set of compartments (terrestrial, atmospheric, continental aquatic and marine), also referred to as 'environments'. Criteria must be defined for each compartment as the basis for choosing the location of stations.

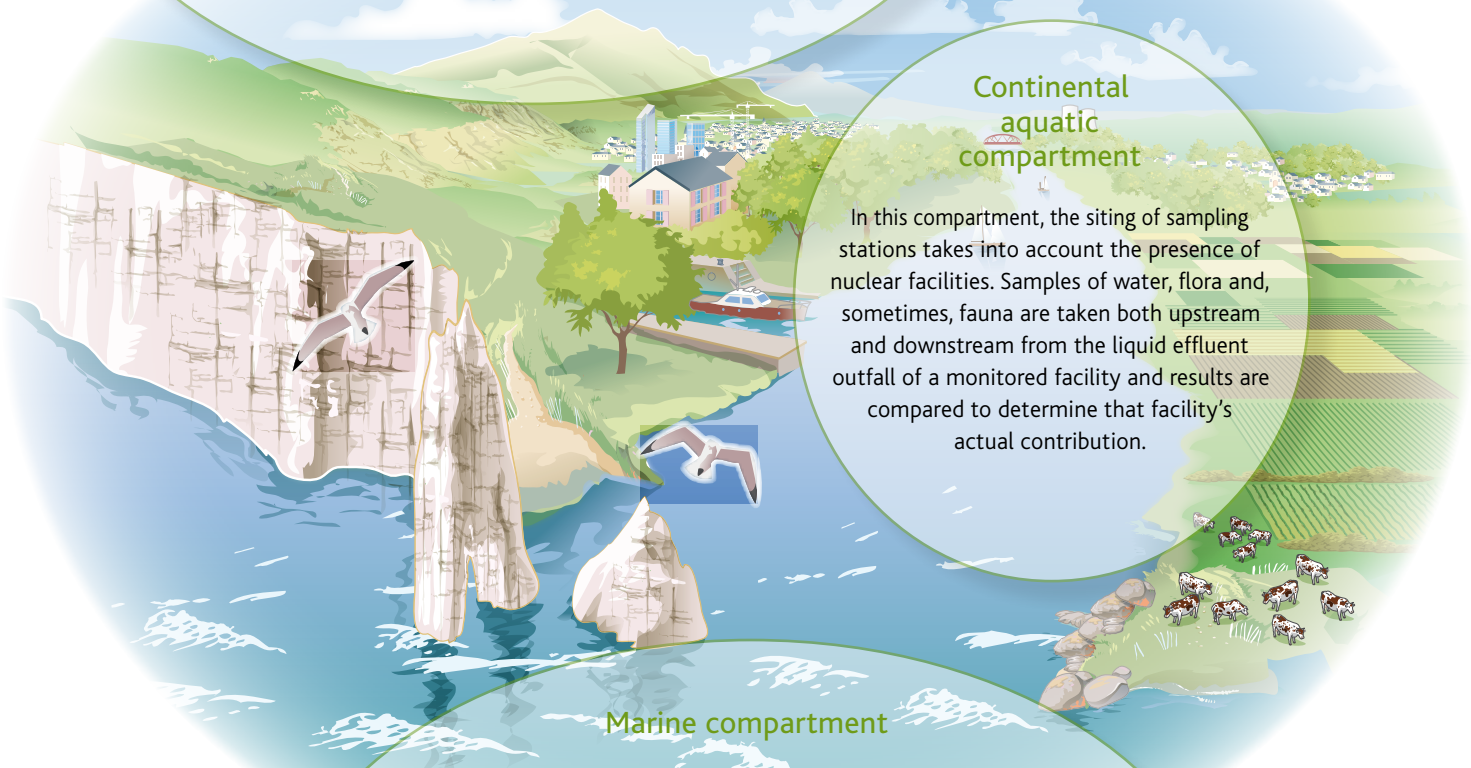
***Table I.2** - Examples of standards applicable to sampling for radiological measurement purposes*

Matrix	Standard	Title
Air	NF M60-760 (October 2001)	• Nuclear energy • Environmental radioactivity measurement • Air • Aerosol sampling for environmental radioactivity measurement
Water	PR NF EN ISO 5667-1 (November 2005)	• Water quality • Sampling • Part 1: General guide to setting up sampling programs and techniques
Soil	NF ISO 18589-1 (December 2005)	• Nuclear energy • Environmental radioactivity measurement • Soil • Part 1: General guidelines and definition
Biological indicators	NF M60-780-2 (March 2001)	• Nuclear energy • Environmental radioactivity measurement • Bioindicators • Part 2: General guide to sampling techniques
Foodstuffs	NF V03-009-1 (July 2002)	• Food products • Measurement of radioactivity in foodstuffs • Part 1: Guide to sampling, transportation and preservation of foodstuffs • Obtaining a laboratory sample

Selecting the location of sampling stations

Terrestrial and atmospheric compartments

Sampling stations are chosen by considering the dispersion conditions of atmospheric discharge from the nuclear facility monitored. Atmospheric aerosol sampling stations and rainwater collectors are installed systematically around nuclear facilities for sectors under the influence of prevailing winds. Whenever possible, milk samples are also taken from farms located near the facility, under the prevailing winds. In addition, some metropolitan areas are also subject to radiological monitoring to assess the exposure of populations in densely built-up areas, whether or not they are close to nuclear or industrial sites.



Continental aquatic compartment

In this compartment, the siting of sampling stations takes into account the presence of nuclear facilities. Samples of water, flora and, sometimes, fauna are taken both upstream and downstream from the liquid effluent outfall of a monitored facility and results are compared to determine that facility's actual contribution.

Marine compartment

The siting of stations considers the location of potential sources of discharges and the conditions of their dispersion in the sea (ocean currents and tidal ranges). The marine environment close to nuclear facilities located along the Channel and North Sea coasts is subject to tidal currents, resulting in the displacement of water masses from west to east. Sampling locations are determined by the fact that the west of the Channel constitutes upstream and the North Sea is downstream in terms of discharge from facilities located along these coasts. In the Mediterranean, the Ligurian current, which runs from east to west, is the primary influence on the movement and dispersion of discharge, for the most part into the Rhône. Samples of seawater, sediments and aquatic flora and fauna are taken in the eastern and western Rhône delta, making allowance for the Ligurian current.

CEA • FOCUS

Collection of environmental monitoring samples from the Marcoule site

In connection with the environmental monitoring of the Marcoule site, the CEA takes more than 4,000 samples annually at 120 different spots. The various nuclear operators on this site are subject to the same monitoring and the site's effluent and environmental control and impact assessment laboratory (LCEI) works with several thousand chemical and radiological analysis results.

In this context, the laboratory, which ensures that samples comply with current standards, took the initiative of compiling a collection of data sheets describing samples taken for environmental monitoring purposes on the site. For each sample, the collection provides an overview of the applicable internal reference systems and the references of sampling standards and regulations. The collection meets the requirements of the laboratory's quality and safety standards (NF EN ISO/CEI 17 025, ISO 14 001, OHSAS 18 001).

It is made up of 26 sheets all on the same model that is intended to be simple and intuitive, and which was distributed to every laboratory employee. It is updated regularly and includes a page for personal notes for users who can add to it as necessary. The analysis of all of these notes helps to update and improve the collection.

Each sheet is designed according to a standard model and includes the following information:

- *details of the sampling point: location, access, why this location was chosen, sampling frequency and reproducibility;*
- *sampling procedure, equipment used and references of applicable documents;*
- *specific sampling conditions adopted to guarantee analysis quality and analysis list;*
- *information required to identify the sample;*
- *maintenance and periodic equipment checks;*
- *specific comments on safety, sampling conditions and equipment.*

Many photos and maps illustrate the sampling methodology.

The collection was completed in September 2010 and monitoring personnel responded to it very positively and consult it daily. It supports training and enhances the versatility of laboratory teams. It serves as an essential reference document during inspections and audits.

© CEA/Marcoule

Figure I.10 - Sample of an aliquot of surface water

© CEA/Marcoule

Figure I.11 - Surface water sample from Codolet lake

Choice of environmental matrices

The tables below show the monitoring methods for the terrestrial, continental aquatic and marine compartments, together with the criteria associated with these choices.

Atmospheric and terrestrial compartments

Table I.3 - Strategic criteria for selecting the matrices sampled in the terrestrial compartment

Environment/ product	Strategic criteria associated with this environment/product	Means of sampling and/or direct measurement
Air	Receiving environment for atmospheric discharge. Radioactive particles and gases in the air deliver a dose to humans through external and internal exposure (inhalation).	• Probes for continuous measurement (air: ambient gamma dose rate). • Continuous sampling and measurement sensors (aerosols). • Aerosol collectors for laboratory measurements. • Environmental dosimeters.
Rainwater	Wet deposition of aerosols (and consequently radioactivity) by leaching from the air column through which the drops of water pass.	• Rainwater collectors.
Soil	Accumulation – concentration of radioactivity by wet or dry deposition. The soil may also be responsible for contaminating vegetables, fruit and grasses through the root system.	• Spot samples (manual). • In situ gamma spectrometry.
Vegetable crops	Contamination by deposition on the aerial portion of the plant or by absorption through the roots. Risk of internal contamination after consumption.	• Spot samples (manual).
Animal products	Radioactivity in feed is transferred to products of animal origin, including milk, which is a major vector for radionuclides (including cesium, strontium, and iodine).	• Spot samples (manual).

Continental aquatic compartment

Table I.4 - Strategic criteria for choosing the matrices sampled in the continental aquatic compartment

Environment/ product	Strategic criteria associated with this environment/product	Means of sampling and/or direct measurement
Continental waters	As the receiving environment for liquid effluent from facilities and any contributions from runoff, water is the direct vector for contamination of the aquatic environment.	• Continuous sampling and measurement systems (IRSN Hydrotéléray monitor). • Water sampler. • Spot samples.
Suspended matter in water	Suspended matter is the preferred vector for radionuclides. Its mobility contributes to the contamination of river banks, beaches or land after flooding.	• Settling tanks used with water collectors. • Laboratory filtration of water samples.
Sediments	Sediments are good integrators of contamination and a reservoir of contamination of the aquatic environment through desorption.	• Spot samples (manual or mechanical).
Aquatic plants	Aquatic plants can fix certain radionuclides quickly. Their broad geographic distribution allows comparison among specific radionuclide activities in different locations.	• Spot samples (manual).
Fish	Humans regularly consume fish, which are good integrators of radionuclides. The geographic distribution of the species sampled also allows comparison of specific activities measured at different sampling points across the country.	• Spot samples (fishing).

Marine compartment

Table I.5 - Strategic criteria for selecting the matrices sampled in the marine compartment

Environment/ product	Strategic criteria associated with this environment/product	Means of sampling
Sea water	As the receiving environment of liquid effluent and contributions of radionuclides via runoff, sea water is a direct vector of contamination in the marine environment.	• Spot samples (manual). • Water collectors.
Sediments	Sediments are good integrators of radionuclides and a reservoir of contamination of the aquatic environment through desorption.	• Spot samples (manual).
Algae	Marine algae react quickly to changes in the radionuclide content of water.	• Spot samples (manual).
Mollusks	Given their feeding methods, marine mollusks are good bioindicators for long-term monitoring, whether they are filter feeders or grazers.	• Spot samples (manual or direct collection from producers).
Crustaceans Fish	As they are at the end of the food chain, fish are good integrators of radionuclides. They are also a large part of the human diet.	• Spot samples (fished or direct collection at ports).

I.6 ANALYSIS PLANS

As soon as they arrive at the laboratory, samples are processed and conditioned according to the radiological tests to be performed. The tests performed on each sample follow predefined plans based on the type of sample, the compartment, and the type of facility or site surveyed (size, type of discharge) and its event history (past incidents, past release, fallout, etc.).

In the case of nuclear facilities, the types of samples and analysis plans are in proportion to the environmental hazards or drawbacks that the facility may represent. Regulatory monitoring around basic nuclear installations is adapted to each type of facility (nuclear power plant, factory or laboratory). Table I.6 summarizes environmental radiological monitoring principles in accordance with existing regulatory provisions.

Table I.6 - Examples of regulatory monitoring requirements applicable to operators near their facilities (source: ASN).

Environment monitored or type of test	Nuclear power plant	Laboratory or factory
Air at ground level	• 4 continuous sampling stations collecting atmospheric dust on fixed filters with daily measurements of gross beta activity. Gamma spectrometry if gross beta activity > 2 mBq/m^3. • 1 continuous sampling station under prevailing winds with weekly tritium measurement (^{3}H).	
Ambient gamma radiation	• 4 monitors at a distance of 1 km with continuous measurement and recording. • 10 monitors with continuous measurement at site perimeter (monthly readings). • 4 monitors at a distance of 5 km with continuous measurement.	• 4 monitors at a distance of 1 km with continuous measurement and recording. • 10 integrating dosimeters at site perimeter (monthly readings).
Rain	• 1 station under prevailing winds (monthly collector) with measurement of gross beta activity and ^{3}H on a monthly mixture.	• 2 continuous sampling stations, including one under prevailing winds with weekly measurement of gross beta activity and ^{3}H.
Liquid waste receiving environment	• River samples taken upstream and at mid-discharge for each discharge (riverside plant), or sampling after dilution in the cooling water and bi-monthly sampling at sea (coastal plant): measurement of gross beta activity, potassium (^{40}K) and ^{3}H, measurement of gross beta activity on suspended matter. • Continuous sampling of ^{3}H (daily average mixture). • Annual sampling of sediments and aquatic flora and fauna with measurement of gross beta activity, ^{40}K and ^{3}H, gamma spectrometry.	• At least weekly sampling of water in the receiving environment with measurement of gross alpha activity, gross beta activity, ^{40}K and ^{3}H. • Annual sampling of sediments, aquatic flora and fauna for gamma spectrometry.
Ground water	• 5 sampling points (monthly check) with measurement of gross beta activity, ^{40}K and ^{3}H.	• 5 sampling points (monthly check) with measurement of gross beta activity, ^{40}K and ^{3}H. • Measurement of gross alpha activity.
Soil	• 1 annual sample of topsoil with gamma spectrometry.	
Plants	• 2 grass sampling points (monthly check) with measurement of gross beta activity, ^{40}K and gamma spectrometry. Measurement of carbon-14 (^{14}C) and total carbon (quarterly). • Annual campaign on the main agricultural products with measurement of gross beta, ^{40}K, ^{14}C and total carbon and gamma spectrometry. activity	• 4 grass sampling points (monthly check). • Annual campaign on the main agricultural products with measurement of gross beta activity ^{40}K, ^{14}C and total carbon and gamma spectrometry.
Milk	• 2 sampling points (monthly check) with measurement of beta activity, ^{40}K and, annually, ^{14}C.	• 1 sampling point (monthly check) with measurement of beta activity and gamma spectrometry (+ ^{3}H and ^{14}C periodically).

Table I.7 provides a simplified representation of the analysis plans as prepared by IRSN around different types of sites and throughout the country.

Table I.7 - Model analysis plans developedby IRSN in connection with radiological monitoring in France

	Radionuclides targeted							
Environment studied	U	Am, Pu	^{3}H	^{14}C	^{90}Sr	^{137}Cs	Iodines	Other beta/ gamma (*)
Environment far from a nuclear site						■		■
Former mining site	■							
Site in the front end of the nuclear fuel cycle	■							
Decommissioned NPP	Gross alpha activity					■		■
Operating NPP			■	■		■		■
Site in the back end of the nuclear fuel cycle			■	■	■	■	■	■
Waste disposal site			■			■		■
Civilian and military research centers			■		■	■		■
Naval bases			■			■		■

■ *Radionuclide targeted systematically*
□ *Radionuclide targeted on a spot basis, depending on the sites or during specific studies*
(*) Other beta/gamma-emitting radionuclides: ^{58}Co, ^{60}Co, ^{134}Cs, ^{40}K, ^{99m}Tc and others.

AFCN • FOCUS

Radiological monitoring in Belgium

Radiological monitoring conducted by the Belgian government agency, the Federal Agency for Nuclear Control (FANC), can be seen as a type of 'environmental screening.' The hope is that nothing or, to be more exact, nothing significant will be found. This monitoring has shown, year after year, that the radiological situation in Belgium generally gives no cause for concern. It reflects efforts by operators of facilities whose activities may have a radiological impact on the environment to reduce that impact. To this end, operators are required not only to take every step to ensure that discharge from their facilities remains below authorized limits, but also to minimize it by applying the ALARA principle.

Radiological monitoring in Belgium covers two complementary aspects:

- *general monitoring across the country, outside areas where significant nuclear activities are carried out. This indicates the level of radioactivity to which the population is naturally exposed. It covers areas at a distance from nuclear sites, such as the coastal region, and other areas known as 'reference', such as the Brussels metropolitan area, which is Belgium's largest and home to 10% of the population;*
- *close monitoring around sites where activities with a possible radiological impact on the environment are carried out. Nuclear power plant operators in Belgium (GDF-Suez Electrabel) are not under any obligation to conduct environmental radiological monitoring. Other facilities set up dosimetric control both onsite and in the surrounding area and, in very rare cases, conduct environmental monitoring nearby. The radiological monitoring implemented by FANC aims at covering the entire country and areas in the vicinity of the following nuclear sites:*
  - *the Doel and Tihange nuclear power plants;*
  - *the area of Belgium close to Chooz nuclear power plant in France;*
  - *the Belgian Nuclear Research Center (SCK•CEN) site, in Mol;*
  - *the Belgoprocess, Belgonucléaire and the Franco-Belgian fuel manufacturing plants (FBFC International) in Mol and Dessel;*
  - *the National Institute for Radioelements (IRE), MDS-Nordion, Sterigenics and Ion Bean Applications SA (Iba) in Fleurus.*

Close monitoring also covers facilities where radioelements are used, including hospitals, universities and certain industrial sectors such as feed phosphate production in the Tessenderlo region. The process used in this non-nuclear industrial activity concentrates a natural radioelement – radium-226 – in the liquid effluent it discharges.

In practice, radiological monitoring in the country keeps track of both artificial and natural radiation levels in two ways:

- *continuously, via the automatic Telerad network, which measures ambient gamma radioactivity in the air;*
- *intermittently, through periodic measurement campaigns in the field and by taking samples for subsequent laboratory analysis.*

Focus (continued)

Focus (continued)

FANC• FOCUS

The Telerad network is the automatic remote radioactivity measurement network in Belgium. It is made up of 219 stations that continuously measure radioactivity in the air and river water. The stations are distributed across the country, around the Tihange, Doel, Mol and Fleurus nuclear facilities, and in urban areas near them, as well as in the vicinity of the Chooz facility in France. They are connected to a centralized system and issue automatic warnings if they detect abnormally high radiation levels. In the event of a nuclear accident, the Telerad network plays a critical role in accident severity assessment, decision-making, optimizing response and countermeasures, and keeping the population informed on an ongoing basis. In normal situations, the Telerad network measures the ambient dose rate due to gamma radiation. This dose rate is associated with the level of natural radiation, which is also called background radiation.

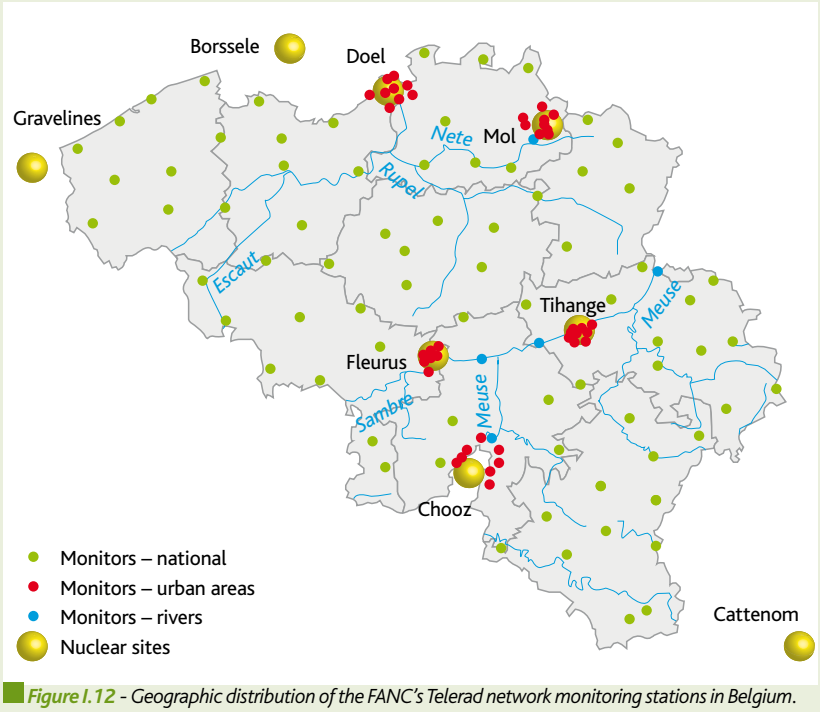


Figure I.12 - Geographic distribution of the FANC's Telerad network monitoring stations in Belgium.

Sampling campaigns and measurements in the field are the keystone of radiological surveillance in Belgium. They are used to obtain a more precise idea of Belgium's radiological profile and must help to determine the exact levels of natural and artificial radiation in the environment and assess radiation doses to the population. They systematically target the main environmental compartments and components of the food chain liable to be contaminated and to which the population may be exposed. Specialized SCK•CEN and Ire-Elit teams take samples for FANC. Sampling frequency has been defined to generate the most useful information possible, making allowance for technical and equipment constraints. The samples are then analyzed in these institutions' laboratories to determine the precise nature and level of radioactivity they contain.

These analyses measure alpha-, beta- and gamma-emitting radionuclides, all together or according to type. In the latter case, they seek, in particular, to measure naturally occurring radionuclides (such as beryllium-7 and potassium-40), which serve as reference points, and radionuclides that are characteristic of specific human activities (such as those associated with the production of nuclear reactor fuel, radioactive tracers used in nuclear medicine and radium-226, a naturally occurring radionuclide that is concentrated in liquid effluent from the feed phosphate production process). FANC then centralizes, analyzes and interprets the results.

The Belgian radiological monitoring program involves nearly 5,000 samples every year, and 29,500 analyses. Atmospheric discharge and liquid effluent from the main nuclear sites are also monitored and analyzed.

Overall, the radiological situation is excellent

Radiological monitoring in Belgium, which provides a precise inventory of environmental radioactivity in the country, as well as the risks to the population, has not revealed any major problems. Artificial radiation is usually much lower than natural radiation, if not simply below the detection limit. Monitoring also clearly shows that the dose rate (ambient radioactivity) under normal conditions, and excluding medical exposure, is determined primarily by the type of soil. The rocky soils in the south of the country give off more radon (natural radioactive gas) than those in the north, which are sandy. The dose rate measured in Wallonia, for example, is higher than that measured in the area around the Doel nuclear plant, which has a negligible radiological impact on the environment. The radiological impact of nuclear power plants, in particular, is negligible, or so low as to be below the detection limit.

Special attention is required

While the radiological situation in Belgium is quite satisfactory, one drainage system, the Laak-Winterbeek-Nete-Escaut system, stands out because of its abnormally high artificial and natural radiation (^{226}Ra) level. Some nuclear facilities in the Mol–Dessel region do have a measurable, albeit slight, impact on the environment. The same is true for the non-nuclear feed phosphate production industry in the Tessenderlo region, which discharges ^{226}Ra. However, the measurable radiological impact of these facilities in the northwest of the country has seen a sharp decline in recent years.

I.7 FROM PREPARATION TO PHYSICAL MEASUREMENT OF SAMPLES

Measuring the radioactivity of an environmental sample begins with its physical preparation. This may range from simply placing it in a standardized container to a more elaborate preparation, such as drying, calcination or freeze-drying, to concentrate the sample. In most cases, analysis does not require the entire sample. The sample is first homogenized so that the amount taken for the test does not bias the representativeness of the measurement. Most monitoring organizations also archive some of the samples analyzed (especially filters) for possible subsequent analysis using additional or more effective methods.

Figure I.13 summarizes the main stages in the transformation of a grass sample, from its collection to physical measurement and archiving.

1 • Grass sampling.

2 • Drying in the oven.

3 • Freeze-drying.

4 • Crushing and homogenization.

5 • Calcination.

© IRSN

6 • Radiation chemistry.

7/1 • Detection of alpha radiation.

7/2 • Detection of beta radiation.

7/3 • Detection of gamma radiation.

8 • Archiving.

© IRSN

*After the sample is collected in the field **(1)**, it must be packaged quickly to prevent any degradation and taken to the laboratory for processing.*

When it arrives, the sample's characteristics are recorded to ensure traceability throughout the process.

*Radioactivity measurement for a sample begins with its physical preparation. This ranges from simple packaging in a standardized container to more elaborate preparation, **such as drying in an oven (2)**, freeze-drying **(3)**, crushing **(4)** and calcination **(5)**, all of which serve to concentrate the sample's radioactivity.*

*The need to concentrate the sample or extract the targeted radionuclides sometimes involves advanced radiation chemistry processing **(6)**, which generally concentrates or separates the radionuclides in question.*

*At the end of this phase, the samples are measured using different kinds of counters depending on the targeted radionuclides **(7)** (alpha/beta proportional counters, alpha counters with photomultiplier tubes, liquid scintillation counters and gamma detectors). They are then archived **(8)**.*

***Figure I.13** - Sample and laboratory analysis phases for monitoring purposes*

Concentrating the sample or extracting the radionuclides to be measured requires the use of a laboratory guaranteeing the highest level of quality during all or some of the stages involved in characterizing the radionuclides in a sample.

After physical preparation, radiochemistry procedures are generally employed to concentrate or separate the targeted radionuclides. In general, laboratories also have methods for processing and conducting physical-chemical analyses of the samples.

At the end of this phase, the samples are encapsulated and sent to the nuclear measurement laboratory. Counters or spectrometers (alpha/beta proportional counters, alpha counters with photomultiplier tubes, liquid scintillation counters, Ge gamma detectors with sample changers, NaI gamma detectors, grid ionization chambers with changer and semi-conductors) are used to detect alpha, beta and gamma radiation. Measurement quality in terms of activity, density and nature, is guaranteed by the use of tracers or standard specific reference sources.

The range of metrological skills implemented by laboratories to measure environmental radioactivity can be seen below:

- gross alpha/beta measurements to monitor aerosol and water filters;
- ^{226}Ra measurement;
- measurement of beta-emitting radionuclides (such as ^{3}H, ^{14}C, ^{63}Ni, ^{90}Sr, ^{241}Pu, and ^{210}Pb);
- measurement of natural or artificial gamma-emitting radionuclides (including ^{137}Cs, ^{134}Cs, ^{60}Co, ^{125}Sb, ^{131}I, ^{129}I, ^{40}K, ^{7}Be, ^{210}Pb, ^{234}Th, ^{214}Pb, and ^{222}Rn);
- measurement of alpha-emitting radionuclides such as plutonium, ^{241}Am and ^{244}Cm, uranium, thorium and ^{210}Po;
- measurement of stable elements, such as K, Na, Ca, Fe, Sr, Ni, Pb.

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Figure I.14 *- Spectrometry measurement on alpha spectrometry system with a grid ionization chamber*

© Y. Geoffray/Areva

Figure I.15 *- Alpha spectrometry measurement*

© IRSN

Figure I.16 *- Measurement by liquid scintillation*

© Acro

Figure I.17 *- Preparation for measuring uranium and radium*

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Figure I.18 - Algae sampling (cystoseira) on the coast.

© French Navy

II

THE NATIONAL ENVIRONMENTAL RADIOACTIVITY MEASUREMENT NETWORK AND THE STAKEHOLDERS INVOLVED IN MONITORING IN FRANCE

II.1 THE NATIONAL ENVIRONMENTAL RADIOACTIVITY MEASUREMENT NETWORK (RNM)

The goals of the French National Environmental Radioactivity Measurement Network (RNM) include centralizing information on environmental radioactivity in France, ensuring that information is transparent and understood by all audiences, and promoting the standardization and quality of laboratory measurements.

Background and goals

Monitoring environmental radioactivity involves many organizations on the French nuclear scene. Based on its missions or regulatory obligations, each stakeholder is positioned in a specific context and responds with its own monitoring strategy. Thousands of results are thus available in France, whether provided by IRSN, nuclear facility operators or other stakeholders in the public, private and non-profit sectors. However, despite the efforts made regarding information and transparency in this area, the great number of stakeholders and information sources makes it difficult for the public to obtain a clear grasp of the results and each stakeholder's role. The quality of information is also a critical issue, particularly in a context as sensitive as environmental radioactivity and in a field as complex as nuclear metrology. It is therefore essential to ensure, in advance, that the laboratories have the requisite technical and organizational skills.

Further to the transposition of European Directive 96/29 into French law, the RNM was set up under the French Public Health Code, as amended by Decree No. 2002-460 of April 4, 2002 on the general protection of persons against the dangers of ionizing radiation. The operating procedures of this network, which were initially set out by ministerial order (October 17, 2003 and then June 27, 2005), were replaced by a decision ratified by ASN in 2008 (No. 2008-DC-0099 of April 29, 2008) to incorporate regulatory changes and, specifically, the publication of Act No. 2006-686 of June 13, 2006 on nuclear transparency and safety (the TSN Act).

The RNM was set up with two main goals:

- to ensure the transparency of information on environmental radioactivity **by making the results** of environmental radiological monitoring in France available to the public;
- to continue developing a quality policy on environmental radioactivity measurements by setting up a laboratory certification system, under the authority of ASN.

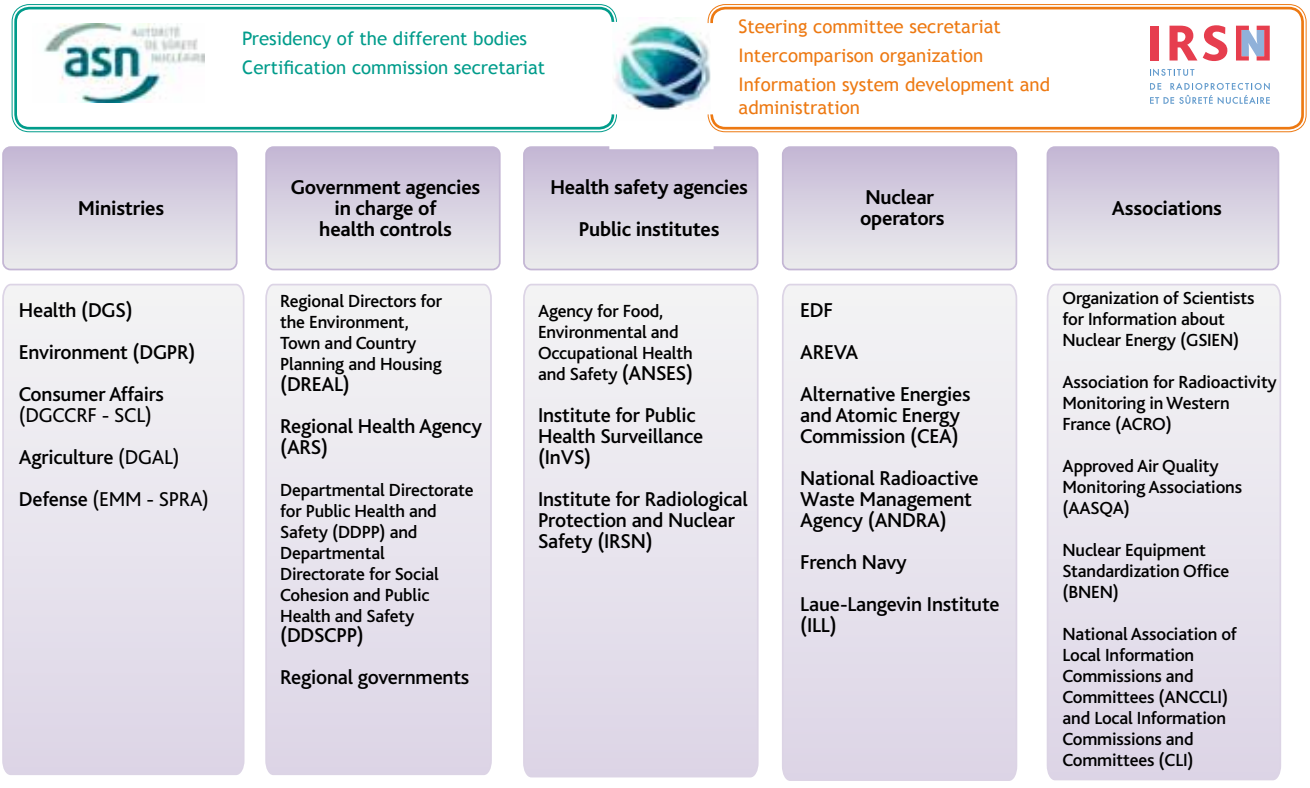
The RNM's mission is to help estimate the doses of ionizing radiation to which the population is exposed and inform the public. To that end, it gathers and issues to the public:

- results of environmental radioactivity measurements;
- summary documents on the country's radiological status and assessment of ionizing radiation doses to which the population is exposed.

The measurements that the RNM gathers are essential for assessing the impact of radioactive substances on health, the environment and economic resources (particularly, water and agriculture).

RNM organization and operation

The RNM operates under the auspices of ASN in collaboration with IRSN (*Figure II.1*) and in partnership with the RNM's main stakeholders, including the Ministries of the Environment (DGPR), Consumer Affairs (DGCCRF), Health (DGS and ARS), Defense (SPRA and



** Different representatives, which may or may not be from other organizations, are also appointed as certified professionals.*

Figure II.1 - Stakeholders of RNM bodies and main producers of measurements of environmental radioactivity in France.

the French Navy), and Agriculture (DGAL), health and safety agencies (InVS and ANSES), the main nuclear operators (EDF, Areva, CEA and ANDRA) and environmental and consumer protection associations (ACRO and GSIEN).

It is coordinated by two entities supervised by ASN. These are a steering committee, which is responsible for the network's strategic policy, and a certification commission, which issues opinions on certification requests. Figure II.1 illustrates the roles of IRSN and ASN, as well as of the main stakeholders in the national network and the main organizations involved in taking environmental radioactivity measurements.

The steering committee issues its opinion on the national network guidelines put forward by ASN. It ensures that the radioactivity data referred to in Article R1333-11 of the French Code of Public Health is published. It may also be required to give its opinion on summary reports on the radiological state of the environment and the impact of nuclear facilities, issued by IRSN or any other entity that requests it to do so.

Who sends the environmental radioactivity measurements to the national network?

In accordance with Article 1333-11 of the French Public Health Code, the results of environmental radioactivity measurements gathered by the RNM are those obtained:

- under laws or regulations concerning the assessment of doses to which the population is exposed and, in particular, results showing the environmental impact of nuclear activities: nuclear operators that are required by law or regulations to provide environmental radioactivity measurements must have these measurements performed by certified laboratories or IRSN and transmit the results for publication on the RNM website;
- by the French Nuclear Safety Authority, regional authorities, government agencies, and public bodies that have measurements performed by certified laboratories or by IRSN;
- by any non-profit association or other private entity that has measurements performed by certified laboratories or by IRSN when the organization that holds these results asks that they be transmitted to the RNM.

Interlaboratory proficiency tests and certifications issued by ASN

Certification to measure radioactivity in the environment concerns all laboratories (public, private, university and non-profit), but directly concern those that perform measurements under legal or regulatory provisions and are required to transmit their measurements to the RNM. These laboratories must submit comprehensive documentation demonstrating the compliance of their organizational structure and practices, as well as take part in interlaboratory proficiency tests organized by IRSN to test the laboratories' technical competency (*see Focus and Figure II.2*). This generally involves aptitude tests in which results obtained by laboratories on identical samples are compared to an assigned value (reference value defined by IRSN). The IRSN tests concern the measurement of beta- and gamma-emitting radionuclides, pure beta emitters and artificial alpha emitters, as well as radionuclides from the decay chains of uranium, thorium and radium and of uranium content, amounting to more than 43 types of different tests.

IRSN is entrusted with a number of tasks regarding these tests, either by ASN through its Decision No. 2008-DC-0099 of April 29, 2008, or by the DGAL as the national reference laboratory for radionuclides, (LNR RN) further to the Order of December 29, 2009. These tasks include preparing samples, delivering them to the laboratories taking part in the tests, determining the assigned values, and conducting statistical analysis of laboratory results.

The samples prepared by IRSN are distributed simultaneously to the participants to be measured at the same time. The sample batch must be homogeneous and stable (in terms of radioactivity) so that no discrepancy can be attributed to a lack of homogeneity or stability.

The number of participants in each test ranges from 15 to 70 and includes several laboratories from outside France. IRSN has been organizing this kind of test for 40 years, with six to seven tests/year conducted today. IRSN has been certified by the French Accreditation Committee (COFRAC) since 2006 to hold these specific interlaboratory tests. These tests primarily allow participating laboratories to obtain or renew certification from ASN or the DGAL, in connection with the regulation, and to ensure the quality of the analytic methods implemented and provide the accrediting organizations with the information needed to determine whether the laboratories have expertise in the analytic processes.

A dedicated Internet site (https://cilei.irsn.fr/) has been available since January 2011 for the dissemination and exchange of information among IRSN and participants.

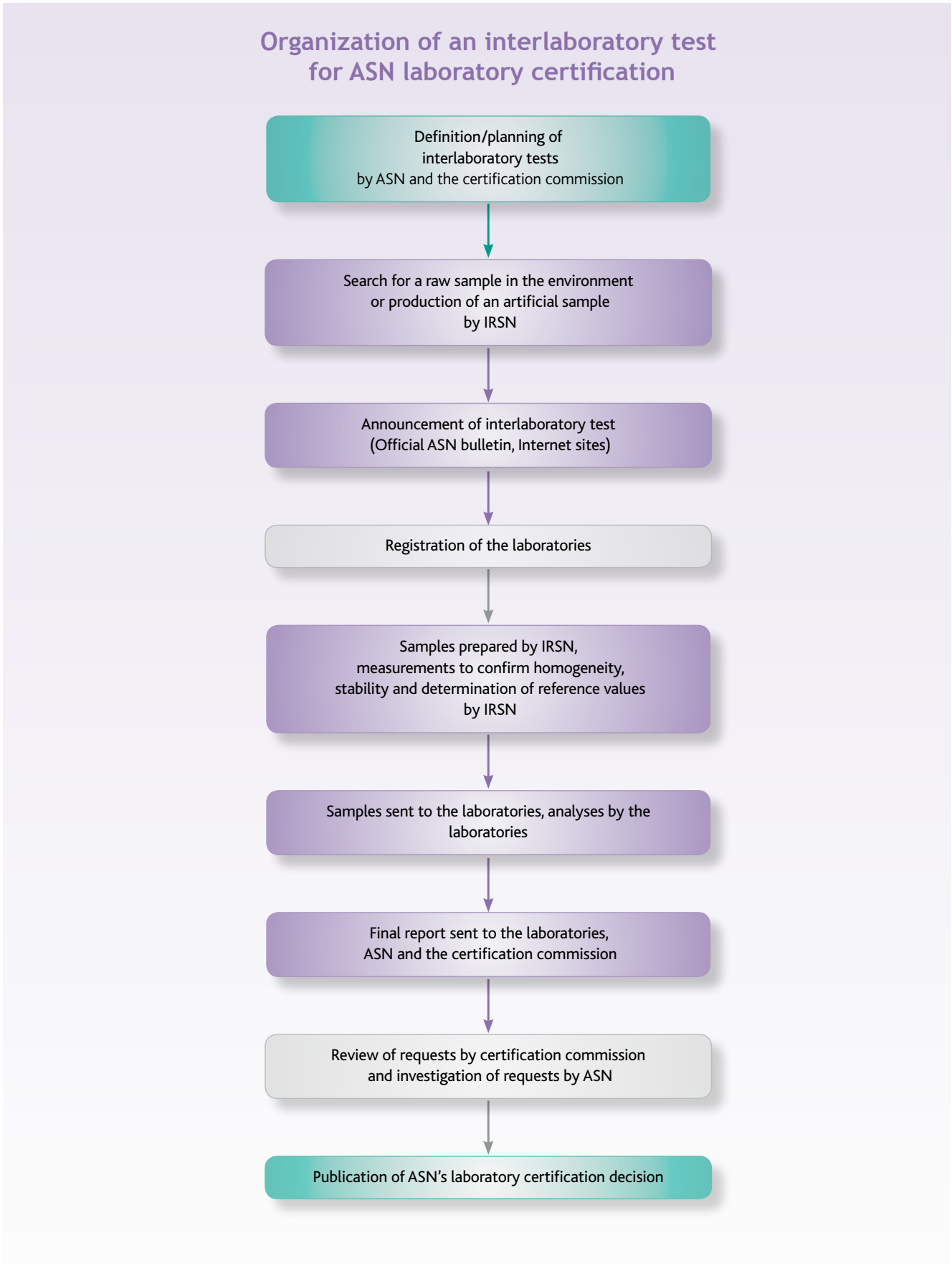


Figure II.2 - Organization of an interlaboratory proficiency test for ASN certification

ASN • FOCUS

Certification of environmental radioactivity measurement laboratories

The ASN certifies laboratories that may release their results on this RNM site. The laboratory certification processes are defined in ASN's decision No. 2008-DC-0099 of April 29, 2008. The certification issued covers measurements made in the laboratory as well as provisions concerning environmental sampling methods.

*Each measurement category, which combines a type of measurement (artificial or natural radionuclides, gamma-, beta- or alpha-emitting radionuclides and ambient gamma dosimetry) and an environmental compartment (water, soil, biological products, including plants, fish and milk) is covered by a specific certification (*Figure II.3*). ASN thus issues 43 different types of certification.*

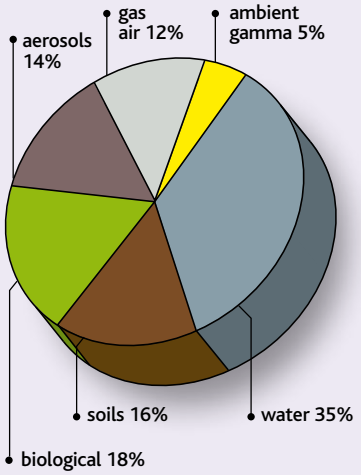


Figure II.3 - Distribution of certifications by environmental compartment as of January 1, 2012

Conducting intercomparison tests of laboratories involves low levels of activity even if, in the environment, the activities of artificial radionuclides are rarely higher than the decision thresholds for the most sensitive measurement methods. Laboratory proficiency is thus tested on samples 'recharged' in the laboratory to reach activity levels of around 0.5 to 10 Bq/kg for artificial gamma-emitting radionuclides (^{60}Co, ^{137}Cs) and 0.05 to 1 Bq/kg for alpha emitters (Pu, Am). However, as the activity levels of uranium and thorium decay chain radionuclides found in the environment are naturally higher (near or above 50 Bq/kg of soil), the proficiency tests are generally performed on samples taken directly from the environment.

Every French or foreign laboratory that seeks acknowledgement of its expertise in this area in connection with the RNM must obtain certification, whether the scope of its activity is defined (industrial site) or not (service provision), and regardless of its status, size, and sector of activity. Primarily, this concerns environmental monitoring laboratories that conduct measurements in accordance with laws or regulations and that, as of January 1, 2009, are required to obtain certification to transmit their measurements to the RNM (including Andra, Areva, CEA, EDF, Max Von Laue – Paul Langevin Institute and the French Navy). However, it also covers all public, private, university and non-profit association laboratories that monitor environmental radioactivity for public agencies, regional authorities or for their own purposes.

To obtain certification, the laboratory must submit documents to ASN showing that its organizational structure and practices comply with the ISO/CEI 17025 standard, which sets out the general requirements applicable to laboratories. These documents also include an application for the certifications sought, along with the laboratory results of the interlaboratory comparison tests conducted by IRSN.
Certification is issued for a maximum of five years on the recommendation of a joint certification commission that bases its findings both on the results obtained in the interlaboratory comparison tests and on the certification application documents submitted by the laboratory.

These decisions are published on ASN's Internet site (www.asn.fr) at the same time as the list of certified laboratories, which is updated twice a year.

Status of certified laboratories on January 1, 2011

*On January 1, 2011, there were a total of 60 certified laboratories (*Figure II.4*). Of that number, 42 were nuclear operators' laboratories, and the others were divided among the private (9), university (5), institutional (2) and non-profit association (2) sectors. These laboratories held 746 certifications covering the 43 certification categories.*

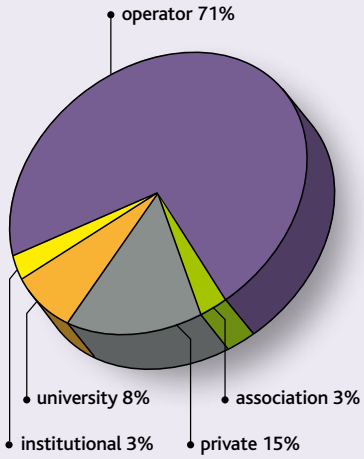


Figure II.4 - Distribution of certified laboratories by status as of January 1, 2012

The largest group (55) of certified laboratories monitor radioactivity in the water, with up to 13 different certifications for monitoring in this environment. Some 40 laboratories have been certified to measure biological matrices (the food chain), atmospheric dust, the air and ambient gamma dosimetry. Another 30 laboratories focus on soils. While most laboratories can measure gamma emitters in all environmental matrices, only a dozen are certified to measure carbon-14, transuranium elements, or uranium and thorium natural decay chain radionuclides in water, soil and biological matrices.

Focus (continued)

Focus (continued)

ASN • FOCUS

Overall assessment of the laboratory certification process

The process for certifying environmental radioactivity laboratories, which came into effect in 2003, drives continuous improvement of practices, regarding both sampling methods and radioactivity measurements. These improvements, due specifically to the implementation of standardized methods, are significant in the area of sampling, but also in the area of measurement. The analysis of eight years of feedback from interlaboratory comparison tests shows, from one test cycle to another, that values transmitted by the laboratories are closer to the reference value provided by IRSN. This is reflected in a generally lower interlaboratory standard deviation between the tests in the first and second certification cycles (2003-2008 and 2008-2012 respectively).

The challenges now facing the ASN laboratory certification system include maintaining the quality of the environmental radioactivity measurement data provided by certified laboratories, improving it further, encouraging certified laboratories to broaden their scope of activity, and allowing new laboratories to participate in the certification process to ensure multiple sources of information. The system is intended to boost public confidence in measurements of the radiological state of the environment released on the RNM Internet site.

Table II.1 - Certifications and intercomparison test schedule 2011-2015

		Type 1		Type 2		Type 3		Type 4		Type 5		Type 6	
Code	Radioactive measurement category	Water **		Soil matrices		Biological matrices		Aerosols on filter		Gas air		Ambient environment (soil/air)	
.. _01	Gamma emitters E > 100 keV		1_01		2_01		3_01		4_01		5_01		-
.. _02	Gamma emitters E < 100 keV		1_02		2_02		3_02		4_02		5_02		-
.. _03	Gross alpha		1_03		-		-		4_03		-		-
.. _04	Gross beta	**	1_04		-		-		4_04		-		-
.. _05	H-3	**	1_05		2_05		3_05		-		See water		-
.. _06	C-14		1_06		2_06		3_06		-		5_06		
.. _07	Sr-90/Y-90		1_07		2_07		3_07		4_07		-		-
.. _08	Other pure beta emitters (including Tc-99)		1_08		2_08		3_08		-		-		-
.. _09	Isotopic U		1_09		2_09		3_09		4_09		-		-
.. _10	Isotopic Th		1_10		2_10		3_10		4_10		-		-
.. _11	Ra-226 + desc.		1_11		2_11		3_11		-		Rn-222: 5_11		-
.. _12	Ra-226 + decay prod.		1_12		2_12		3_12		-		Rn-220: 5_12		-
.. _13	Pu, Am isotopes (Cm, Np)	*	1_13 *	*	2_13 *		3_13		4_13 *				-
.. _14	Halogen gases		-		-		-		-		5_14		-
.. _15	Noble gases		-		-		-		-		5_15		-
.. _16	Gamma dosimetry		-		-		-		-		-		6_16
.. _17	Uranium content		1_17		2_17		3_17		4_17		-		-

2011 2012 2013 2014 2015

* in 2015 and 2016: reversal of EIL 1_13 and 2_13
** EIL 1_04 and 1_05 in sea water scheduled in 2014

The RNM information system and its Internet site

Article 4 of ASN approved decision No. 2008-DC-0099 puts IRSN in charge of managing the RNM. To that end, the Institute must:

- centralize environmental radioactivity measurement data, transmitted in accordance with Article II of Article R1333-11;
- analyze this data;
- send it to ASN and the French Institute for Public Health Surveillance (INSV), in accordance with Article L.1413-4 of the French Public Health Code;
- release the data to the government agencies responsible for nuclear activities and to the public;
- preserve and archive the data for an unlimited period of time.

The RNM information system, which was developed by IRSN, allows organizations that produce radioactivity measurements to send their data, formatted in accordance with a jointly defined data exchange protocol (*Figure II.5*), via a secure Internet connection.

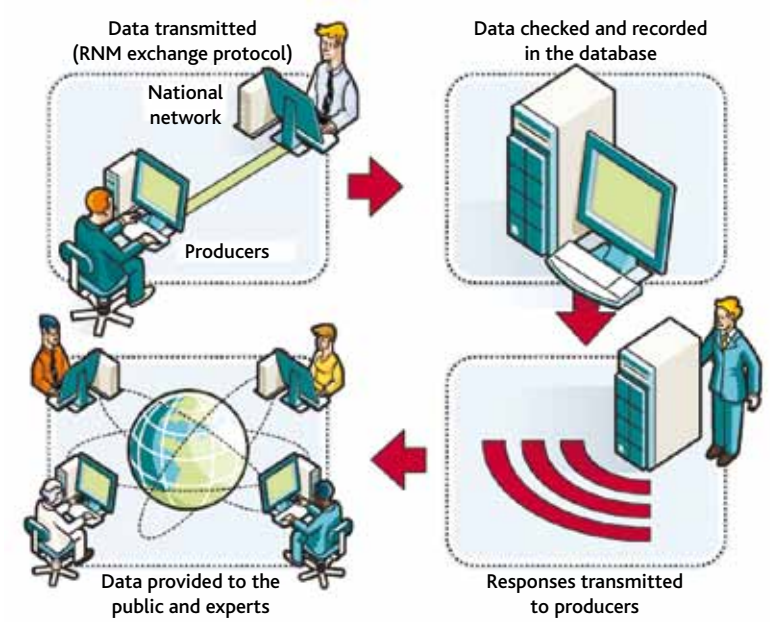


Figure II.5 - Organization of the RNM information system

The data is fed into the RNM database that came into operation in January 2009 and that has already received 600,000 measurement results (as of December 31, 2011). The database is updated very regularly, with an average of 17,500 measurements added every month. More than 40% of the results sent to the RNM come from IRSN monitoring networks.

The database is accessed via an information system that can provide all the information to the public and experts through an Internet mapping portal (www.mesure-radioactivite.fr).

www.mesure-radioactivite.fr
Réseau national de mesures de la radioactivité de l'environnement

The opening of the RNM Internet site was a major step forward in achieving transparency.

The RNM has been developed with an awareness of the need to take into account the concerns of all stakeholders who contribute to the network as data producers or members of the network's bodies.

Visual presentation, educational content, accessibility and understanding of data placed online have all been identified by these stakeholders as areas that could be improved. The national network's information system will go on changing, not only to incorporate the technical improvements it needs to function properly, but also to meet the expectations of Internet users and take into account their comments on how measurement data is presented.

II.2 WHO MONITORS RADIOACTIVITY IN FRANCE?

Monitoring involves many stakeholders, primarily nuclear facility operators, nuclear safety authorities who are responsible for regulation, and IRSN. Other stakeholders in the society, specifically associations – including local information commissions and committees, air quality monitoring and non-profit environmental protection associations - also participate in studies or environmental radioactivity monitoring.

The French Institute for Radiological Protection and Nuclear Safety (IRSN)

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

IRSN helps to assess the radiological status of the environment in three ways:

- by conducting assessments as part of its technical support to the relevant authorities: ASN or the French Representative in charge of Nuclear Safety and Radiation Protection for Defense-related Activities and Facilities (DSND), prefects and Regional Directorates for the Environment, Town and Country Planning and Housing (DREAL). These assessments involve examining nuclear facility applications for water intake and liquid effluent discharge permits (DARPE), analyzing nuclear facility safety reports, with a particular focus on the characteristics and vulnerability of knowledge of ground water and the provisions made by

the operator to monitor it, and evaluating technical documentation (on the environmental impact of former uranium mining sites, for example). This work allows the relevant authority to set out the requirements for discharge permits or operating licenses for these facilities, and those for controlling the impact of former uranium mining sites. In addition, IRSN experts may be called on to support the inspections initiated by ASN or the DREALs;

- **by contributing to radiological monitoring across the country,** as part of the tasks assigned to it in its founding charter, Decree No. 2002-254 of February 22, 2002, amended on April 7, 2007. In that connection, IRSN conducts regular monitoring around nuclear sites, complementing the monitoring procedures set up by nuclear operators, as well as more general monitoring in France;
- **by conducting studies and research on environmental radioactivity** IRSN regularly acquires data on environmental radioactivity from the radioecological studies it conducts at the request of nuclear operators, public authorities or civil society representatives (including CLIs, local authorities, and non-profit associations), or as part of its own research programs. This data allows it to consolidate its knowledge of the radiological state of the environment.

Its main measurement results can be consulted via its environmental radioactivity Internet portal, (http://environnement.irsn.fr).
Internet site: www.irsn.fr

French Nuclear Safety Authority (ASN)

As part of its responsibilities defined in the Nuclear Safety and Transparency Act (the TSN Act), **ASN** makes technical regulatory decisions that apply to nuclear facility operators.

Within this context, it lays down radioactivity monitoring requirements concerning nuclear sites and the areas surrounding them (excluding defense-related facilities).

These requirements are defined in ratified decisions (and previously in ministerial orders). ASN ensures that these requirements are met, particularly by reviewing the monitoring records kept by operators, and by conducting inspections. Under the TSN Act, ASN is responsible for organizing continuous radiation protection monitoring in France.

As part of its regulatory monitoring of nuclear facilities, it also accredits laboratories that measure environmental radioactivity. Last, it assists the French Ministry of Health in defining the technical requirements applicable to health inspections of the radiological quality of water intended for human consumption, and in accrediting laboratories conducting control measures.
Internet site: www.asn.fr

Nuclear Safety Authority for Defense-Related Facilities and Activities (ASND)

With regard to defense-related facilities and activities, the DSND, which reports to the Minister of Defense and the Minister of Industry, is responsible for reviewing effluent discharge and water intake permit applications, in accordance with the French Defense Code. Requirements for environmental radiological monitoring at these facilities are defined by ministerial orders, based on the DSND report after the operators' permit applications have been examined.

The two authorities, ASN and the DSND, consult on all issues that may have an impact on effluent discharge and water intake permit applications, and on environmental monitoring at sites accommodating civil and defense facilities.

Nuclear facility operators

Nuclear facility operators are responsible for monitoring effluents discharged by their facilities and for environmental monitoring on and around nuclear sites. In general, this monitoring activity is defined by the regulatory requirements laid down in discharge permits, which require operators to implement a regular environmental monitoring program at their sites (known as 'regulatory' monitoring). The radioactivity measurements on the samples taken in this regard must be conducted by certified laboratories.

This monitoring system, which is the responsibility of the nuclear site operator, is the main source of measurement results that provide a regular update on the radiological state on these sites and within a few kilometers of them.

Nuclear facility operators have laboratories specializing in radiological monitoring that sample and analyze air, soil and water samples.

Internet sites:
www.areva.com
www.edf.fr
www.cea.fr
www.andra.fr
www.ill.fr
www.defense.gouv.fr/marine

IRSN • FOCUS

What are the main fuel cycle facilities in France ?

Systematic environmental monitoring is conducted at all fuel cycle facilities.

*This cycle includes the following industrial stages (*Figure II.6*):*

- *extraction of uranium from mines (former mining sites now managed by Areva);*
- *concentration and conversion of uranium compounds (Comurhex Malvési and Pierrelatte);*
- *isotope enrichment in uranium-235, a process that involves increasing the concentration of a chemical element in one of its isotopes (Eurodif and SET on the Tricastin site);*
- *fabrication of MOX fuel (Marcoule);*
- *fuel fabrication and assembly (FBFC Romans-sur-Isère);*
- *use in nuclear power plant reactors (EDF, 22 plants including 19 in operation, representing a total of 58 pressurized water reactors);*
- *processing of spent fuel removed from reactors and recycling (Areva La Hague) and R&D in these areas (CEA Marcoule);*
- *waste processing and disposal (Andra, waste disposal facilities in the Manche department and in Soulaines and Morvilliers).*

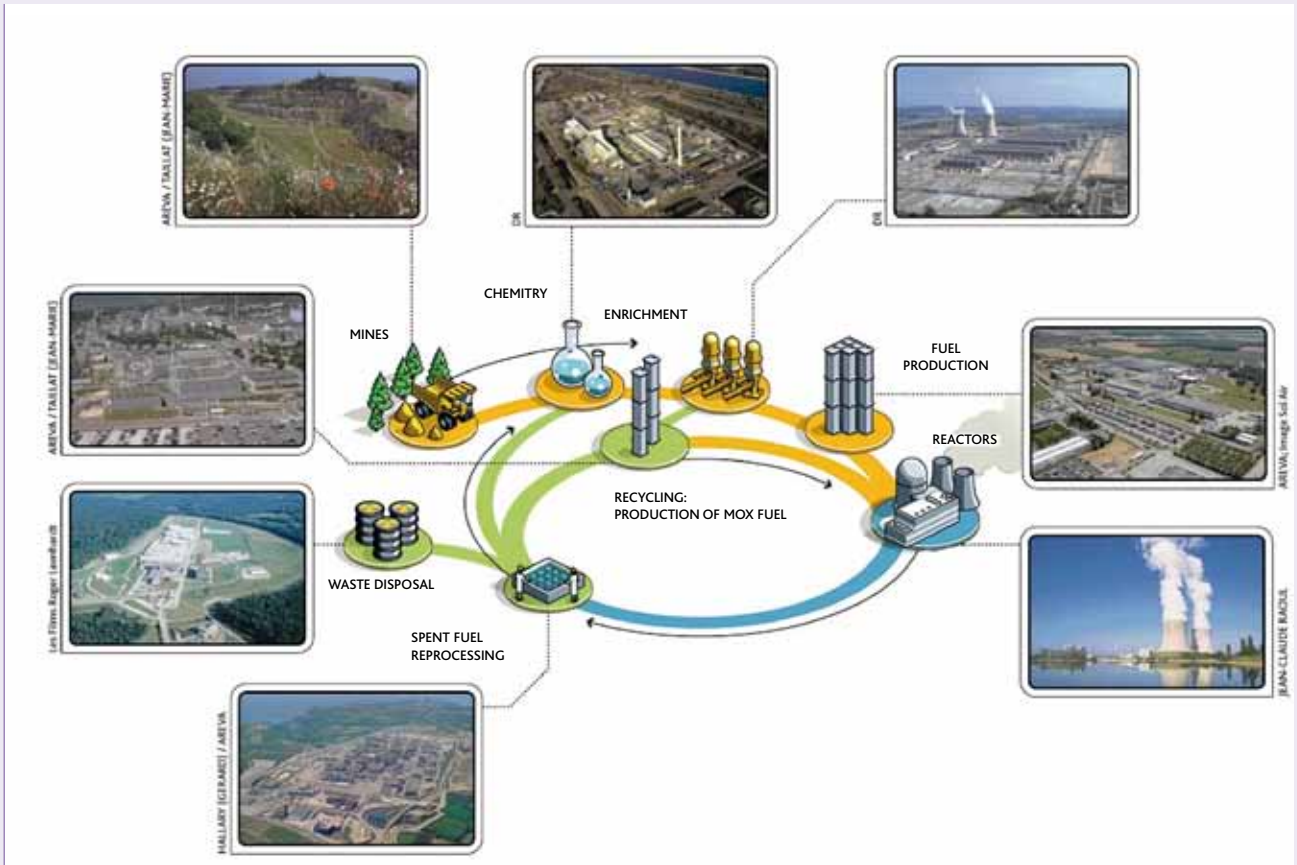


Figure II.6 - Simplified illustration of the nuclear cycle

Ministry directorates and government agencies in charge of health inspections

These directorates and agencies are generally responsible for conducting health inspections on food (animal and vegetable foodstuffs and drinking water) and animals intended for food. This activity entails looking for chemical, physical and biological agents, including radioactive substances, that could pose a health risk for the population.

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MINISTÈRE
DE L'AGRICULTURE
DE L'ALIMENTATION
DE LA PÊCHE
DE LA RURALITÉ
ET DE L'AMÉNAGEMENT
DU TERRITOIRE

The Directorate General on Food Safety (DGAL) prepares an annual plan for monitoring potential radionuclide contamination of foodstuffs (milk and dairy products, eggs, meat, fish and seafood). The objective of this plan is to test the radiological quality of foodstuffs, particularly food products from areas around nuclear facilities. Samples are taken on a department-by-department basis by agents from the Departmental Directorate for Social Cohesion and Public Health and Safety (DDCSPP).
Internet site:
www.agriculture.gouv.fr/alimentation

DGAL • FOCUS

Monitoring of foodstuffs by the DGAL

The Directorate General on Food Safety (DGAL) of the Ministry of Agriculture, Food, Fisheries, Rural Affairs and Town and Country Planning (MAAPRAT) is responsible for safety inspections of animal feed and foodstuffs of animal origin and, for primary production (at the farming stage), of vegetable foodstuffs.

The regulatory basis for health inspections includes several European texts grouped together in a 'health and safety package'. Its framework is EC Regulation No. 178/2002, which sets out the overall principles and instructions regarding food legislation, establishes the European Food Safety Authority and defines food safety procedures. It includes the Community's rapid alert system (RASFF, the Rapid Alert System for Feed and Food), which allows immediate communication among Member States in the event of a health threat caused by an operator or a country outside the EU, and all the tools available to the risk manager: contacts with the organization responsible for assessing food risks (EFSA at the European level, ANSES/IRSN at the national level) based on its areas of expertise, the possibility of withdrawing/recalling products from the market, and/or notifying consumers.

*Under this body of regulation, each EU Member State may or must perform analyses on certain foods. Every year, the DGAL sets up several dozen contaminant monitoring and inspection plans to track changes in contamination levels and confirm that a foodstuff complies with a regulatory standard (*Figure II.7*). The plans set out to confirm that operators are not responsible for any fraud (addition of prohibited substances or presence of residues of veterinary drugs), non-observance of health and safety standards (microbiological contaminants), or inadvertent industrial or natural contamination (mycotoxins, environmental contaminants such as heavy metals or dioxins).*

Radionuclides are addressed specifically in an annual monitoring plan. This was first set up following the Chernobyl accident to check contamination levels in French food, then established on a permanent basis with the cooperation of the AFSSA (now ANSES). The plan was revised in 2008 with IRSN involved as the national reference laboratory in the field. As such, the Institute organizes interlaboratory tests for laboratories certified by the DGAL to inspect the radiological quality of foodstuffs, develops analytical methods and techniques, and provides the DGAL and the laboratory network with technical and scientific support.

The radiological quality of a foodstuff is regulated only in post-accident situations, starting with import inspections on foodstuffs potentially affected by the Chernobyl and Fukushima accidents (EC regulation No. 733/2008 and EC regulation No. 297/2011 respectively). Simultaneously, Euratom Regulation No. 3954/87 sets the maximum acceptable national levels of radioactive contamination for foodstuffs and animal feed after a nuclear accident, or any other radiological emergency.

The prospective monitoring plan in place addresses two objectives: to increase knowledge regarding a reference contamination level that could provide comparison values in the event of a nuclear accident and improved understanding of the actual impact on food; and to maintain an active network of certified laboratories (nine departmental laboratories, overseen by IRSN), capable of managing the quality and quantity of the many analyses to be undertaken in the event of emergency.

The plan addresses the monitoring of foodstuffs produced near nuclear facilities or located in the area of persistent fallout from the Chernobyl accident or previous atmospheric tests, and the study of contamination levels of products from across the country (bulk milk) or products from

coastal areas (fish, mollusks and crustaceans). It involves performing multi-radionuclide analysis (including cesium isotopes, iodine and tritium) of some 700 annual samples taken by the Departmental Directorates for Social Cohesion and Public Health and Safety. The assessments show very slight radiological traces, with the vast majority of results below detection limits and a few quantifiable results (particularly for game in the areas where fallout persists), but below the applicable standards in the event of accident. For example, in 2010, quantifiable levels of cesium-137 were found in only two samples of milk, one of honey, two of beef and eight of fish, at an average of 0.07 Bq/kg, by comparison to the regulatory limits of several hundred Bq/kg. Only certain boar samples taken in the areas where fallout persists show more marked, although still slight, contamination levels, with a maximum of 50 Bq/kg and an average of 12.43 Bq/kg (for seven of the 58 samples taken).

All of the annual foodstuff monitoring assessments conducted by the DGAL may be viewed at: http://agriculture.gouv.fr/dispositif%20-surveillance%20-controle-securite-sanitaire-aliments-564

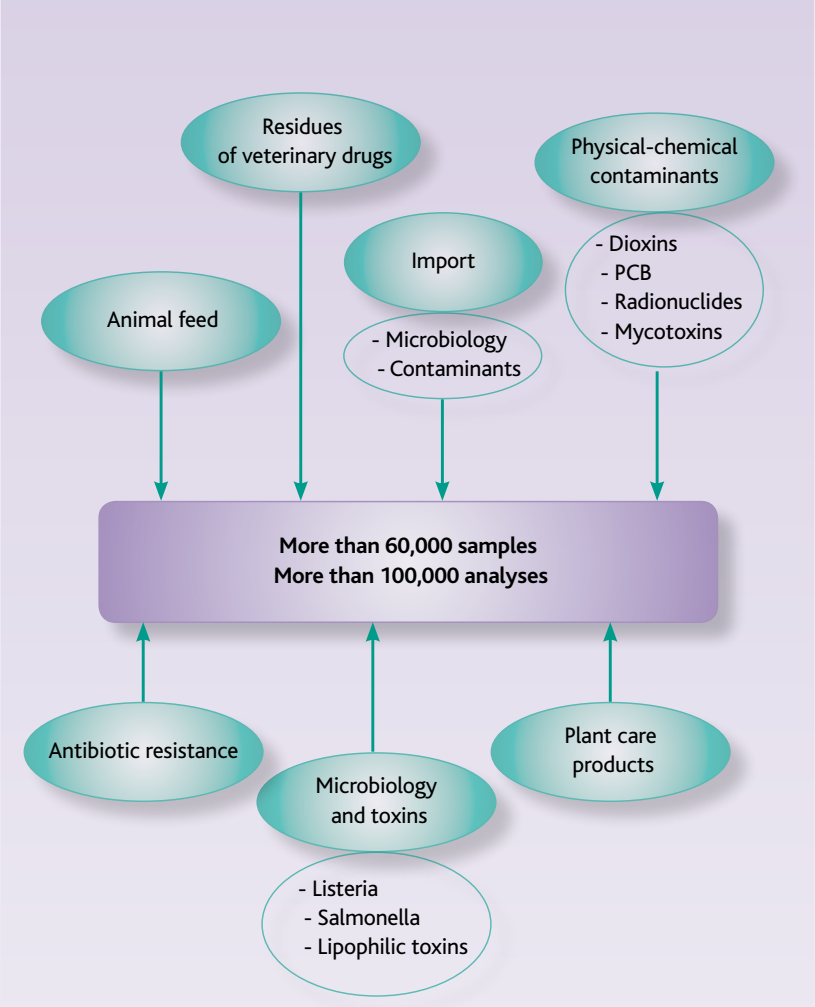

Figure II.7 - DGAL monitoring of foodstuffs

The Directorate for Competition, Consumer Rights, and Protection Against Fraud (DGCCRF) has regularly inspected the radioactive contamination of consumer products since 1986, the year of the Chernobyl accident. These inspections primarily concern vegetable foodstuffs. Every year, several hundred samples are taken from the domestic market at the product marketing stage.
Internet site: www.economie.gouv.fr/dgccrf

Regarding water, the Directorate General for Health (DGS) ensures the protection of the public with regard to various uses of water (drinking water, water for recreation, domestic hot water, bottled water and waste water). As part of the health inspection activities assigned to them under the French Public Health Code, the Local Health and Social Services Departments (DDASS) or Regional Health Agencies (ARS), as they are now called, have regularly inspected the radiological quality of water intended for human consumption since 2005

In February 2011, the French Nuclear Safety Agency, the Directorate General for Health and the Institute for Radiological Protection and Nuclear Safety published the results of the second annual national assessment of the radiological quality of water distributed in public systems. Over the 2008-2009 period, the Regional Health Agencies (ARS) conducted 72,300 analyses at catchment or on water available through public distribution systems, in accordance with the European 98/83/EC directive. These controls are based on measuring four indicators: tritium, the activity of alpha- and beta-emitting radionuclides and the total indicative dose (exposure to ionizing radiation attributable to the ingestion of water over a one-year period).
For more information
www.mesure-radioactivite.fr/public/IMG/pdf/ASN_DGS_IRSN_Bilan-qualite-radiologique-eau-2008-2009.pdf
Internet site:
www.sante.gouv.fr/eau-potable.html

Collectivités territoriales

Local authorities

Some local authorities, especially the *Conseils Généraux* (local government authorities at department level), have set up complementary environmental monitoring networks, independent of industry and government agencies, in departments where significant nuclear activities are carried out.

Many *Conseils Généraux*, along with municipalities and metropolitan areas, rely on analytical laboratories to test the radioactivity of various environmental samples (including water, air, foodstuffs, soil and waste).

If these radioactivity measurements are taken to meet legal or regulatory requirements, for example under the French Public Health Code or the Environmental Code, they must be conducted by certified laboratories and their results published on the RNM Internet site.

Non-profit associations

In France, various non-profit associations that come under the French Act of 1901 are also involved in monitoring radioactivity in the environment. Some of them send data to the RNM (e.g., Acro).

The Association for Radioactivity Monitoring in Western France (ACRO) and the Commission for Independent Research and Information on Radioactivity (CRIIRAD), created in 1986 following the accident in Chernobyl, have their own radioactivity measurement laboratories and publish their results. They mainly work for local authorities, environmental organizations, laboratories and producer and consumer organizations.

Internet sites:
www.acro.eu.org
www.criirad.org

The Approved Air Quality Monitoring Associations (AASQA) operate and develop a national network of measurements of the physical-chemical quality of the air, under the auspices of the Ministry of the Environment. The air quality monitoring system includes 40 approved associations, which make up the ATMO monitoring network. The Environment and Energy Management Agency (ADEME), is responsible for the technical coordination of this system, together with the Ministry of the Environment. Some AASQAs have sensors for monitoring environmental radioactivity, in general when nuclear facilities are located in the region. Ten or so AASQAs are equipped with one or more automatic continuous monitors that measure atmospheric radioactivity.

Internet sites:
www.atmo-france.org/fr
www.ademe.fr

ANCCLI
Association Nationale des Comités et Commissions Locales d'Information

Local Information Commissions and Committees (CLI) were set up in the 1980s in areas around most nuclear facilities at the initiative of the *Conseils Généraux*, pursuant to a circular issued by the Prime Minister on December 15, 1981. The TSN Act strengthened the CLIs by granting them legal status. Article 22 of the Act provides for the creation of a CLI for each basic nuclear installation (one CLI may cover several facilities in the same area). The CLIs, which form the **French National Association of Local Information Commissions and Committees (ANCCLI),** are generally concerned with monitoring, information and consulting in the area of nuclear safety, radiological protection and the impact of nuclear activities on humans and the environment. The information they need to fulfill their mission comes from facility operators, ASN and other government agencies. They may have assessments conducted or measurements taken of environmental discharge from the facilities concerned.

Internet site: www.anccli.fr

Figure II.8 - Grass sampling

III

EVENTS AND SPECIFIC ASSESSMENTS

III.1 MONITORING THE IMPACT OF THE FUKUSHIMA ACCIDENT ON FRANCE (METROPOLITAN FRANCE AND FRENCH OVERSEAS DEPARTMENTS, REGIONS AND COMMUNITIES)

Introduction

In order to monitor the radiological impact on France of the Fukushima Daiichi accident on March 11, 2011, IRSN stepped up environmental radioactivity monitoring in metropolitan France and in French overseas departments, regions and communities. The purpose of this enhanced monitoring was to confirm and quantify the expected presence in the atmosphere of radioactive elements in the form of particles in suspension (aerosols) and gaseous radioactive iodine (especially iodine-131), and to monitor their fate in the environment and their possible impact on the food chain (via rainwater, grass, leafy vegetables or milk). The collaboration of many institutional partners across France ensured that this enhanced monitoring was conducted under optimum conditions.

Moreover, the French Nuclear Safety Authority (ASN) also asked operators of basic nuclear installations, who already continuously carry out regulatory radioactivity monitoring in the vicinity of their facilities, to perform additional measurements for the purpose of detecting any airborne artificial radionuclides, attributable to the accident.

Over a period of six weeks, this yielded a total of:

- **more than 5,700 measurement results** from IRSN, from approximately 1,400 samples (all types);
- **more than 3,000 measurement results** from nuclear operators and associations.

All of these monitoring results were analyzed by IRSN in real time and posted on a dedicated website. Between March and May 2011, the authorities and the public therefore had access to the latest information (daily at first and then at less regular intervals) on the radiological situation in France.
Since early May 2011, concentrations of artificial radionuclides have returned to levels close to the decision thresholds and the enhanced monitoring programs have been suspended.

At the same time, nuclear operators have continued the regulatory monitoring required of them and associations have also done their part to remain vigilant by carrying out sampling campaigns. This chapter takes into account these results, which focus on the terrestrial compartment.

Lastly, IRSN published a detailed report (IRSN-DEI 2011-01) on its website in late January 2012 analyzing the impact of the Fukushima accident on France: http://www.irsn.fr/FR/expertise/rapports_expertise/Documents/environnement/IRSN_Analyse-impact-Fukushima-France_012012.PDF

Description of the enhanced monitoring program

IRSN's enhanced monitoring program involved putting the Teleray monitoring network on alert, taking specific environmental samples at more frequent intervals, and installing environmental dosimeters at various sites in France.

To set up certain equipment and carry out environmental sampling, IRSN sought the help of local contacts in the French meteorological institute, Météo-France, the National Gendarmerie and some nuclear operators, as well as decentralized government departments in metropolitan France (Departmental Directorates for Public Health and Safety – DDPP) and in the French overseas departments and regions (Directorates of Food, Agriculture and Forestry – DAAF). This was done with the agreement and on the instructions of the Directorate General on Food Safety (DGAL).

The maps in Figures III.1 to III.3 provide an overview of IRSN's enhanced monitoring system, set up to provide optimum coverage of French territory in order to assess the radiological impact of air masses contaminated by the Fukushima accident.

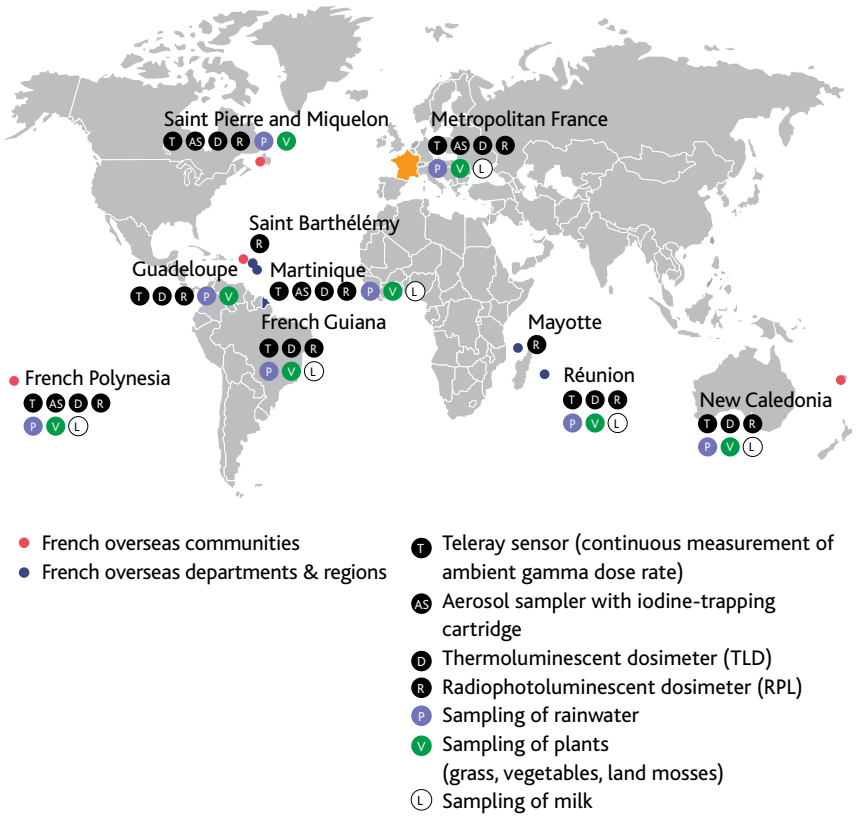

Figure III.1 - Overview of the IRSN systems set up in French overseas departments, regions and communities to monitor the impact of the Fukushima accident.

Figure III.2 - Location of the atmospheric compartment monitoring systems used by IRSN to monitor the consequences in metropolitan France of the accident at the Fukushima Daiichi nuclear power plant.

Figure III.3 - Places where milk and plant samples were taken specifically as part of IRSN's efforts to monitor the consequences in France of the accident at the Fukushima Daiichi nuclear power plant.

Throughout the period during which this contamination was measured, the monitoring program was constantly adapted to the changing situation in Japan and to the results obtained. Milk and plants were initially sampled two to three times a week, but this was gradually reduced to once a week right across France. After April 25, given the general downward trend in activity levels measured in the environment, the number of monitoring points was also scaled down.

Once airborne activity had returned to virtually the same levels as those measured prior to the accident, the bulk of the specific program put in place by IRSN was discontinued as of May 6. Most of the environmental dosimeters were analyzed on or after this date. For the purpose of research, specific samples - mainly of meat - nevertheless continued to be taken.

As well as the actions mentioned above, ASN asked nuclear operators to perform measurements on air samples in order to look for trace levels of artificial radionuclides attributable to the accident.

This special monitoring, which complemented the usual regulatory monitoring, comprised:

- **a daily gamma spectrometry measurement** performed on the geographically distributed cluster of aerosol sampling filters, for the purpose of detecting artificial radionuclides, aiming for a decision threshold[1] lower than 0.1 mBq/m³ (for cesium-137);
- **a gamma spectrometry measurement of gaseous radioactive iodines** sampled on an activated carbon cartridge at intervals of 24 to 72 hours.

*1 – **The metrological decision threshold** is the minimum counting value obtained while measuring a sample, above which the presence of radioactivity in the sample can be concluded, with an acceptable risk of error.*

In view of the changing environmental situation in France, ASN eased its additional monitoring requirements for operators with effect from April 18:

- **a weekly gamma spectrometry measurement** performed on the cluster of daily aerosol sampling filters, aiming for a decision threshold lower than 0.01 mBq/m³ for cesium-137;
- **a gamma spectrometry measurement of gaseous iodines** sampled on a cartridge at one-week intervals.

On May 4, ASN asked the nuclear operators to stop additional monitoring, as it was no longer justified given the steady decline in levels of airborne artificial radionuclides.

In all, 36 nuclear sites (EDF, Areva, CEA, ANDRA and ILL) took part in this additional monitoring (*Figure III.4*).
In addition to the measurements submitted by basic nuclear installation operators, the four French Navy bases (Cherbourg, Brest, Île Longue and Toulon) also provided information, specifically gamma spectrometry data on atmospheric aerosol filter samples, gaseous iodine-trapping cartridges, and rainwater and grass samples.

The Bordeaux-Gradignan nuclear research center also sent IRSN its gamma spectrometry analysis results.

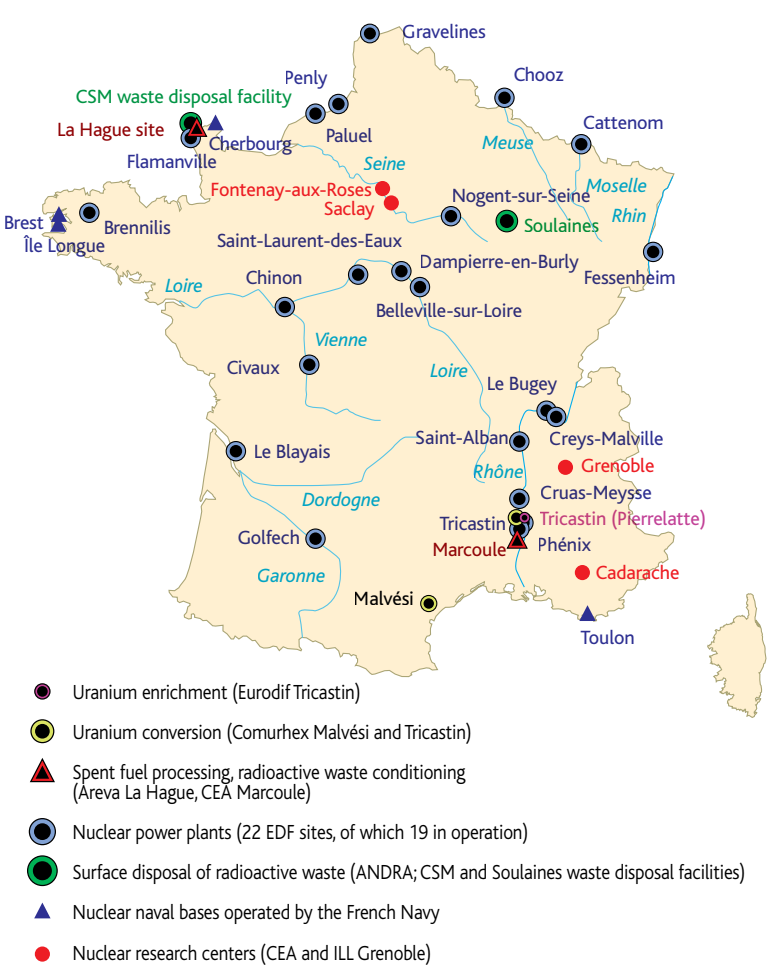

Figure III.4 - Location of the nuclear sites that participated in additional monitoring of airborne radioactivity after the Fukushima accident.

Results of enhanced atmospheric monitoring

Measurement results for iodine-131 in aerosols

In metropolitan France, all measurement results obtained on air samples taken up to March 23 were below the decision thresholds of the analysis techniques used, and were between less than 0.01 and 0.05 mBq/m³. Traces of particulate iodine-131 were detected for the first time in an aerosol sample collected between March 21 and 24 at a very high-volume IRSN sampling station, located on the summit of Puy-de-Dôme in south-central France, at an altitude of 1,465 m (activity concentration estimated at 0.04 mBq/m³ with the activity measured being normalized to a single day, i.e. March 24). The other measurement results obtained on daily samples taken on March 24 were all below the decision thresholds (nine IRSN samplers and 25 nuclear operator samplers, representative of the whole country).

Further results in the days that followed confirmed that particulate iodine-131 had been detected nationwide. The average activity concentrations over the sampling period peaked in metropolitan France between March 27 and April 9 (*Figure III.5*), with values sometimes reaching 1 to 2 mBq/m³ in different regions of the country. After this date, the activity fell to levels lower than 0.01 mBq/m³ by early May.

With regard to the French overseas departments, regions and communities, particulate iodine-131 was detected at Fort-de-France in a sample collected between March 24 and 31 (0.21 mBq/m³), and also on Saint Pierre and Miquelon in a sample collected between March 25 and April 1 (0.48 mBq/m³). Significant values continued to be observed at Fort-de-France until April 14 (0.15 mBq/m³), and on Saint Pierre and Miquelon until April 22 (0.28 mBq/m³).

Measurement results for gaseous iodine-131 trapped on activated carbon cartridges

In metropolitan France, all measurement results obtained from sampling up to March 25 were below the decision thresholds of the analysis techniques used (*Figure III.6*).

Iodine-131 in gaseous form was detected for the first time in samples collected between March 24 and 26 at Cherbourg and Cadarache (a few tenths of a mBq/m³). During the next few days, further traces of gaseous iodine-131, with activity concentrations between a few tenths and a few millibecquerels per cubic meter, were detected throughout metropolitan France. Peak activity concentrations were measured in samples collected between March 28 and April 8 (17 values between 3 and 7.4 mBq/m³). From April 25 on, the activity concentrations measured were below the decision thresholds. All significant measurements (above the decision threshold) obtained in metropolitan France during the whole monitoring period are shown in the previous figure, with the results corresponding to the last sampling date.

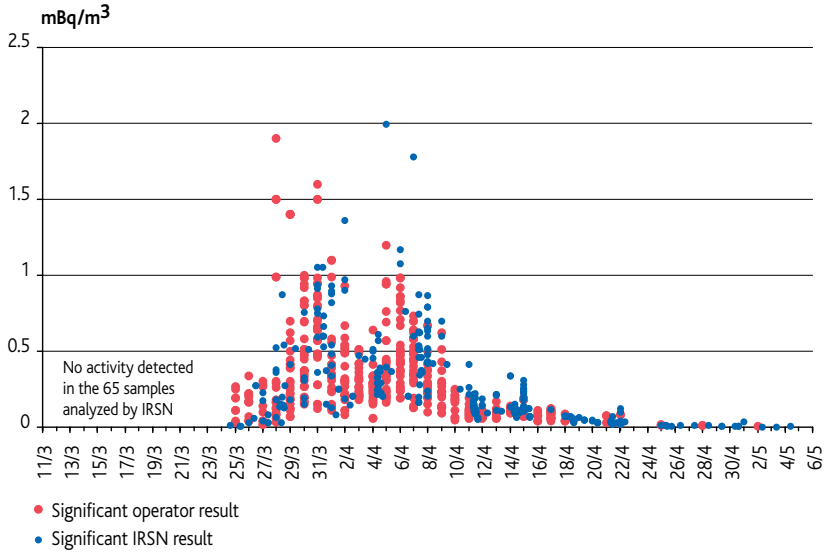

Figure III.5 - Iodine-131 activity concentrations measured in aerosols in metropolitan France (mBq/m³).

In the case of the French overseas departments, regions and communities, significant gaseous iodine-131 activity levels were measured only on Saint Pierre and Miquelon, in a sample collected between March 26 and 28 (0.81 mBq/m³ and in several two-day samples collected between April 1 and 19 (average values between 0.12 and 4.8 mBq/m³).

Comparison with historical levels measured in France

Normally, no iodine-131 can be detected in the atmosphere. Only significant releases as a result of an incident or accident may cause measurable concentrations, as was the case after the Chernobyl accident in 1986 or, more recently, following a release from a Hungarian plant producing radionuclides for pharmaceutical purposes.

By way of comparison, the iodine-131 activity levels measured during the second half of March and early April 2011 were 1,000 to 10,000 times lower than those measured in western Europe in the days following the Chernobyl accident. This mainly concerns the particulate fraction of iodine-131 , as, at that time, few measurements of the gaseous fraction were carried out.

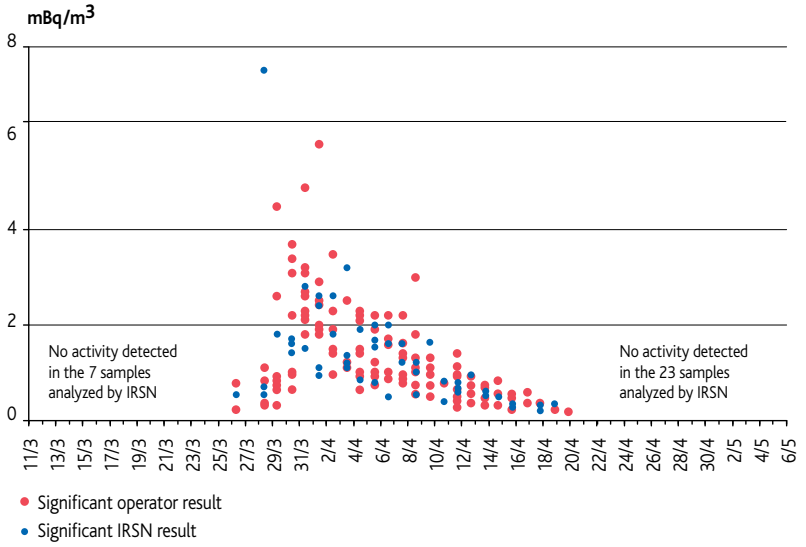

Figure III.6 - Gaseous iodine-131 activity concentrations measured in metropolitan France (mBq/m³).

Measurement results for cesium-134 and -137 in aerosols

Traces of cesium-134 and cesium-137 were detected in different locations in France at levels about ten times lower than those of iodine-131 (*Figure III.7*). The activity ratio between the 134 and 137 isotopes of cesium measured in aerosols was calculated to be close to 1.

Comparison with historical levels measured in France

No cesium-134 had been measured in the atmosphere since the mid-1990s due to its relatively short half-life (2.1 years), resulting in its rapid disappearance. Before the Fukushima accident, cesium-137 could be measured in the atmosphere in France, at a level in the region of 0.1 to 0.2 µBq/m³, using sampling stations equipped with powerful air intake systems (300-700 m³/h).

The cesium-137 activity levels measured after the Fukushima accident were 10,000 to 100,000 times lower than the highest values recorded in France in the days following the Chernobyl accident, which corresponded to a million-fold increase in the ambient value at that time (approximately 1 µBq/m³). Furthermore, the releases as a result of the Chernobyl accident had a lasting effect on the activity levels in the atmosphere since, even though the level of cesium-137 fell very quickly in the days and weeks following the arrival of contaminated air masses in France, due to fallout in rain and the effect of dispersion, it took well over ten years for it to return to the level measured in the days before the accident.

Cesium-137 release caused by the Fukushima accident (less than 10% of that occurring in the wake of the Chernobyl accident) and its dispersal over a distance of more than 10,000 km increased the ambient level in France only by a factor of 1,000 compared with the level during the few days prior to the accident. These quantities were clearly not sufficient to replenish the levels of atmospheric cesium-137 since, by October 2011, i.e. five months after the accident, the ambient level of cesium-137 in the atmosphere already represented just twice the level measured before the accident.

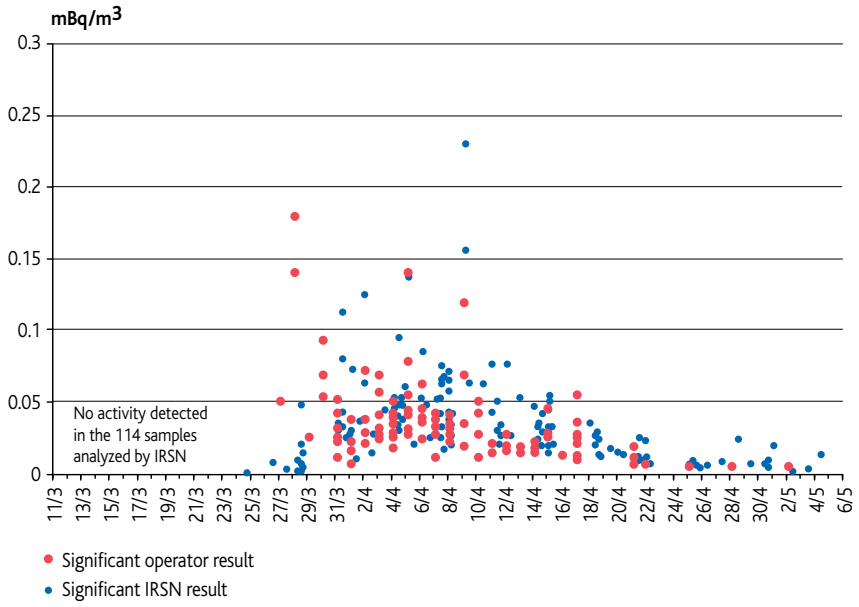

Figure III.7 - Cesium-134 activity concentrations measured in the atmosphere in metropolitan France (mBq/m³).

Results of monitoring ambient dose rate (Teleray network)

To illustrate the absence of any significant increase in the ambient gamma dose equivalent rate, the graphs in Figure III.8 show the trends over time in the regional average dose rate for northern, northeastern, northwestern, central, southeastern and southwestern France. Each curve represents the average of the hourly measurements from each of the sensors set up in the French administrative regions.

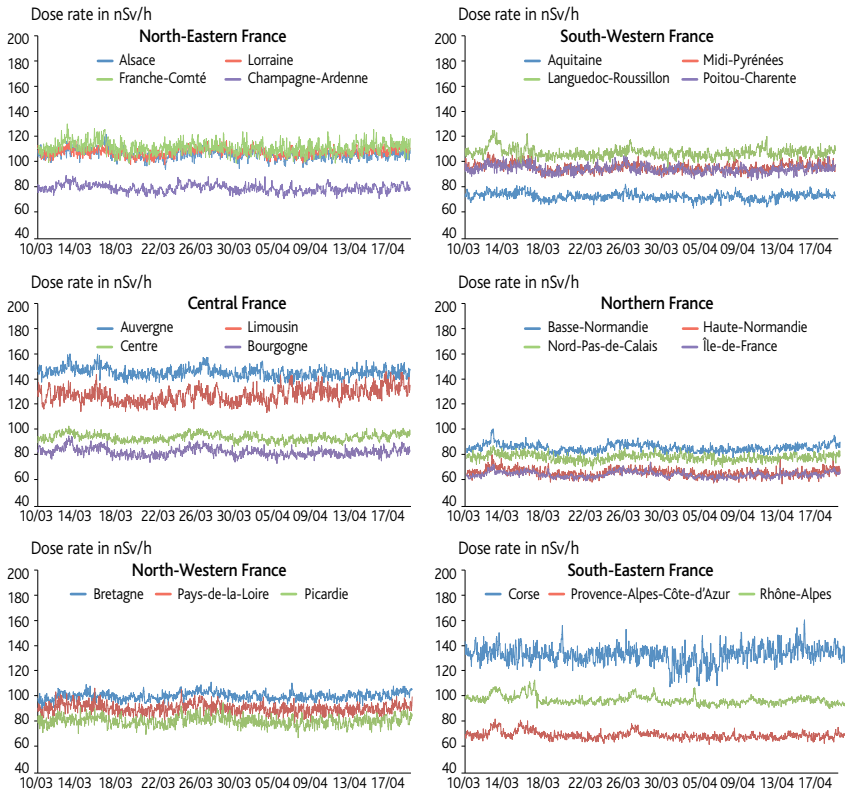

Figure III.8 - Regional averages (per French administrative region) of the hourly measurements from the Teleray sensors, with metropolitan France divided into six large zones (nSv/h).

These results show minor fluctuations (of about 10 nSv/h), comparable with those usually observed by the Teleray network, due to the behavior of natural radionuclides in the atmosphere, e.g. radon and its decay products, during changing weather conditions.

In any event, the artificial radionuclide activity levels observed in France after the Fukushima accident, which were a few mBq/m³ at most, cannot be the cause of these occasional regional fluctuations.

Results of enhanced monitoring of the land environment

Enhanced monitoring of the land environment primarily focused on analyzing samples of plants (grass, moss/lichen mixture and leafy vegetables) and milk. In the discussion below, where the measurements were carried out more than 15 days after sampling, any non-significant results (those below the decision thresholds) obtained from these samples were disregarded and are not shown on the graphs, because of the short radioactive half-life of iodine-131 (8 days).

Measurement results for iodine-131 in grass, mosses and lichens

A total of 226 samples of plants (grass, moss/lichen mix) were specifically analyzed by IRSN, and a further 33 by the Association for Radioactivity Monitoring in Western France (ACRO) and the Manche department analytical laboratory (LDA 50). The nuclear operators also contributed by carrying out their own regulatory environmental monitoring and by occasionally collecting additional samples (*Figure III.9*).

In metropolitan France, the first traces of iodine-131 were measured in a grass sample taken in Pélussin in central France on March 26 (0.09 Bq/kg wet weight). This became more widespread in the days that followed, detected at activity levels between 0.29 and 15 Bq/kg wet weight, with average activity levels of about 2.08 Bq/kg wet weight over the period from March 26 to April 15. The highest activity was observed in a grass sample collected on March 28 in Gradignan, near Bordeaux.

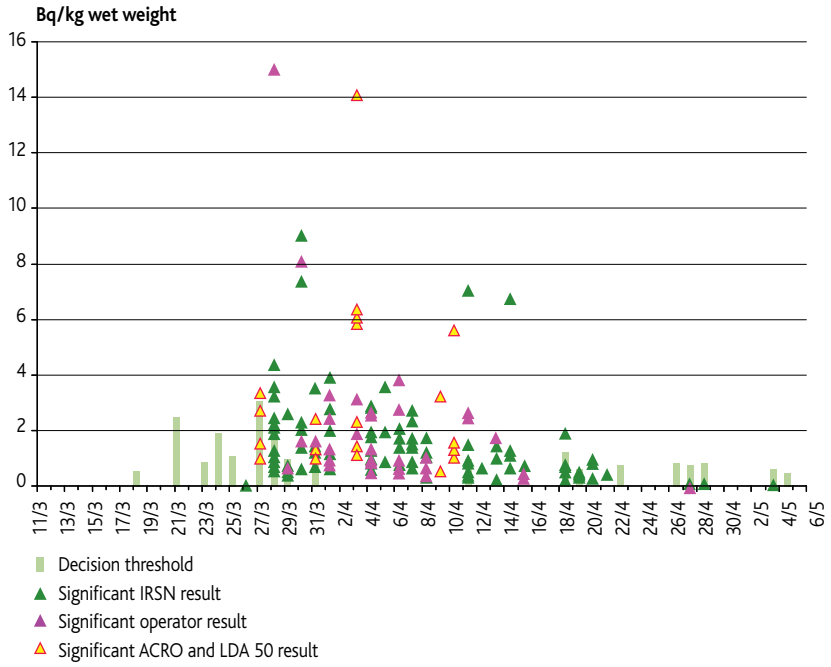

Figure III.9 - Iodine-131 activity measured in grass in metropolitan France by IRSN, nuclear operators and various associations between early March and early May 2011 (Bq/kg wet weight).

After April 15, the iodine-131 activity levels in grass showed a downward trend. The values measured from early May on did not exceed 0.12 Bq/kg wet weight and were frequently below the decision thresholds of the measuring equipment.

Analysis of the data acquired based on a geographical division of France (north/south and east/west) indicates that activity levels of a similar magnitude were observed right across French territory, albeit with some geographical and chronological fluctuations due to the movements of the air masses. The variation in activity levels observed may also be related to that observed in precipitations causing deposits in the soil and to the variability of sampling. Based on these findings, it cannot be concluded that some French regions were more affected than others, as was expected, given the global dispersion of the radionuclides released during the Fukushima accident.

In the French overseas departments, regions and communities, analysis of a grass sample collected on March 28 in Martinique found iodine-131 for the first time, with a specific activity of 0.80 Bq/kg wet weight. Traces of iodine-131 were also detected in the next few days on Guadeloupe in two grass samples, and in five samples of moss/lichen mixtures taken on Saint Pierre and Miquelon. Iodine-131 was not detected in the other French overseas departments, regions and communities of French Guiana, Réunion, Tahiti and New Caledonia.

Measurement results for cesium isotopes

A total of 43 grass samples collected in metropolitan France were found to have significant cesium-134 activity levels attributable to releases from the Fukushima Daiichi nuclear power plant. The values ranged between 0.07 and 2.79 Bq/kg wet weight. Cesium-137, associated with cesium-134 or otherwise, was also measured at several sampling stations in metropolitan France, with activity levels of between 0.04 and 4.7 Bq/kg wet weight, i.e. values that were often observed pre-Fukushima due to the persistence of this radionuclide, which was deposited following atmospheric nuclear tests and the Chernobyl accident.

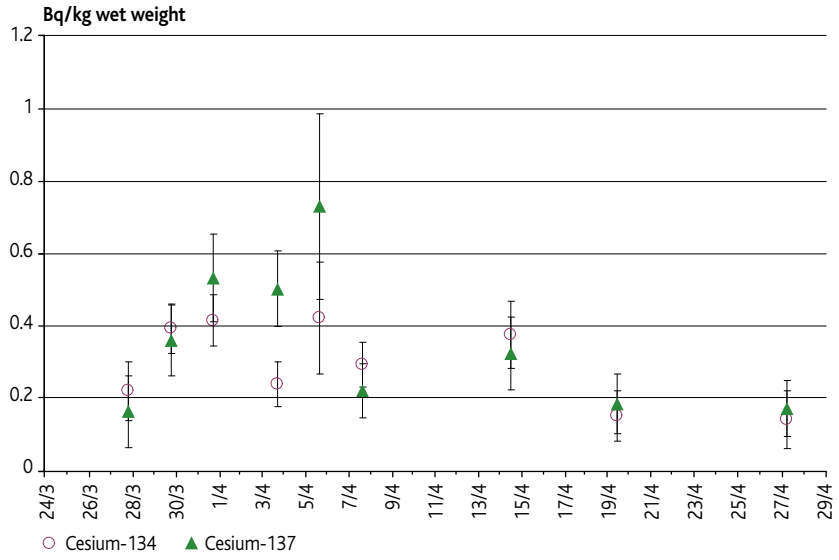

Figure III.10 - Variation in activity levels of cesium-134 and cesium-137 measured in grass at Sainte-Colombe-en-Bruilhois (southwestern France) in March and April 2011 (Bq/kg wet weight).

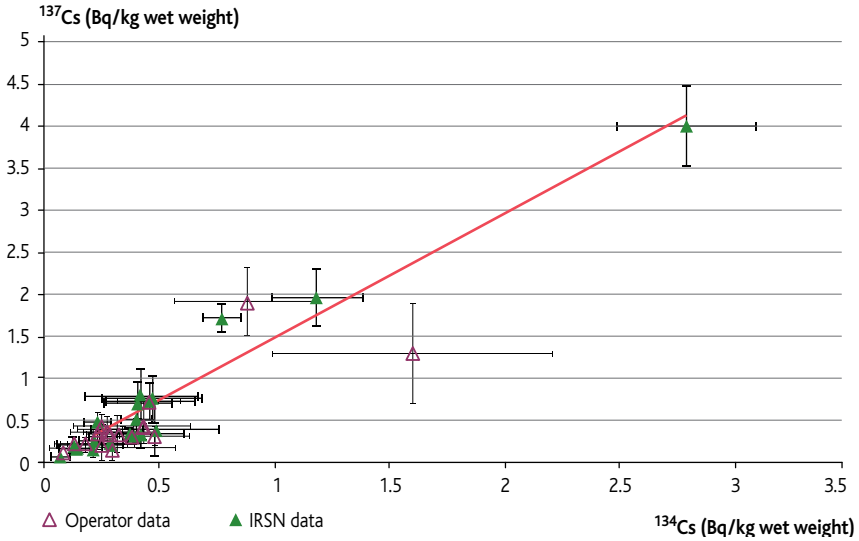

Figure III.11 - Correlation of activity levels of cesium-134 and cesium-137 measured in grass samples taken between March 18 and May 6, 2011.

Overall, the activity measured is similar from one place to another and, at the same location, the cesium-134 or cesium-137 activity is generally ten times lower than that of iodine-131.

Looking at the specific activity of these radionuclides over time, observed at the same sampler in southwestern France, there is an activity peak in grass around April 6 (*Figure III.10*).

The activity ratio of cesium-134 to cesium-137 measured in grass is close to 1 (*Figure III.11*).

In the French overseas departments, regions and communities, only two samples of plants (mixtures of mosses and lichens), collected on Saint Pierre and Miquelon, were found to have significant combined cesium-134 and cesium-137 activity levels, attributable to releases resulting from the Fukushima accident.

Some plant samples only had significant cesium-137 activity, measuring about 10 Bq/kg wet weight (13.8 Bq/kg wet weight for one land moss sampled on Saint Pierre and Miquelon on March 29). Since no cesium-134 was detected, these activity levels cannot be attributed to the accident at the Fukushima nuclear power plant, and are explained by the persistence in the soil (and in plants growing in the soil) of cesium-137, deposited following atmospheric nuclear tests.

Analyses carried out on vegetables and herbs

More than a hundred vegetables were monitored in metropolitan France and French overseas departments, regions and communities (leafy vegetables such as lettuce and spinach) and, to a lesser extent, other types of vegetables and herbs (headed cabbage, celeriac, carrots and thyme).

The first traces of iodine-131 (0.14 Bq/kg wet weight were detected on March 28 on spinach leaves sampled in the municipality of Narbonne in southern France. Further significant values were subsequently measured in metropolitan France, mainly on lettuce and spinach samples collected in the southeast of the country. Up until April 19, the activity levels measured varied between 0.05 and 2.10 Bq/kg wet weight (*Figure III.12*).

Analyses conducted after this date showed that there was no longer any significant activity in metropolitan France. By way of comparison, after the Chernobyl accident, the maximum iodine-131 activity observed in lettuce in France ranged from 300 to 3,000 Bq/kg wet weight in May 1986.

Cesium-134 was only detected four times, in spinach sampled on April 4 in Tourdan and Bollène, both in the south-east, and in thyme sampled in Ginasservis and Herqueville, in south-eastern and north-western France, respectively. The activity levels recorded were low, between 0.05 and 0.34 Bq/kg wet weight.

No significant iodine-131 or cesium activity was measured in the 11 lettuce samples collected on Guadeloupe. In the other French overseas departments, regions and communities, radiological monitoring concerned only samples of milk and grass, and of mosses and lichens in the case of Saint Pierre and Miquelon.

Analyses of milk

IRSN, nuclear operators and the Manche department analytical laboratory (LDA 50) analyzed more than 200 samples of milk (from goats, sheep and cows) between March 18 and May 5, 2011.

Beginning on March 28, iodine-131 was detected in the north-west of France (0.43 Bq/L in goat's milk in Sepmes and 0.15 Bq/L in cow's milk in Les Brouzils). In the days that followed, significant activity levels were detected at most of the sampling stations in metropolitan France, with levels varying between 0.05 and 3.10 Bq/L. The highest levels were observed in goat's and sheep's milk, with values between 0.06 and 3.10 Bq/L, while the activity range measured in cow's milk was 0.05 to 0.66 Bq/L.

From mid-April on, activity levels fell in metropolitan France, and by early May, only goat's milk contained significant levels, lower than 0.2 Bq/L (*Figure III.13*). After April 22, the amount of iodine in cow's milk could no longer be quantified. Note that, following the Chernobyl accident in April 1986, the iodine-131 activity levels measured in France in milk samples taken in May 1986 ranged from 100 to 600 Bq/L.

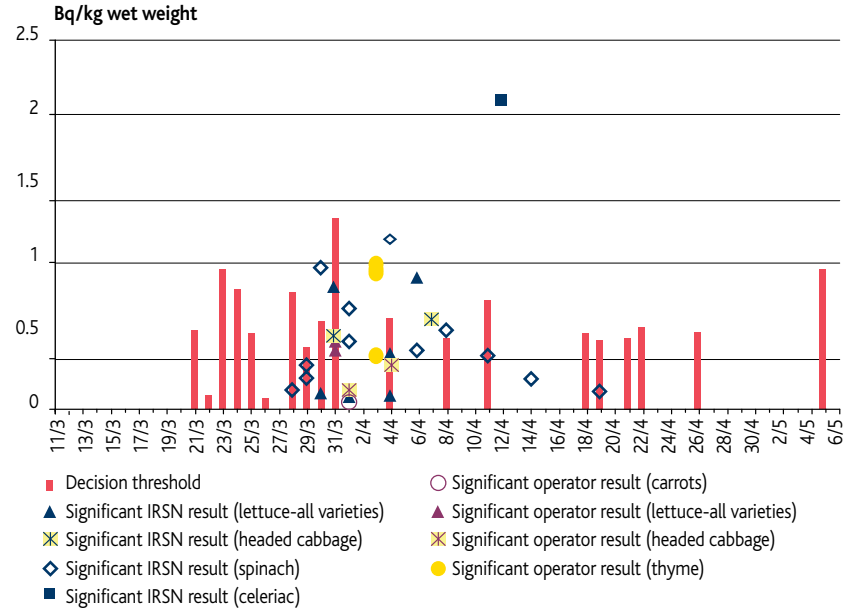

Figure III.12 - Iodine-131 activity measured in vegetables and herbs grown in metropolitan France between early March and early May 2011 (Bq/kg wet weight).

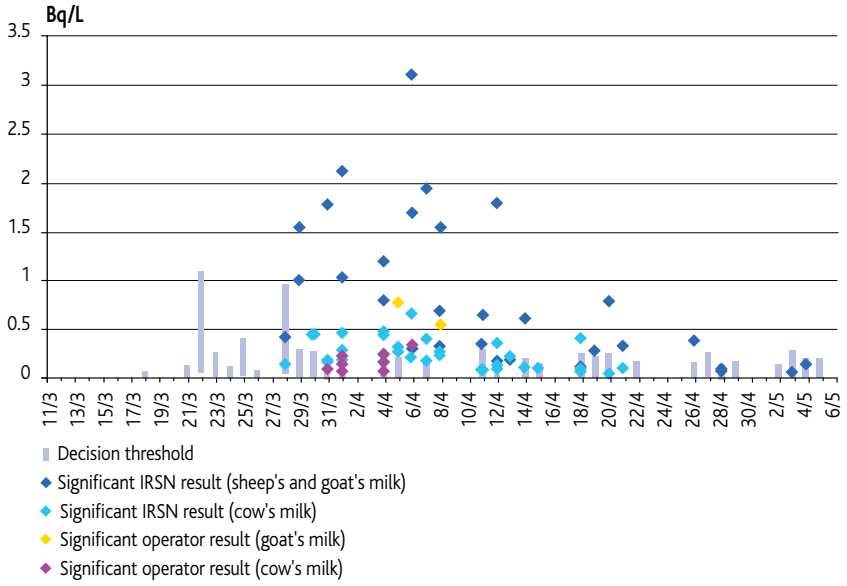

Figure III.13 - Iodine-131 activity measured in milk in metropolitan France between mid-March and early May (Bq/L).

Only three samples had very low cesium-134 activity levels (maximum of 0.1 Bq/L for the sample taken in Sepmes on April 7, 2011. Traces of cesium-137 were measured in several samples due to the persistence of cesium-137 deposited following atmospheric nuclear tests and the Chernobyl accident.

As regards the French overseas departments, regions and communities, significant iodine-131 activity levels (maximum 0.27 Bq/L) were found in only three samples of cow's milk collected in French Guiana. No significant activity was detected elsewhere in these regions during this period.

ACRO • FOCUS

Monitoring of plant cover in France set up after the Fukushima accident

As soon as the arrival of radioactive gas and particles from Japan was announced, the Association for Radioactivity Monitoring in Western France (ACRO) began organizing the task of monitoring fallout in metropolitan France. Volunteers took grass samples methodically and regularly at various locations throughout the national territory for analysis purposes. The objective was to find out whether the food chain might be affected (Figure III.14).

The first sampling campaign was carried out between March 27 and 31, 2011 (Figure III.15). *After radioactive iodine (iodine-131) was detected in the plant cover in some places, a second campaign was organized a week later, which confirmed its presence nearly everywhere within French territory at levels higher than those measured during the first campaign. Given the situation in Japan and in order to track these changing contamination levels, a third campaign took place between April 8 and 13. During this third week, cesium-134 was detected in Puy-de-Dôme and Gironde in south-central and southwestern France, respectively. As with radioactive iodine, cesium-134 (and most likely associated cesium-137) originated from releases from the Fukushima plant. A fourth campaign was organized in May 2011. This time no iodine-131 was detected and cesium-137 was found on only one site.*

Why is grass so important?

Plant cover, especially grass, is first to be affected by atmospheric deposition. Accordingly, radiological analysis of plant samples by gamma spectrometry often provides more information about the overall situation than direct analysis of the air mass. By monitoring grass that cows, sheep and other livestock will graze on, any impact on the food chain (particularly meat and milk) can be anticipated. This type of monitoring also makes it possible to find out more about the potential level of contamination of leafy vegetables, such as lettuce, for example. To sum up, organizing plant cover monitoring yields data about actual radioactive fallout and enables a preventive estimate to be made of the risk associated with eating various foodstuffs.

What protective measures were needed?

The contamination levels measured during this evaluation period remained low, requiring no food restriction measures. ACRO simply advised consumers to wash leafy vegetables, even though this is only effective up to a point. However, although this contamination may be relatively low level, it is not normal and should not be trivialized.

***Samples were taken by volunteers from various associations in accordance with a strict, codified** approach to ensure reliable analyses. Sampling was preferably carried out in places well away from trees, hedges and houses. At each site, a sufficient number of surface area units were collected to meet analysis requirements. At the ACRO laboratory, the wet samples were qualitatively and quantitatively analyzed by gamma spectrometry as soon as possible.*

Figure III.14 - Samples of grass were taken by ACRO as part of its campaign to monitor plant cover in France in the wake of the Fukushima accident.

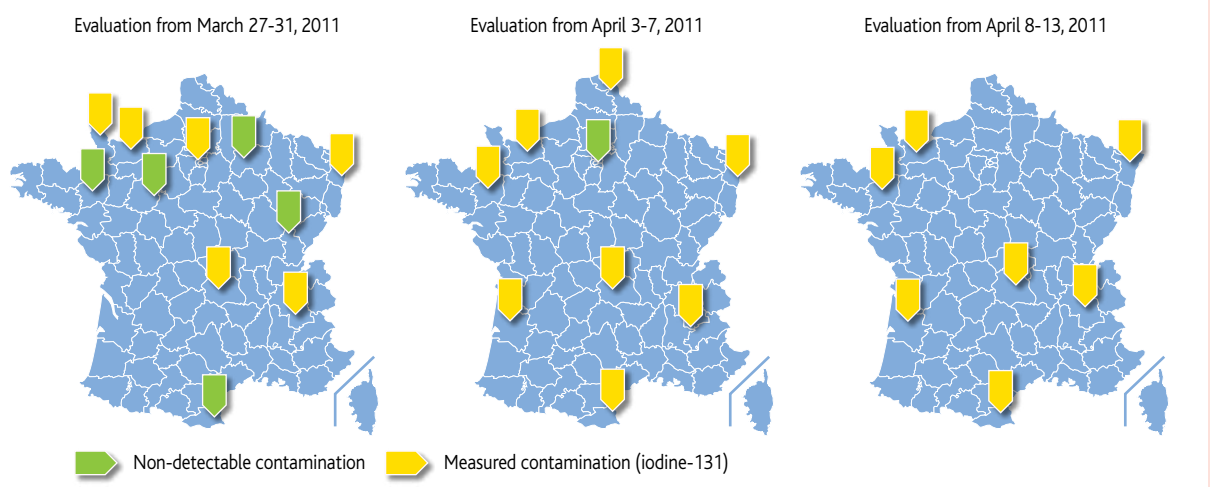

Figure III.15 - Evaluation of iodine-131 contamination of grass between March 27 and April 13, 2011.

III.2 ACCIDENTAL TRITIUM CONTAMINATION AT SAINT-MAUR-DES-FOSSÉS AND BONDOUFLE, NEAR PARIS

On November 3, 2010, CEA informed the nuclear safety authorities that an employee of one of its outside contractors (2M Process based in Saint-Maur-des-Fossés, near Paris) had been found to be contaminated with tritium during routine screening on the Valduc site in eastern France. The contamination was due to the presence, in one of the company's buildings, of an experimental device comprising a molecular sieve, which had come from the CEA Valduc site and had been wrongly assumed not to contain tritium. This experimental equipment had previously been used for tests on the Études et Diffusion site in Bondoufle, south of Paris.

At the request of the French Nuclear Safety Authority (ASN), IRSN staff arrived at Saint-Maur-des-Fossés the next day to carry out an initial characterization of the tritium contamination of the company premises and the immediate vicinity. Early results revealed significant contamination of the premises and clear traces in samples taken very close (within a few meters) to the company site. These initial findings prompted IRSN to conduct several investigations, once again at the request of ASN:

- tritium measurements on samples of water, air and plants collected in the vicinity of the company building, in order to ascertain the significance and extent of the environmental traces found and to monitor changes over time;
- measurements of tritium in the urine of local residents living close to the 2M Process building. The results showed traces of tritium in some samples but the evaluations performed by IRSN based on these results produced extremely low dosimetric estimates, with no associated health risks for these individuals;
- dosimetric evaluations of the exposure to tritium of 2M Process employees and visitors on the Saint-Maur-des-Fossés and Bondoufle sites, and investigation of tritium remaining on the premises of Études et Diffusion in Bondoufle.

IRSN's environmental monitoring activities in 2010 and 2011 were conducted in parallel with CEA's cleanup operations in the 2M Process building on and after November 9, 2010. Cleanup proceeded in several stages, under the supervision of ASN and the Val-de-Marne prefecture: removal of the most contaminated objects, i.e. the main sources of tritium emission (November 9-10, 2010), disposal of plant equipment (November 30 to December 3, 2010) removal of casework and carpets (December 8-10, 2010), and cleaning of surfaces (December 2010 and early January).

As from March 16, 2011, IRSN cut back its monitoring to take into account the measures implemented by CEA in response to administrative order no. 2010/7819 of December 15, 2010. Under the terms of this order, IRSN periodically received the results obtained by CEA and was tasked with interpreting them, in particular comparing them with its own measurement results.

Figure III.16 summarizes the changes over time observed in tritium concentrations in water vapor in the air of the 2M Process building, in the premises adjacent to this company's site and in the courtyard of 2M Process between November 25, 2010 and February 1, 2012.

It can be seen that the activity levels fell by a factor of 100 between mid-November 2010 and mid-July 2011, in connection with the various decontamination operations. During the last quarter of 2011, the tritium activity of the plant bubbler decreased seven-fold (from 1,410 Bq/m³ on September 7, 2011 to 186 Bq/m³ on February 1, 2012).

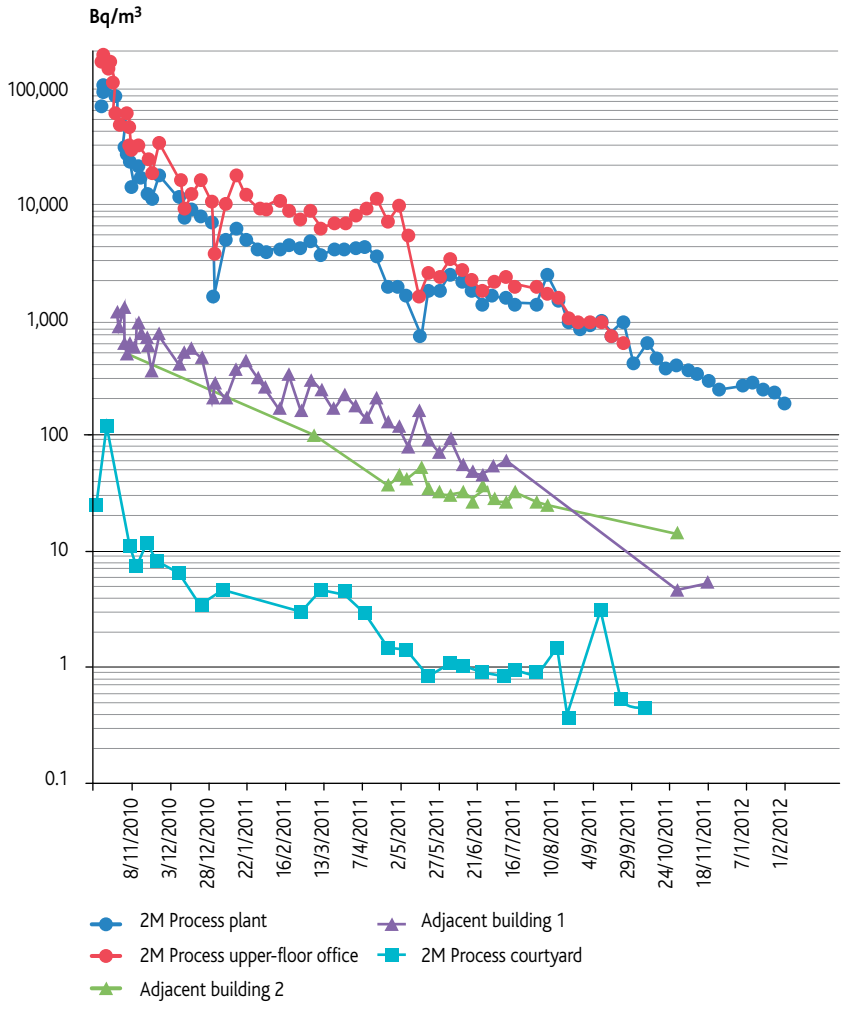

Figure III.16 - Summary of tritium activity in water vapor in air measured at Saint-Maur-des-Fossés between November 2010 and February 2012 – IRSN and CEA measurements (NB logarithmic scale).

The final results of measurements carried out by CEA and IRSN in the courtyard of 2M Process confirmed the continued gradual decline observed since December 2010 in the airborne tritium levels measured in the courtyard, but nevertheless indicated the persistence of tritium emissions from the 2M Process building.

In addition, as part of its environmental monitoring brief, IRSN regularly took samples of rainwater in the courtyard and surface water at various locations in the monitored zone, in order to measure tritium activity. The tritium traces observed in November 2010 in this water gradually decreased during 2011, and by the end of the year had reached levels that were difficult to detect with the analytical techniques used. Since the final results obtained were below the decision thresholds, IRSN decided to cease water monitoring beyond the perimeter of the courtyard of the 2M Process building at the end of 2011.

Similarly, since leaves are excellent biological indicators (exchanges with tritium present in the air (molecules of tritiated water) are rapid, permanent and make it possible to monitor the dynamic changes in airborne tritium during the days prior to sampling), IRSN regularly collected samples of plants (mainly ivy leaves at the stem tips, but also bay leaves) at various locations in the monitored zone, in order to measure total tritium activity. As from March 16, 2011, IRSN shared this monitoring task with CEA. All of the results obtained, including those from the last campaigns conducted from August to December 2011, are available on the IRSN website and can be used to track geographical and chronological changes in the tritium traces.

Figure III.18 shows the changes over time in the tritium activity measured between November 5, 2010 and December 14, 2011 in leaves (nettles, bay and ivy) sampled near the 2M Process building.

Figure III.17 - Sampling of water vapor in air with the H3R-7000 system in the courtyard of 2M Process.

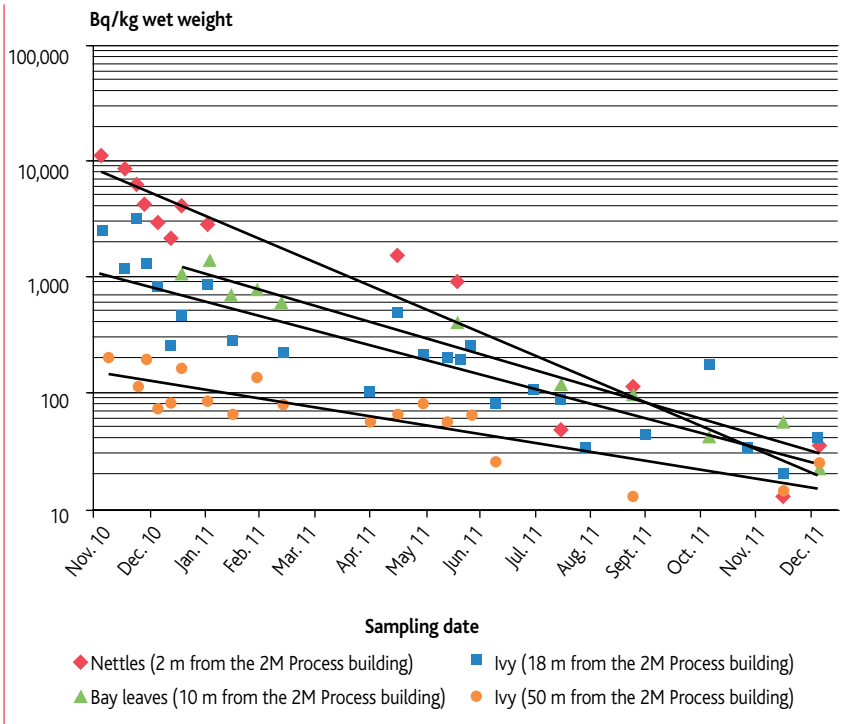

Figure III.18 - Changes over time in tritium activity (in Bq/kg wet weight) measured between 5 November 5, 2010 and December 14, 2011 in leaves (nettles, bay and ivy) sampled near the 2M Process building (NB logarithmic scale).

Tritium activity was highest in the leaf samples taken less than 10 meters from the building, mainly in the courtyard of 2M Process. A slow but gradual decline in tritium activity in leaves was observed as time went by, falling from several thousand Bq/kg wet weight in November and December 2010 in plants growing 2 meters away from the building to less than 50 Bq/kg wet weight since the last quarter of 2011. Beyond the courtyard, within a radius of about 50 meters around the 2M Process building, tritium activity in foliage can still be measured today but is often close to or below the decision thresholds (30 Bq/kg wet weight for Q4-2011). Finally, beyond the 50-meter mark, the tritium level in plants is systematically below the decision thresholds of the measuring equipment, confirming a rapid decrease with increasing distance from the 2M Process site, previously observed in surface water.

Values between 30 and 100 Bq/kg wet weight are currently observed only within a 50 m radius of the site. These results clearly indicate the influence of the tritium emitted by the 2M Process building, which falls off rapidly with distance from the site. In absolute terms, the values obtained are negligible in terms of radiological risk to human health. Consequently, IRSN decided in late 2011 to stop taking plant samples beyond a 50 m perimeter of the contaminated building.

With more than 350 measurement results acquired during 24 sampling campaigns, IRSN had access to accurate information about geographical and chronological changes in tritium levels on the premises and in the immediate vicinity of the 2M Process site. The final measurement results obtained from IRSN and CEA's environmental monitoring around the site confirmed the main earlier observations:

- **tritium in plant (leaves) and water** samples taken in the vicinity was by then measurable only very close to the site. Its concentration decreased rapidly with distance from the site, becoming undetectable with the analytical methods used, beyond a radius of about 50 meters;
- **the general decline in tritium** activity was likewise confirmed in the atmosphere and in the plant samples taken in the courtyard of the 2M Process building. This trend can be correlated to that observed in the measurements made by CEA inside the 2M Process building, which is still being decontaminated.

Although all of the results obtained in the vicinity demonstrate beyond doubt that slight environmental traces caused by tritium releases from the 2M Process building still persisted by early 2012, they cannot invalidate the evaluation of the doses received by local residents living closest to the building (*see the report on the IRSN website*). Given the persistence of observable environmental traces and the environmental monitoring program implemented by CEA, IRSN decided to continue monitoring on a more limited scale during the first half of 2012, at quarterly intervals, in the immediate vicinity of the 2M Process building.

All tritium measurement results, both on surface water and rainwater and on plants, have been mapped and can be consulted on the IRSN website (www.irsn.fr).

To find out more and to view the latest information notice published by IRSN, see http://www.irsn.fr/FR/Actualites_presse/Actualites/Pages/20120222_contamination-tritium-st-maur_resultats-mesures-environnement.aspx

III.3 IRSN ASSESSMENTS ON THE ORFLAM-PLAST SITE IN PARGNY-SUR-SAULX IN NORTH-EASTERN FRANCE

In support of government departments, IRSN regularly conducts special studies on sites where radioactive material has been used or disposed of, and where a level of radioactivity higher than natural background radiation still persists today. These are usually former industrial sites that generated manufacturing process residues, or former research laboratories. The Institute's role is to look for sources of contamination and assess the environmental and human risks. These assessments form the basis of regular reports submitted to the authorities. Below is a summary of the ongoing assessments conducted by the Institute in 2010 in the municipality of Pargny-sur-Saulx in northeastern France, the site of Orflam-Plast, a company that is now defunct.

Between 1932 and 1967, Orflam-Plast, a company once based in Pargny-sur-Saulx in the northeast of the country, made lighter flints using cerium extracted from monazite ore. The chemical extraction process resulted in significant quantities of solid, thorium salt-based residues, which were used as backfill and spread all around the plant.

Since 2009, IRSN has conducted many radiological assessments at the request of the French National Radioactive Waste Management Agency (ANDRA) on areas suspected of being contaminated by deposits of these tailings (*see IRSN's 2009 radiological report, pp. 151-152*).

In July 2010, ANDRA asked IRSN to carry out further radiological investigations in the vicinity of the plant. This pinpointed two new contaminated areas:

- **The first is located on the property of the former plant chemist,** where four areas of interest, each limited in size, were identified and found to have a dose equivalent rate at 50 cm ranging from 100 to 700 nSv/h (i.e. more than ten times the background value measured in the municipality). Analysis of the soil sample taken in the most contaminated area confirmed the presence of decay products of the ^{232}Th series, in particular ^{228}Ac, the first decay product of the ^{232}Th series. The specific activity measured for this element is 2,300 Bq/kg, i.e. more than 75 times the value found in soil in the Marne region.
- **The second area is located on the banks of the Saulx** river, where an area of interest has been found with a dose equivalent rate at 50 cm of between 120 and 315 nSv/h. Furthermore, an empty contaminated drum was found in the Saulx.

The conclusions of these assessments were submitted to ANDRA, which is responsible for managing the work to be carried out on the Orflam-Plast site and for securing the contaminated areas outside the site.

In addition, from mid-June to mid-July 2010, ANDRA commissioned the restoration of the shoreline of the Étang de la Gravière in southern France. Figure III.19 shows the radiological surface mapping obtained during the initial inspection in April 2009. The three areas of interest circled in red are where work was carried out.

Contaminated soil was removed to a depth of several meters and replaced with clay and topsoil. The criterion used in cleaning up the affected areas was a measured dose equivalent rate of 200 nSv/h, which will allow anglers and hikers to reuse the site without any constraints.

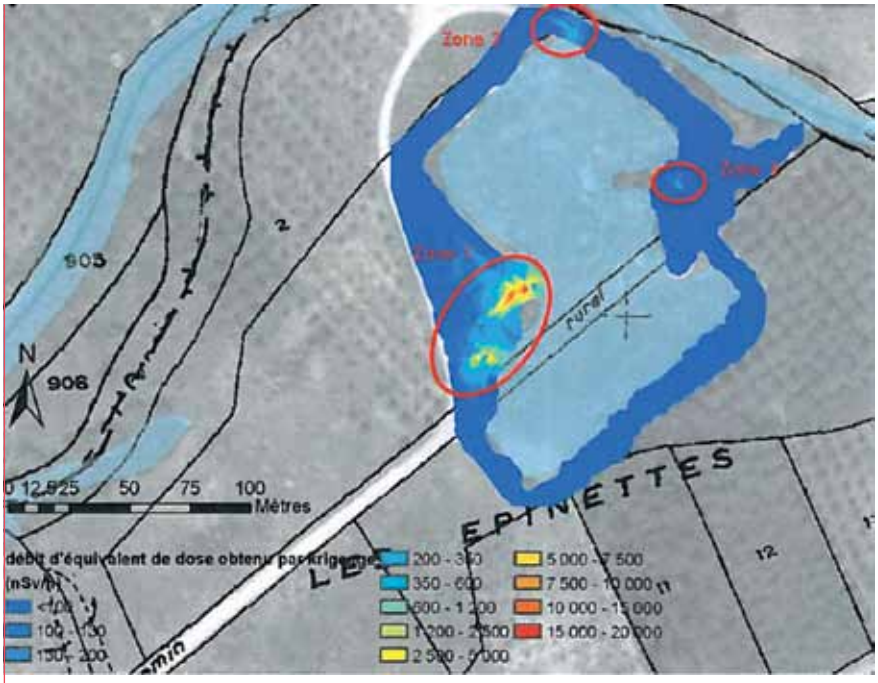

Figure III.19 - Initial mapping of the shoreline of the Étang de la Gravière in southern France; the three areas of interest that were cleaned up are highlighted.

At the request of ANDRA, IRSN carried out the final radiological inspection after the cleanup operations. Since no indication of distance had been associated with the dose equivalent rate value, IRSN used a 50 cm measuring distance, in accordance with standard practice in this field.

Radiological surface mapping was carried out using IRSN's Socrate mobile device (*Figure III.20*).

Comparison of the maps before and after cleanup (*Figures III.19 and III.20*) confirmed the effectiveness of these operations, since no dose equivalent rate values higher than 400 nSv/h have subsequently been recorded in any of the three areas.

However, this inspection revealed the existence of four relatively small patches with measured values exceeding the criterion applied (200 nSv/h).

Additional work was therefore required in these four areas of interest (indicated by black circles in Figure III.20), which ensured compliance with the cleanup criteria established.

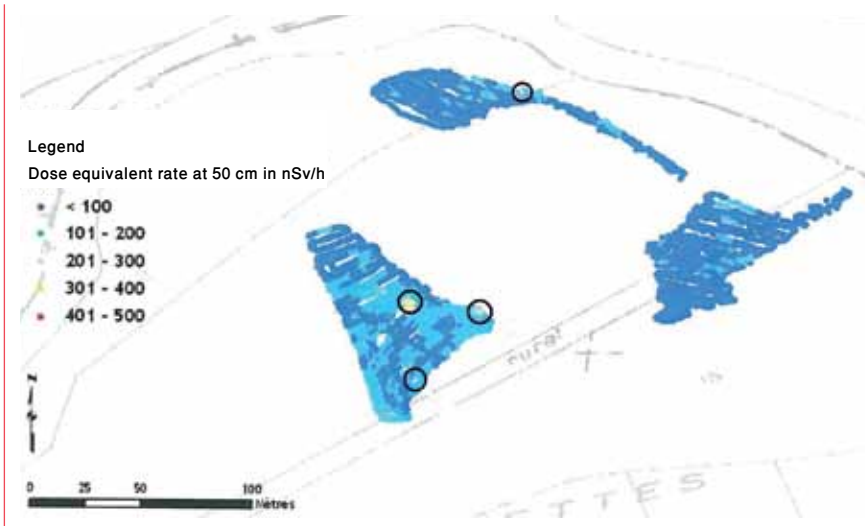

Figure III.20 - Radiological surface mapping of the shoreline of the Étang de la Gravière after initial restoration. The areas marked with black circles had dose equivalent rates higher than 260 nSv/h.

III.4 RADIOACTIVE RELEASES ASSOCIATED WITH NATURAL EVENTS

At European level, 2010 was marked by two natural events that both resulted in radioactive ash being released into the atmosphere, albeit with significant differences in terms of the type of particles, the origin of the radioactivity and the concentrations involved. The first of these events is associated with the eruption of the Eyjafjöll volcano in Iceland between mid-April and mid-May, while the second concerns the fires that raged in western Russia mainly during the first two weeks of August 2010.

Forest fires in the regions contaminated by the Chernobyl accident

The spate of forest fires in western Russia during the summer of 2010 (*Figure III.21*) as a result of the heat wave prompted IRSN to consider the environmental impact of fires in areas contaminated by radioactive fallout from the Chernobyl accident, and particularly the possibility of long-range redistribution of artificial radioactivity.

In consultation with Météo-France, IRSN monitored changes in the air masses and selected around ten aerosol samplers within its OPERA-Air atmospheric monitoring network to undertake priority measurements. Weather conditions, and particularly the fact that the air masses originated over the ocean, prevented the plumes of ash from heading for western Europe. The values measured were among the lowest usually recorded and are typical of oceanic air masses. These results can be explained by the prevailing westerly winds over western Europe during this period and by the fact that the few high-pressure systems were not strong enough to affect the general wind conditions.

A fact sheet on monitoring this phenomenon is available on the IRSN website at: http://www.irsn.fr/FR/Actualites_presse/ActualitPages/20100831_resultats-analyse-IRSN-feux-de-forets-russie.aspx

For more information

Forest fires had already run rampant in Ukraine, Belarus and Russia between mid-August and early September 2002, during which time a momentary advection of masses of air towards western Europe resulted in an increase (by a factor of four at most) in the residual ^{137}Cs background activity in the atmosphere. Cesium-137, an artificial radionuclide present in the atmosphere only in aerosol form, has been monitored since the late 1950s using filtration stations in the OPERA-Air network. It has persisted for several years in ultra-trace amounts (approximately 0.2 µBq.m^{-3} of air)[2] in the lower atmosphere, primarily due to the wind resuspending soil particles containing traces of earlier deposits of ^{137}Cs. As they grow, plants take up a very small fraction (transfer factor of about 10^{-3} m^2/kg) of the ^{137}Cs activity present in the soil, by root transfer.

IRSN research has shown that approximately 8% of the ^{137}Cs activity in wood is emitted into the atmosphere when wood is burned. Consequently, the combustion of biomass, particularly in winter, also contributes to maintaining a residual level. In all cases, the airborne levels are so low that around 30 to 50,000 m^3 of air per sample have to be filtered to be able to quantify the ^{137}Cs present. In conclusion, the summer 2010 fires in eastern Europe are not thought to have had any environmental radiological impact or, logically, any health impact on France. The same applies for other countries that closely monitored this episode, such as Finland.

2 – 1 µBq.m^{-3} = 1 millionth of a becquerel per m^3 of air is equivalent to the decay of one radioactive atom per second in a volume of one million m^3 of air.

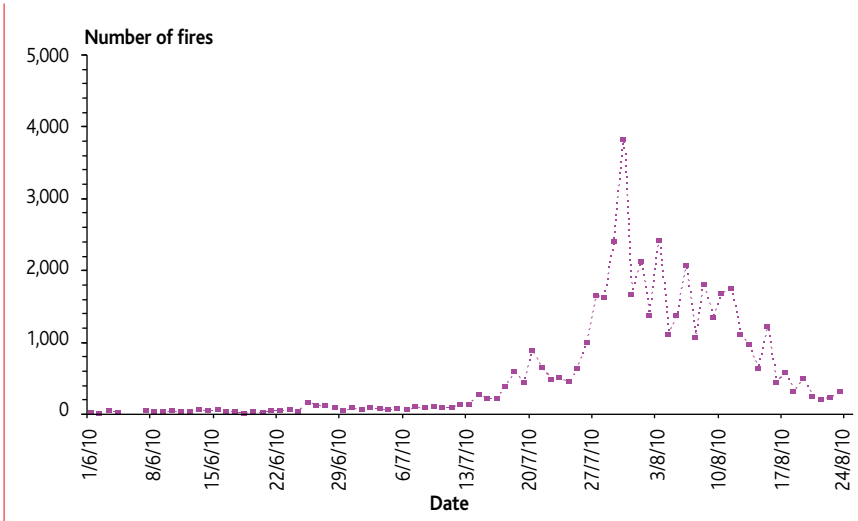

Figure III.21 - Variation in the daily number of fires in Ukraine, Belarus and western Russia between early June and late August 2010.
Source of data: FIRMS Global Fire Alerts - UN-FAO/UMD/NASA

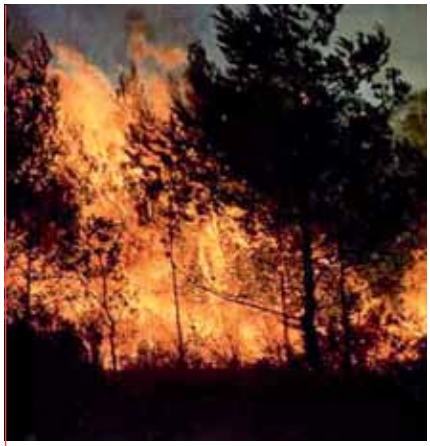

Figure III.22 - Approximately 8% of the ^{137}Cs activity in wood is emitted into the atmosphere when wood is burned.

Impact of the ash cloud produced by the eruption of the Icelandic Eyjafjöll volcano

Between April 14 and 16, 2010, some 70 to 80 million m³ of tephra[3] are believed to have been projected into the atmosphere by the Icelandic volcano (*Figure III.23*). Taking into account the uranium (~ 2 ppm) and thorium concentrations naturally present in magma and the quantities of ash discharged, it can be estimated that, over a period of three days, the volcano spewed out approximately 400 metric tons of uranium and 1,300 metric tons of thorium, with a thorium/uranium ratio of 3.3, i.e. a source term of 20 TBq[4] of uranium and 16 TBq of thorium.

Most of this was deposited on the flanks of the volcano itself and on adjacent land. The rest was carried aloft and dispersed far away from Iceland, over the North Atlantic and Europe.

Over France, the plume remained mainly at an altitude between 500-1,000 m and 3,000 m. The volume concentration measured in the air at ground level corresponds to approximately 1 µBq/m³ for uranium-238 and 0.8 µBq/m³ for thorium-232. These results can be compared to the level of lead-210 (decay chain of uranium-238), which is permanently present in the atmosphere at an annual average level in France of about 500 µBq/m³ (varying annually between 100 and 1,600 µBq/m³). The levels of polonium-210 in rainfall that had cleansed the atmosphere in April were between 7 and 62 mBq/L (IRSN data). These levels are normal and consistent with the activity measured in the atmosphere.

For more information

As part of its radioactivity monitoring brief, IRSN devoted particular attention to tracking the plume of volcanic ash that passed over France between April 15 and 21, 2010, mainly in the northern third of the country. In particular, polonium-210 (used as a specific tracer for volcanic plumes) and lead-210 were measured, since they are decay products of the uranium-238 chain. The volcanic eruptions were considered to be responsible for nearly 50% of the polonium-210 levels in the lower atmosphere (< 6 km), where the average atmospheric concentration was approximately 50 µBq/m³. The aerosol samplers in the OPERA-Air network, which are routinely used to monitor radioactivity in the atmosphere (*Figure III.24*), did not reveal any anomalies that might have confirmed the presence of volcanic dust in measurable quantities significantly higher than this reference value, at ground level in France.

At the same time, the Lidar[5] networks deployed between France and Switzerland, in particular, showed that most of the cloud had passed over northern France at an altitude of between 500 and 1,500-2,000 m. Because of the dilution of the air masses, the altitude of the ash, and its relatively low uranium and thorium content to start with, the measurement results are within the variation ranges usually observed.

This episode temporarily grounded a large number of aircraft in Europe but also ultimately led to different particle concentration thresholds being established (vigilance threshold at 200 µg/m³ or threshold for risk of engine damage from 2 mg/m³). By way of comparison, the concentration level at ground level did not exceed a few tens of µg/m³, i.e. it was within a range of normal values typical of an urban pollution event.

An information notice on this specific episode is available on the IRSN website at: http://www.irsn.fr/FR/Actualites_presse/Actualites/Pages/20100610_Nuage_cendres_volcan_islandais_Eyjafjoll.aspx

5 – Light Detection and Ranging. *Optical measuring device that uses a laser beam to determine, after reflection of the incident signal, clouds and particles suspended in the atmosphere.*

Figure III.23 - Eruption plume of Eyjafjöll.

3 –Solid and liquid material arising from magma and rocks from the volcanic vent, entrained by gases and ejected with them during a volcanic eruption; data estimated by the French Geological Survey (BRGM).
4 –1 TBq = 10^{12} becquerels

Figure III.24 - Very high-volume (700 m³/h) aerosol sampler in IRSN's OPERA-Air network (Puy-de-Dôme site in south-central France).


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IV

MONITORING IN METROPOLITAN FRANCE AND THE OVERSEAS TERRITORIES

IV.1 ATMOSPHERIC COMPARTMENT

The dose in air

The gamma dose equivalent rate in air ("dose rate") is measured by two types of devices:

- **"active" devices**, where the measurement is performed instantly in situ;
- **"passive" devices**, where the dose is integrated for a period of time and then measured in the laboratory (*Figure IV.1*).

Active devices, such as those in IRSN's Teleray remote measurement network or EDFs network of monitors, provide continuous monitoring and return the results within a few minutes. Combined with communication and information technology devices, they form alert networks. The daily or monthly mean measurement data from each monitor is sent to the French national environmental radioactivity measurement network (RNM) by all organizations that perform measurements.

Passive measurements are taken by dosimeters that remain in place over a long period, generally six months, but this can vary from one month to a full year. After laboratory analysis, the integrated dose measured is then converted to a dose equivalent rate over time, taking the exposure time of the dosimeters into account. The data sent to the RNM consists of the dose rates over time, associated with a measuring period.

More than 102,000 measurement results of the gamma dose equivalent in air were extracted from the RNM database for the period January 2010 to June 2011. The pie charts in Figure IV.2 show the number of monitoring points and the number of associated measurements for each organization. IRSN also manages a network of approximately 700 passive dosimeters.

Figure IV.1 - Instruments used to measure the gamma dose equivalent rate in the atmosphere: on the left, an active device (Gamma Tracer probe from the EDF network) and on the right, a passive device (radiophotoluminescent (RPL) dosimeter).

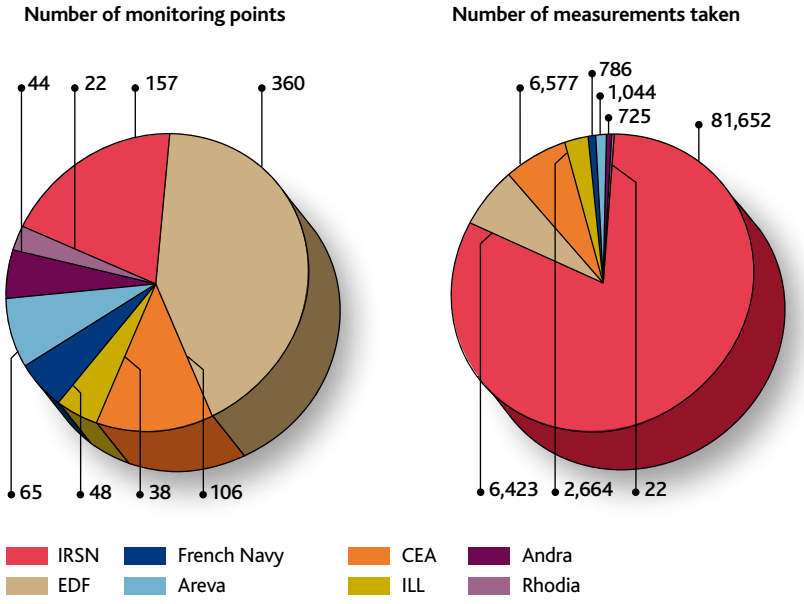

Figure IV.2 - Inventory, by organization, of the number of points and environmental dosimetric monitoring measurements in France declared to the RNM (active and passive devices).

Figure IV.3 illustrates the geographical distribution of all the monitoring points for active devices. IRSN's Teleray network covers the entire territory, where the points were determined to target areas with a high population density, as well as all the nuclear sites. The overseas departments, regions and communities are also continuously monitored and the results detailed in a special report. The Teleray network is currently being modernized and redeployed. Four hundred new remote measurement monitors are being installed and the operation, which began in 2011, is expected to be completed by 2015.

The other data providers concentrate their environmental monitoring within a close perimeter of their facilities. EDF has 360 monitors distributed around its 19 nuclear power plants (NPP) (see Focus) and the French Navy has 48 monitors shared between the four naval ports; the CEA, Areva and ILL sites generally have a few active monitors (4 in Marcoule, 4 in Saclay, 5 in La Hague, 4 in Grenoble), while most of the passive dosimeters are in operation.

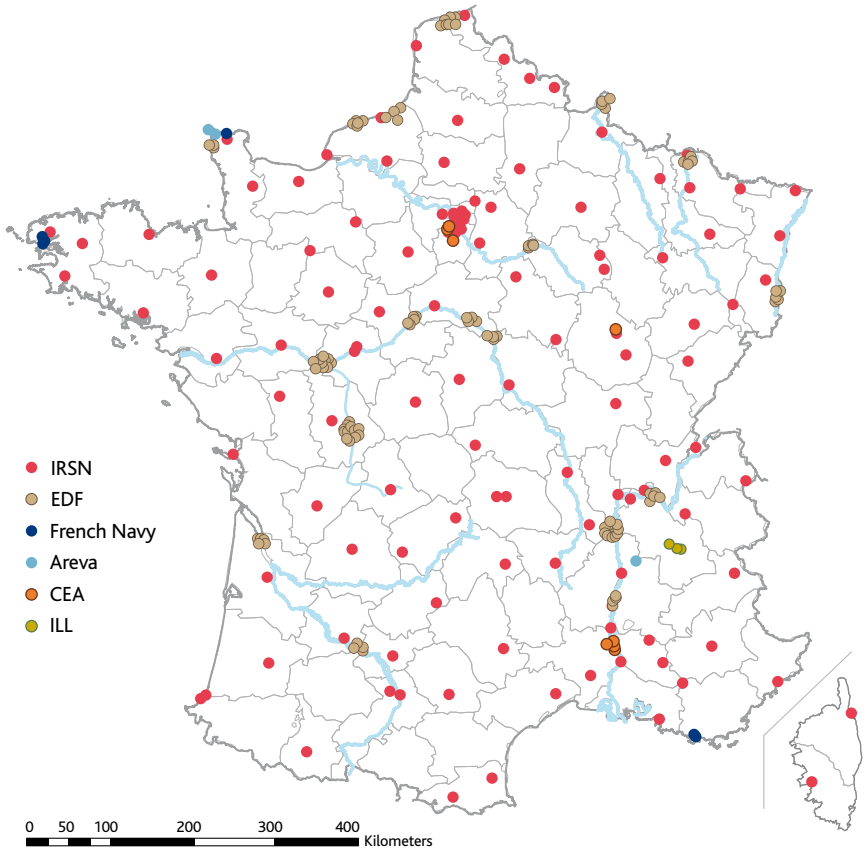

Figure IV.3 - Location of dose equivalent rate active measuring devices.

EDF • FOCUS

Distribution of EDF area monitors around NPPs

The ambient gamma dose rate measuring monitors on EDF sites are always distributed according to the areas in the vicinity.

There are generally ten "fence" monitors, four "1 km" monitors, four "5 km" monitors and ten "10 km" monitors (non regulatory). Until 1990, the ten "fence" points were monitored by passive dosimeters.

As an example, Figure IV.4 shows the distribution of monitors around the Civaux nuclear power plant.

Figure IV.4 - Geographical distribution of ambient gamma dose measurement points around the Civaux nuclear power plant (EDF).

The passive devices are measuring instruments specifically designed for the environmental monitoring of sites whose activities do not justify the presence of a warning system. They can also be used in addition to a warning system.

The environment of the French National Radioactive Waste Management Agency (ANDRA) and Rhodia sites is exclusively monitored by passive dosimeters. Both types of devices coexist on other nuclear sites. This is the case on ILL, EDF, CEA and Areva sites.

Since 1985, IRSN has also had a network of environmental monitoring dosimeters permanently installed across the entire territory. This network is currently being upgraded and it is planned to phase out thermoluminescent dosimeters (DTL) in favor of radiophotoluminescent (RPL) dosimeters; starting in 2012.

Figure IV.5 illustrates the geographical distribution of all the monitoring points for passive devices.

The average gamma dose equivalent rate calculated from all the measurements taken in metropolitan France by IRSN's Teleray network was 92 nSv/h for 2010 and the first six months of 2011. This average was similar to that of previous years (*Figure IV.6*).

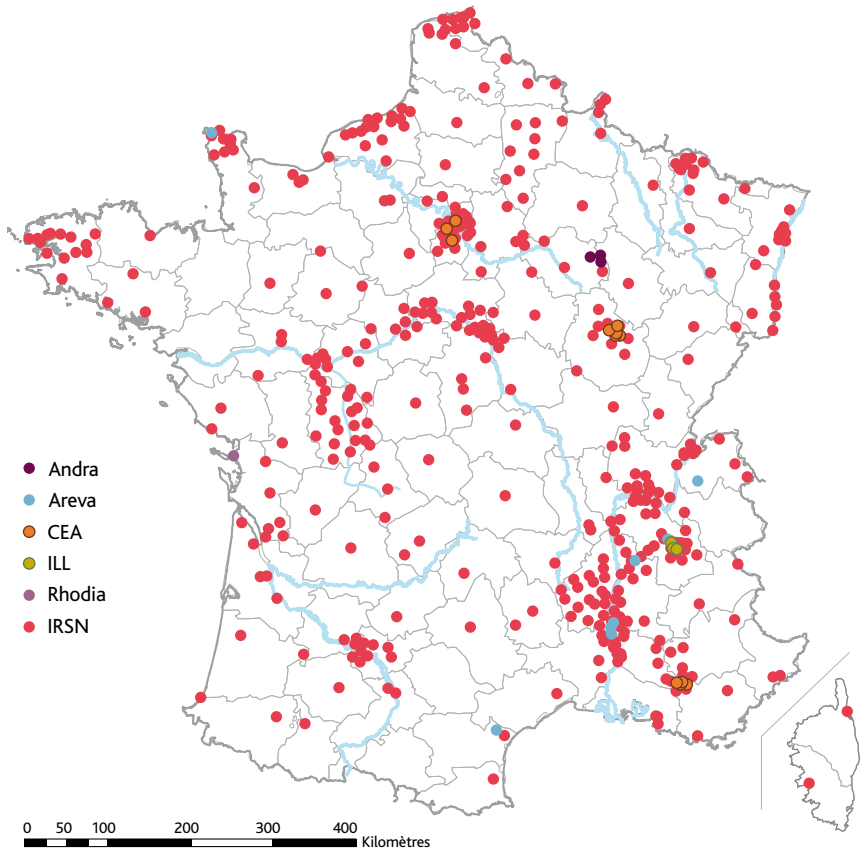

Figure IV.5 - Location of ambient gamma dose passive measuring devices.

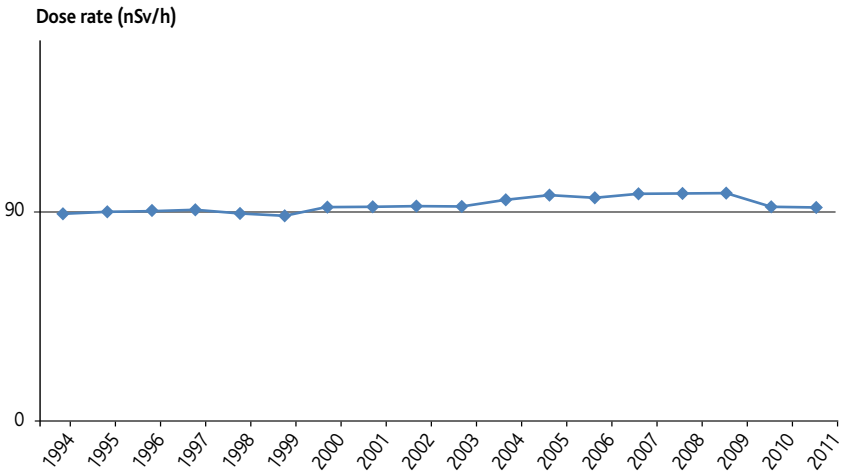

Figure IV.6 - Changes in Teleray network annual average measurements from 1994 to 2011 nSv/h.

Figure IV.7 illustrates the variability of the dose rate in air measured by active and passive devices. The maps reflect the respective influences of the two contributors to dose rates in air: terrestrial radiation related to the geological nature of the land and cosmic radiation, which depends on altitude.

Figure IV.8 shows that the dose rate associated with cosmic radiation alone can reach 80 nSv/h at an altitude of 2,000 m.

The dose rate in air is higher in regions where granitic rocks predominate (Auvergne, the Alps, Corsica, Limousin) than in sedimentary basins characterized by low terrestrial radiation (Paris and Aquitaine basins, Rhône valley). Figure IV.9 illustrates the average calculated for each region of metropolitan France.

The differences between the two maps shown in Figure IV.7 are basically due to the location of the devices, with their characteristics playing only a relatively small part. More specifically, certain high values due to active devices are related to the presence of probes installed on mountain tops with high cosmic radiation and not associated with no passive devices.

There is little difference between the measurements provided by both types of devices when they are less than 100 meters apart (*Figure IV.10*). One of the causes of the few differences observed is the significant uncertainty that can be associated with the measurement provided by a dosimeter, particularly when the integration time is short (one month). The significant difference noted in the case of measurements taken around La Rochelle is explained by the fact that some of the dosimeters used for monitoring the Rhodia site are located within the plant (*see Chapter VII*).

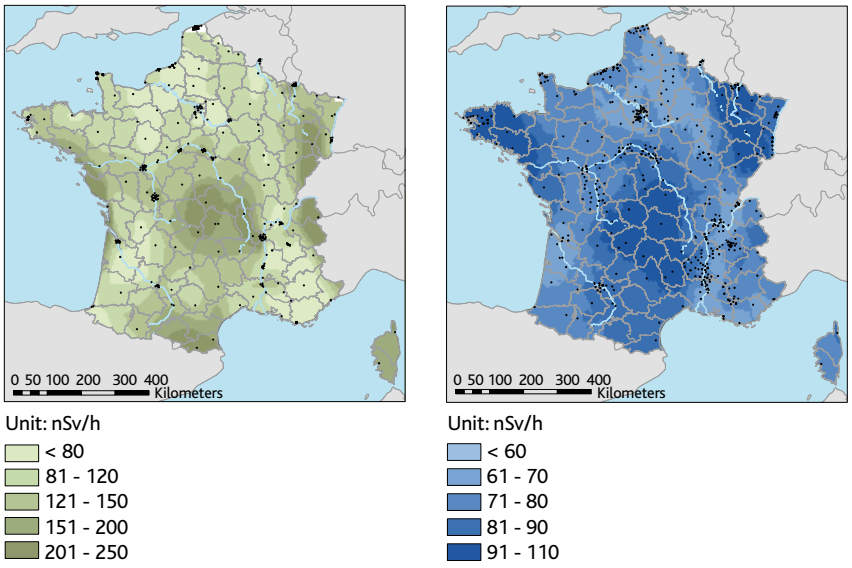

Figure IV.7 - Map of dose rate measurement data for active devices (left) and passive devices (right).

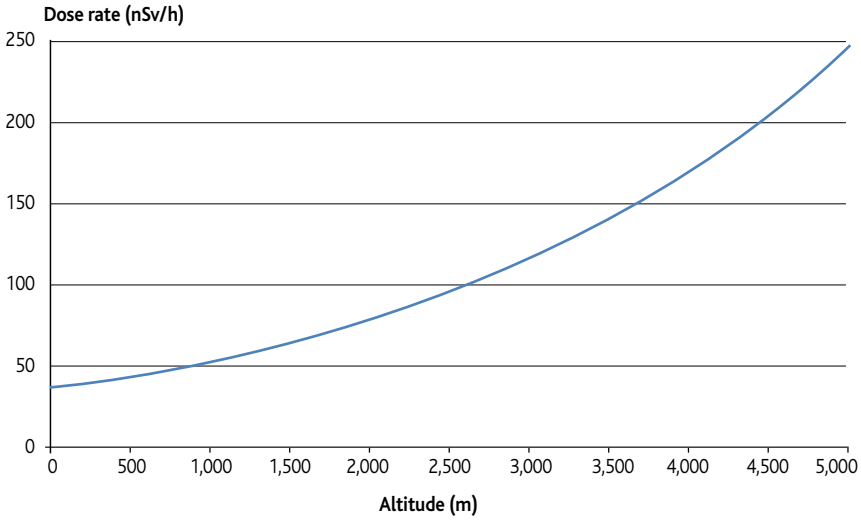

Figure IV.8 - Contribution of cosmic radiation to the dose rate, depending on altitude.

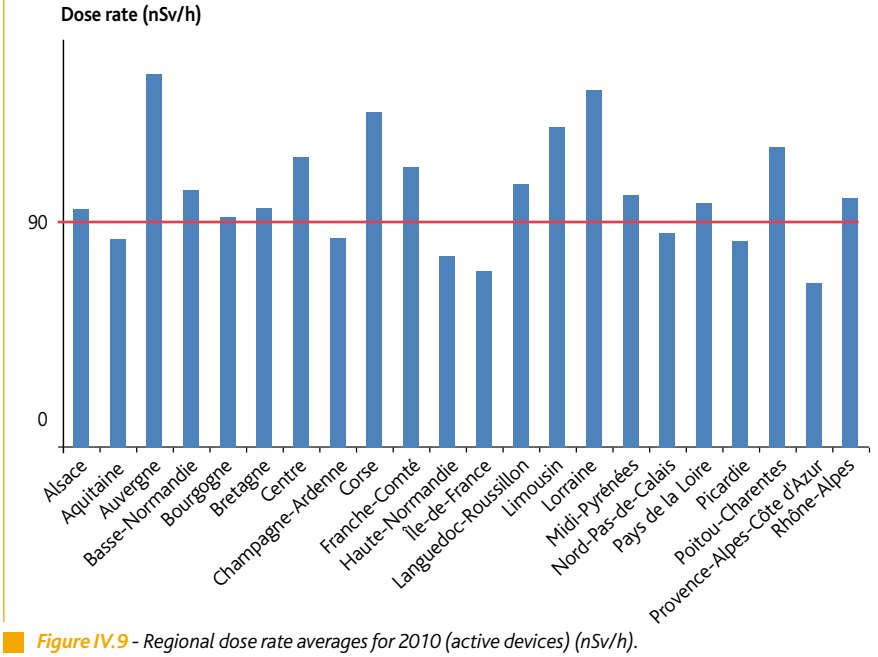

Figure IV.9 - Regional dose rate averages for 2010 (active devices) (nSv/h).

Figure IV.11 shows the relative stability of the dose rate measurements recorded by the Teleray network monitors between January 2010 and June 2011 for different location categories. These values were stable compared with those from previous years.

The temporary interruption of data seen on this graph indicates when the new monitoring system for the Teleray network came into operation and interrupted communications between the monitors for 24 hours in December 2010. In addition, in December 2010 and January 2011, some probes installed on mountain tops malfunctioned, in particular the probe on the Aiguille du Midi in the Alps (altitude 3,800 m), where the average dose rate was approximately 300 nSv/h. Considering the small number of stations in this category, the absence of data for stations where a malfunction occurred greatly impacted and visibly lowered the average dose rate (*Figure IV.11*).

The large fluctuations observed in mountain top measurements can be explained by the effect of the blanket of snow which screens terrestrial radiation. Other fluctuations can be explained by meteorological phenomena. For example, a storm after a dry period can suddenly bring natural atmospheric radioactivity down to the ground, causing a temporary increase in the dose rate measured.

The graph in Figure IV.12 shows that no fault was detected over this period around nuclear sites by any of the contributors to the National Environmental Radioactivity Measurement Network. Thresholds were nevertheless sometimes exceeded, but this could always be explained by a natural event (storm) or by planned exposure to an artificial radioactive source (calibration, a convoy of vehicles transporting radioactive material passing through).

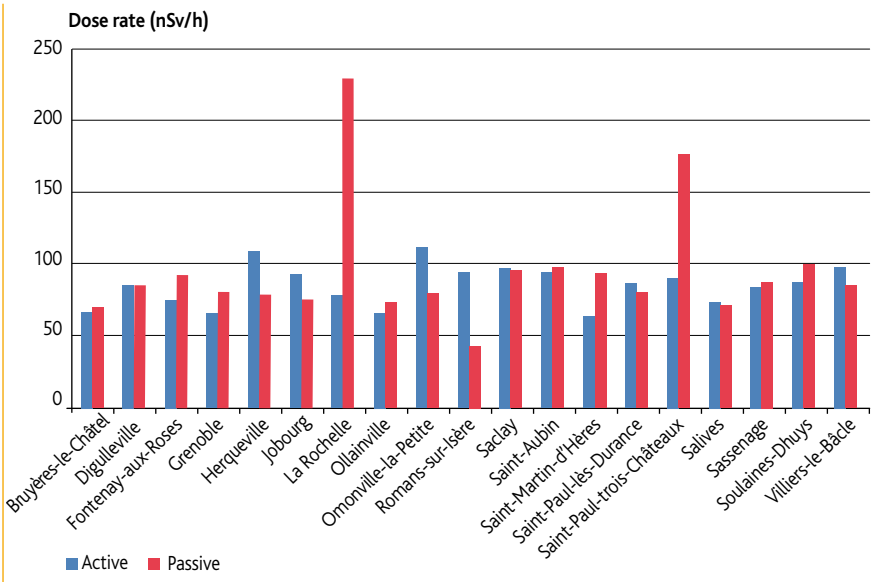

Figure IV.10 - Comparative analysis of measurements performed by active and passive devices (nSv/h).

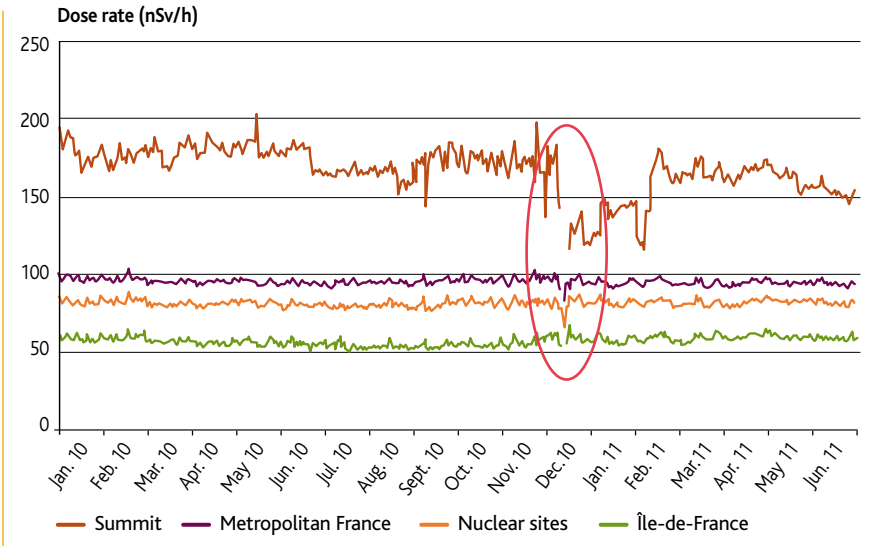

Figure IV.11 - Changes in the average dose rate by site category for the IRSN Teleray network (nSv/h).

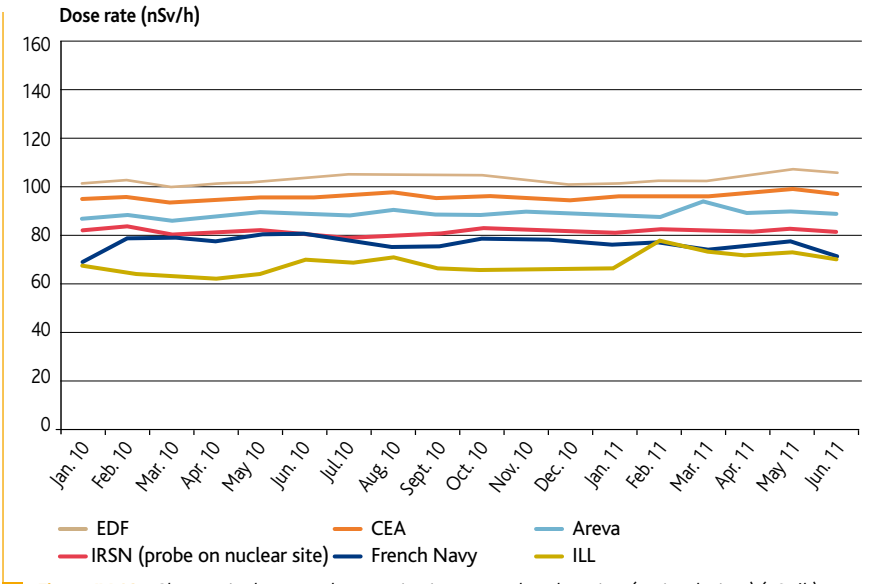

Figure IV.12 - Changes in dose rate, by organization, around nuclear sites (active devices) (nSv/h).

Atmospheric aerosols

IRSN monitors the radioactivity of atmospheric aerosols across France by means of two types of complementary stations (*Figure IV.13*) which constitute the OPERA-Air (environmental radiation monitoring network:

- **low-volume stations** providing weekly information about aerosol radioactivity;
- **very high-volume stations** that quantify the ambient background for the radionuclides present in very low quantities in the air (for example cesium-137). Some of these stations also have a rainwater sampling system.

Low-volume stations in the OPERA-Air network

Forty-four low-volume stations were in operation during the period covered by this radiological report (*Figure IV.14*). After a sampling period of 24 hours at an average flow rate of approximately 7 to 10 m³/h, each station's filter was measured. In weekly groups, the filters were then measured by gamma spectrometry in a laboratory.

If the period between the end of March 2011 and the beginning of May 2011 is excluded, during which traces of cesium-137, cesium-134 and iodine-131 released during the Fukushima NPP accident were observed, the measurements did not identify any other artificial radionuclide and indicated that this event had had a fairly consistent effect across the entire territory (*see Chapter III*).

Figure IV.13 - Location of IRSN stations in the OPERA-Air aerosol sampling network.

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Figure IV.14 - IRSN OPERA-Air low volume network.

Table IV.1 lists all the average decision thresholds of the different artificial radionuclides accessed via samples gathered by these stations and the measuring conditions usually applied. The samples taken in France further to the Fukushima accident were analyzed for longer periods. This resulted in the decision threshold being lowered and cesium activity levels of approximately 0.03 mBq/m³ observed (*Table IV.2*).

Table IV.1 - Average decision thresholds of the different artificial radionuclides identified in atmospheric aerosols routinely sampled by low-volume IRSN stations in the environment in France.

Radionuclide	Decision threshold (mBq/m³)
Actinium-228	0.4
Antimony-124	0.4
Antimony-125	0.2
Silver-108m	0.06
Silver 110m	0.08
Cesium-134	0.064
Cesium-137	0.065
Cobalt-57	0.04
Cobalt-58	0.11
Cobalt-60	0.09
Iodine-131	0.27
Manganese-54	0.08
Potassium-40	2
Protactinium-234m	10
Sodium-22	0.07
Tellurium-123m	0.05
Zinc-65	0.19
Thorium-234	0.6

Table IV.2 - Mean activity levels measured in ^{137}Cs, ^{134}Cs and ^{131}I in aerosols in the environment in France during the period impacted by radioactive discharge from the accident at the Fukushima nuclear power plant.

Radionuclide	Mean activity (mBq/m³)
Cesium-134	0.030 ± 0.002
Cesium-137	0.034 ± 0.002
Iodine-131	0.075 ± 0.003

Gamma spectrometry measurements indicate the constant presence of beryllium-7 and lead-210, naturally occurring radionuclides formed respectively under the effect of solar radiation in the upper atmospheric layers and the emanation of radon-222 from soil (lead-210 is one of the long-lived radioactive decay products of this gas). Beryllium-7 and lead-210 concentrations in atmospheric aerosols vary with seasonal climate changes (*Figures IV.15 and IV.16*).

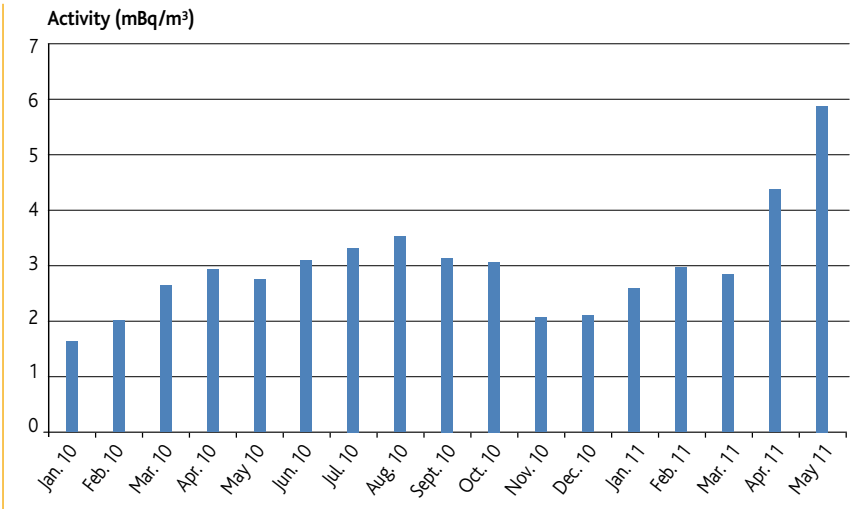

Figure IV.15 - Mean beryllium-7 activity measured by the low-volume stations in the IRSN OPERA-Air network (mBq/m³).

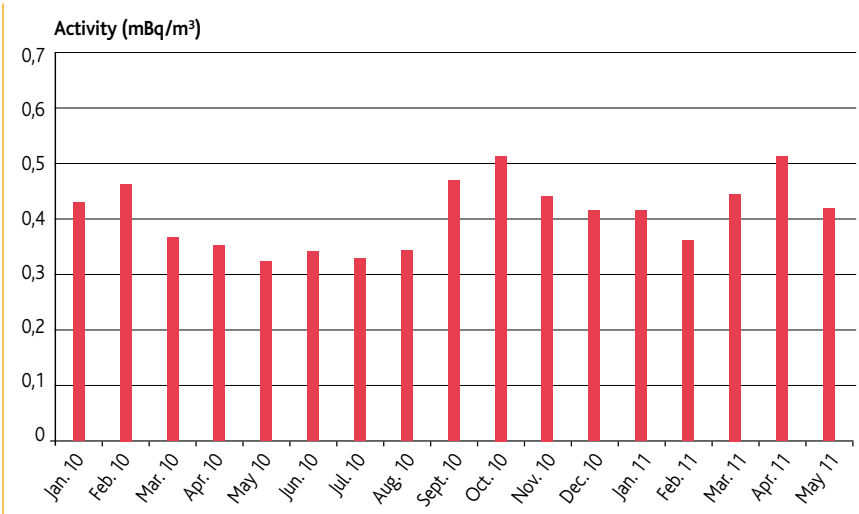

Figure IV.16 - Average lead-210 activity measured by the low-volume stations in the IRSN OPERA-Air network (mBq/m³).

Very high-volume stations in the OPERA-Air network

The OPERA-Air network has eight stations with a flow rate of between 300 and 700 m³/h. Sampling takes place over ten consecutive days to accumulate a large quantity of aerosols. In addition, advanced metrology allows infinitesimal traces of cesium-137 to be measured at levels above the decision thresholds (approximately 0.1 µBq/m³).

The stations monitored the atmospheric fallout in France from the Fukushima accident, over its entire life. The station at the summit of the Puy-de-Dôme in central France (*Figure III.23 in Chapter III*) was the first to detect traces of cesium-137 and particulate iodine-131. In addition to the data from other stations located on the plain, the arrival of air masses over France could be dated between March 23 and 24, 2011.

The data collected by these stations showed that unlike the fallout from the Chernobyl accident, the increased cesium-137 activity in the air masses following the Fukushima accident did not last; the activity concentration of this radionuclide in the air returned to its previous level in less than six months (*Figure IV.17*).

This was due to the distance from the Japanese power plant and to the fact that most of the cesium deposited on oceans could no longer give rise to resuspension phenomena liable to maintain the prolonged persistence of this radionuclide in the air. Moreover, the iodine-131 quickly disappeared, due to its short radioactive half-life.

For more information
Chapter III – The Fukushima Accident

Rainwater

Since 2010, the rainwater collected each month (*Figure IV.18*) in France (*Figure IV.19*), apart from samples collected near nuclear facilities, is kept, but only analyzed in the event of an accident.

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Figure IV.18 - Rainwater collector.

Apart from at the time of the Fukushima accident when monitoring was intensified (*see Chapter III*), the rainwater collected each month was not analyzed in 2010 and 2011.

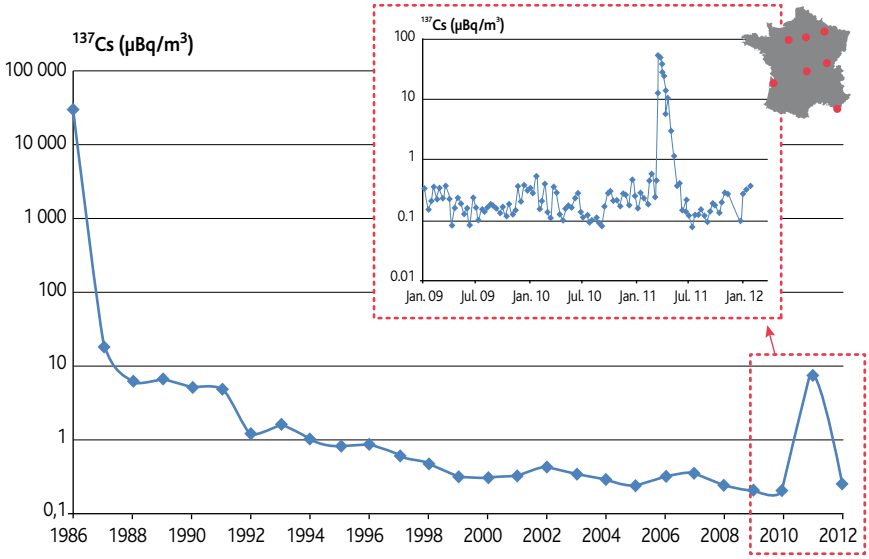

Figure IV.17 - Mean cesium-137 activity (metropolitan France) in atmospheric aerosols from 1986 to 2012 (µBq/m³).

Figure IV.19 - Location of rainwater collectors situated outside the influence of nuclear facilities.

IV.2 CONTINENTAL ENVIRONMENT

Terrestrial compartment

The radiological state of areas not affected by the effluent released by nuclear facilities is based on very low-level measurements taken during specific studies or radiological reports.

In addition, the departments regularly monitor foodstuffs (at least once a year). Since 2009, a network of plant and animal production samplers has been rolled out by IRSN across the whole of France with the assistance of the decentralized units of the Directorate General on Food Safety (DGAL) and the Directorate for Competition, Consumer Rights, and Protection Against Fraud (DGCCRF) to reinforce the monitoring of a geographical area, where necessary.

This radiological monitoring focuses on two of the main French agricultural products: milk and cereals. These products have been monitored since the beginning of the 1960s, providing records of the fallout from atmospheric nuclear weapons tests and the Chernobyl accident, as well as their persistent effects. In addition, some samples of mushrooms from the areas most affected by fallout from the Chernobyl accident are regularly analyzed to determine their cesium-137 content.

Milk

In addition to collecting milk from farms near nuclear facilities, samples from cooperatives or dairies are used to obtain representative reference values for bovine, caprine and ovine milk production from the departments in France and keep watch over the health of the French population.

The sampling frequency, which by default is once a year, can be increased in the event of a radiological incident.

The radioactivity measured in milk is now intrinsically of natural origin. During the period of January 2010 to May 2011, as in previous years, potassium-40 activity was largely predominant and varied, depending on the department, between 32 ± 13 and 68 ± 10 Bq/L for cow's milk and between 52 ± 7 and 71 ± 10 Bq/L for goat's milk. The activity measured in sheep's milk collected in the Alpes-Maritimes in the southeastern corner of France amounted to 36.4 ± 3.9 Bq/L.

After the Fukushima accident, some milk collected in metropolitan France between March and May 2011 showed traces of iodine-131, cesium-134 and cesium-137. The results of this incident are presented in Chapter III.

Cesium-137 and strontium-90 are also measured more or less regularly in French milk. As a result, traces of strontium-90 of between 0.022 ± 0.01 and 0.113 ± 0.018 Bq/L were observed in most of the samples analyzed (weighted average of 0.0322 ± 0.0017 Bq/L over the entire collection period under consideration – *Figure IV.21*). The presence of this radionuclide represents residual material of the fallout from past atmospheric nuclear weapons tests. No increase in its activity was detected in milk samples from farms in the vicinity of nuclear facilities.

Note: Strontium-90 was measured on only a few samples, as the procedure requires prior chemical treatment that is difficult to carry out on fresh milk. The results available for 32 departments show a range of activity levels in metropolitan France.

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Figure IV.20 - Preparing milk samples.

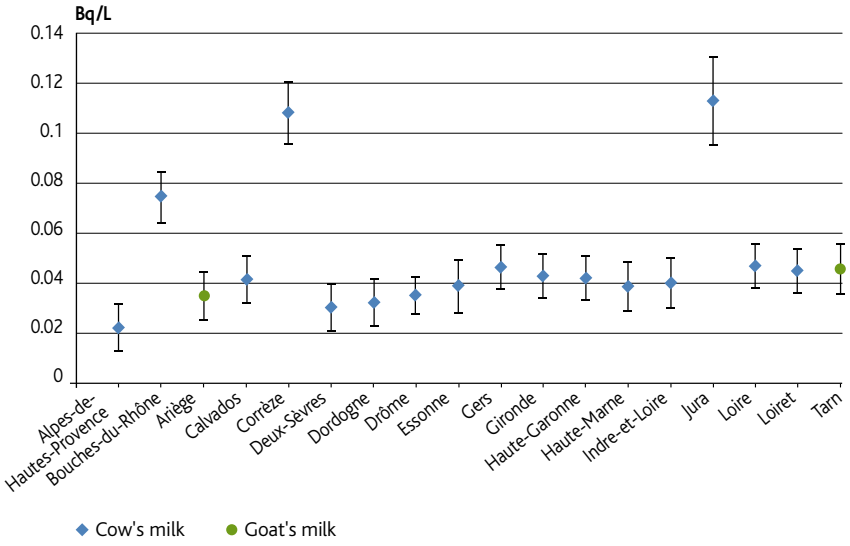

Figure IV.21 - ^{90}Sr activity levels in milk collected in French departments between January 2010 and May 2011 (Bq/L).

Similarly, the cesium-137 activity of 0.117 ± 0.031 and 0.194 ± 0.05 Bq/L was respectively measured in milk collected in 2010 in the Cantal and Puy-de-Dôme departments in south-central France. These traces are attributable to earlier fallout from nuclear tests and the Chernobyl accident. Figure IV.22 shows that in May 1986, ^{137}Cs activity levels reached several dozen Bq/L. Apart from these two samples, cesium-137 activity levels in milk collected from the departments in France in 2010-2011 were below the decision thresholds (< 0.6 Bq/L).

Finally, the tritium in the milk produced in the Côte-d'Or in eastern France was measured (11 ± 2.3 Bq/L in milk collected on April 27, 2010 and 15 ± 2.6 Bq/L in that collected on March 15, 2011). These activity levels were related to atmospheric radioactive discharge from the CEA Valduc facility (*see Chapter VI - CEA Valduc Monitoring*).

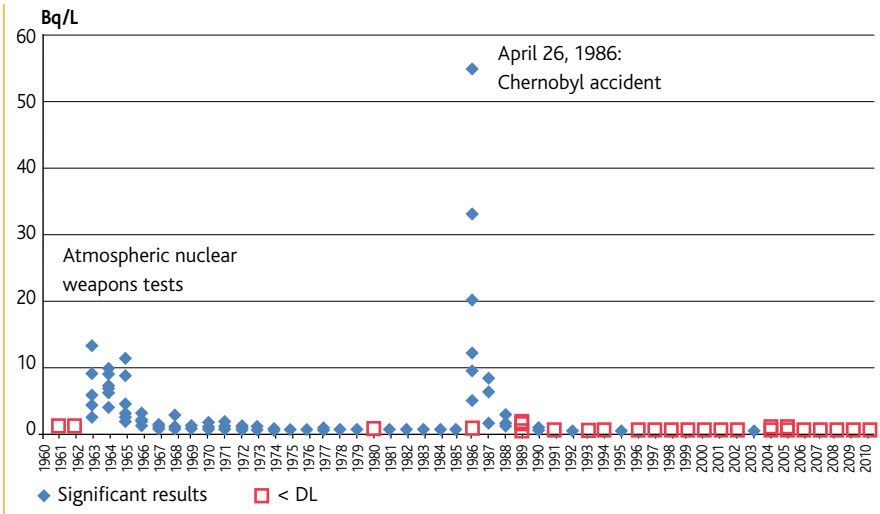

Figure IV.22 - Cesium-137 activity levels in milk analyzed in the Allier department (Bq/L).

Cereals

Radiological monitoring of wheat in metropolitan France is carried out with the assistance of the French National Institute for Agricultural and Marine Products (France AgriMer) which takes samples from 210 silos across France. The samples are then grouped into 21 regional blends. The results obtained in 2010 are given in Table IV.3.

As with milk, most radioactivity in wheat grains is of natural origin, in particular potassium-40 activity.

As in previous years, the only artificial radionuclide detected in wheat was strontium-90, which was the residue from atmospheric fallout from atmospheric nuclear weapons tests. Figure IV.23 illustrates the reduction in activity of this radionuclide in cereals from 1969 to the present day, in all regions.

Regional monitoring complements the monitoring carried out around the main nuclear facilities. Results are presented in Chapters V and VI.

Table IV.3 - Activity levels measured in durum wheat samples (2010 harvest) – Regional mixtures (Bq/kg wet).

Region	Specific activity (Bq/kg wet)						
	^{40}K	^{54}Mn	^{58}Co	^{60}Co	^{90}Sr	^{134}Cs	^{137}Cs
Alsace	115 ± 23	< 0.50	< 0.64	< 0.50	0.11 ± 0.01	< 0.48	< 0.49
Aquitaine	112 ± 16	< 0.50	< 0.78	< 0.47	0.11 ± 0.02	< 0.45	< 0.47
Auvergne	106 ± 16	< 0.56	< 0.76	< 0.52	0.19 ± 0.02	< 0.49	< 0.50
Bourgogne	114 ± 24	< 0.56	< 1.23	< 0.48	0.19 ± 0.02	< 0.44	< 0.51
Bretagne	105 ± 24	< 0.53	< 0.78	< 0.49	0.26 ± 0.03	< 0.46	< 0.52
Centre	110 ± 24	< 0.70	< 0.76	< 0.51	0.12 ± 0.02	< 0.49	< 0.53
Champagne-Ardenne	104 ± 23	< 0.61	< 2.02	< 0.51	0.12 ± 0.01	< 0.51	< 0.52
Franche-Comté	95 ± 22	< 0.57	< 0.63	< 0.46	0.18 ± 0.02	< 0.47	< 0.51
Île-de-France	109 ± 20	< 0.53	< 1.29	< 0.42	0.05 ± 0.01	< 0.44	< 0.46
Languedoc-Roussillon	128 ± 27	< 0.51	< 0.72	< 0.51	0.10 ± 0.01	< 0.48	< 0.56
Limousin	99 ± 24	< 0.47	< 0.60	< 0.53	0.23 ± 0.04	< 0.47	< 0.55
Lorraine	100 ± 15	< 0.49	< 0.67	< 0.55	0.13 ± 0.02	< 0.47	< 0.47
Midi-Pyrénées	113 ± 24	< 0.70	< 1.36	< 0.51	0.18 ± 0.02	< 0.51	< 0.51
Nord-Pas-de-Calais	108 ± 24	< 0.52	< 0.64	< 0.54	0.07 ± 0.01	< 0.46	< 0.46
Basse-Normandie	105 ± 22	< 0.49	< 0.70	< 0.48	0.17 ± 0.02	< 0.58	< 0.49
Haute-Normandie	105 ± 23	< 0.56	< 0.95	< 0.42	0.12 ± 0.01	< 0.49	< 0.49
Pays de la Loire	102 ± 25	< 0.59	< 0.70	< 0.48	0.18 ± 0.02	< 0.49	< 0.50
Picardie	101 ± 21	< 0.54	< 0.81	< 0.51	0.12 ± 0.05	< 0.47	< 0.57
Poitou-Charentes	109 ± 24	< 0.62	< 0.78	< 0.49	0.16 ± 0.02	< 0.55	< 0.55
Provence-Alpes-Côte-d'Azur	114 ± 24	< 0.75	< 3.23	< 0.58	0.14 ± 0.02	< 0.55	< 0.54
Rhône-Alpes	114 ± 20	< 0.48	< 0.77	< 0.42	0.15 ± 0.03	< 0.39	< 0.41

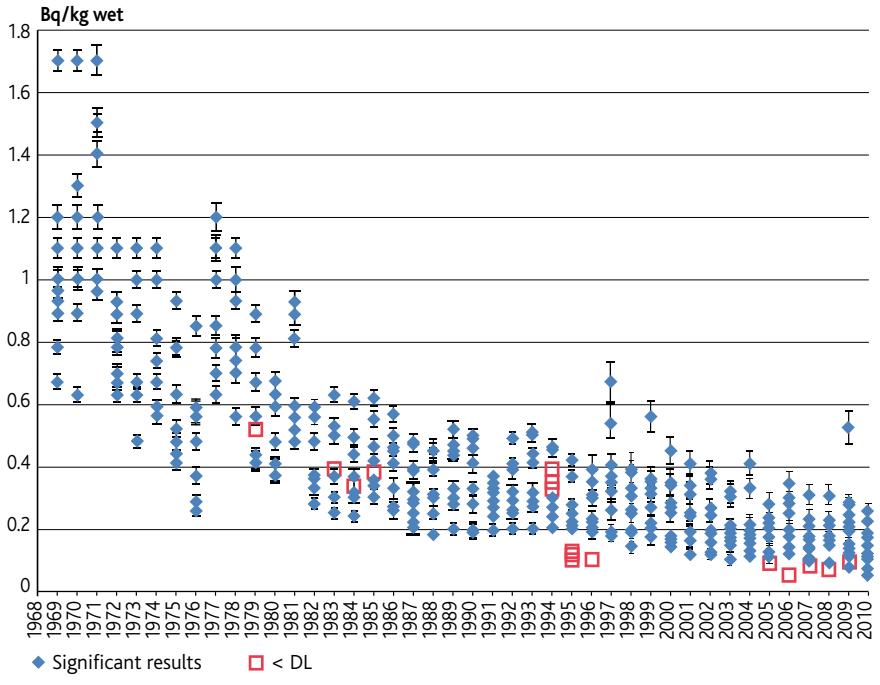

Figure IV.23 - Strontium-90 activity levels measured on wheat samples from 1969 to 2010, in all regions (Bq/kg wet).

Mushrooms

Mushrooms are among the few foodstuffs produced in France in which cesium-137 from earlier fallouts is still measured on a regular basis. In 2010, mushroom samples were taken from areas where such fallout was at its highest (*Table IV.4*).

Most of the samples contained traces of cesium-137 that were nevertheless still below the maximum permissible level of radioactive contamination set at 1,250 Bq/kg wet by Euratom Regulation No. 2218-89 of July 18, 1989 modifying Regulation No. 3954-87 of December 22, 1987.

Table IV.4 - Activity levels measured in mushrooms collected in 2010 (Bq/kg wet).

Department	Species	Cesium-137 specific activity (Bq/kg wet)
Bas-Rhin	Boletus	28.8 ± 2.5
Corse-du-Sud	Mushroom (non identified species)	1.91 ± 0.37
Doubs	Chanterelle	13.9 ± 1.7
Drôme	Boletus	3.71 ± 0.43
	Lactarius sanguifluus	121 ± 10
Haute-Corse	Amanita rubescens	0.23 ± 0.06
Haut-Rhin	Boletus edilis	8.1 ± 1
	Black trumpet	1.18 ± 0.21
Meurthe-et-Moselle	Fawn pluteus	< 0.1
	Delicious or lactarius sanguifluus	0.24 ± 0.09
Puy-de-Dôme	Lactarius	3.5 ± 0.34
Rhône	Black trumpet	0.37 ± 0.1
Vaucluse	Girolle	6.1 ± 0.6

Fukushima accident

Following the incident that occurred on March 11, 2011 at the Fukushima nuclear power plant in Japan, monitoring of activity levels was increased across France from March 21 to May 6, 2011.

Samples of grass, milk and leafy vegetables were collected throughout the country, from areas outside the influence of French nuclear facilities, by associations, departmental laboratories and the departmental services of the DGAL, DGCCRF and IRSN.

The strategy deployed during this incident and the associated analysis results are presented in Chapter III.

Aquatic compartment

Around thirty semi-automated water samplers have been installed throughout France to monitor rivers and streams. Water monitoring is supplemented by an automated remote radioactivity measuring system that provides continuous measurements: the HydroTeleray network (*Figure IV.24*). The results of the analyses performed on samples taken immediately downstream of nuclear facilities are given in Chapters V and VI.

Figure IV.24 - Location of IRSN water samplers downstream of nuclear facilities and HydroTeleray network stations.

The water sampling network

For each water sampler, the water from the tank is pumped at a rate of 15 mL per hour to generate a sample of approximately 2 L every six days. The samples are sent once a month to a laboratory, where the fractions of raw and 0.45 µm filtered water are analyzed (*Figure IV.25*).

In addition to the water samplers and sampling points immediately downstream of nuclear facilities (*see detailed results in Chapters V and VI*), there are three IRSN stations at distant locations:

- on the Loire, downstream of the nuclear facilities at the Ponts-de-Cé water treatment station in the west of France;
- on the Rhône, downstream of all the nuclear facilities at the Vallabrègues dam in southern France;
- on the Seine, downstream of the nuclear facilities at Croissy-sur-Seine to the west of Paris.

The analyses performed in 2010 and 2011 show that tritium is the main radionuclide almost permanently detectable in these rivers.

The tritium activity measured in the Seine downstream of any nuclear facility at Croissy-sur-Seine was approximately 12.5 ± 2.9 Bq/L in 2010; in the water in the Rhône at Vallabrègues, it was 7.3 ± 2.4 Bq/L and in the Loire at Angers, 20.3 ± 2 Bq/L. The activity levels measured are related to the liquid discharge from the nuclear facilities located along the banks of these rivers, or whose discharge reaches their drainage basins.

Figure IV.25 - Detailed view of an IRSN water sampler.

The HydroTeleray network

The HydroTeleray network, set up in 1993, provides real-time radiation monitoring of water from the seven major French rivers, downstream of all nuclear facilities at Ponts-de-Cé (Angers) on the Loire, Croissy-sur-Seine on the Seine, Vallabrègues (Arles) on the Rhône, Vogelgrün on the Rhine, Rancennes on the Meuse, Boé (Agen) on the Garonne and Apach on the Moselle (*Figure IV.24*).

The purpose of this network is to continuously ensure that the levels of activity of the water courses that might result from an accident situation are acceptable from a health point of view, before they cross national land and sea borders. At each station, a gamma spectrometry measurement is performed during an integration time of two hours for a water flow of approximately 5 m³/h.

The system consists of an NaI detector (sodium iodide) situated in a stainless steel lead-shielded tank to reduce the natural background (*Figure IV.26*). The decision thresholds are approximately 0.5 at 1 Bq/L for cesium-137, iodine-131 and cobalt-60. The data is automatically analyzed, stored and retransmitted to the concentrator on the IRSN Le Vésinet site. An alarm can be triggered if an abnormal activity level is detected.

In 2010 and 2011, only sporadically detected radionuclides were of natural origin, including lead-214, bismuth-214 from radon-222 progeny, and potassium-40.

Figure IV.26 - Boé HydroTeleray station (near Agen) performing real-time radiological monitoring of water from the Garonne.

IV.3 MARINE AND COASTAL ENVIRONMENT

The marine and coastal environment is monitored by coastal sampling stations situated along all the coasts of France. The number of stations and their location are determined by the proximity of nuclear facilities, the desire to ensure good geographical cover and the implementation of specific study programs.

There are two types of stations:

- **sampling stations** influenced by discharge from coastal nuclear facilities, which monitor spatial and temporal changes in the radiological state of the near-field environment;
- **reference stations,** characterizing the background and any sources of radionuclide emissions other than those from discharge from nuclear facilities on the French coastline. They particularly monitor the radionuclides carried to their marine environment by major rivers.

All the results from these stations are given in this chapter and classified by coastal area: North Sea and Channel, Atlantic and Mediterranean.

As the dilution capacity of the marine environment is greater than that of the continental aquatic environment, coastal monitoring focuses more on bioindicators (seaweed, mollusks, crustaceans, fish) that concentrate pollutants and thus provide a better understanding of the state of the environment than some direct seawater measurements. The analysis of certain bio-indicators plays an important part in supplying data to the food products observatory set up in 2009 in partnership with the DGAL and DGCCRF. With respect to biological matrices, the analysis of carbon-14 and organically bound tritium results is summarized in specific Focus sections.

The Channel - North Sea coast

The radioactivity currently observed in the Channel and North Sea marine aquatic environment comes mainly from discharge from spent fuel reprocessing plants at La Hague in France and Sellafield in England. The measurements and modeling of the dispersion of radionuclides discharged by these facilities in the marine environment show that the impact of this discharge is no longer noticeable to the west of Roscoff. This chapter therefore focuses on the results of measurements performed on the samples taken from the coastal current between Roscoff and Dunkirk.

Sea water

Tritium in the sea water in the Channel and the North Sea is measured at activity levels generally similar to or greater than 5 Bq/L. It is mainly caused by liquid effluent discharge from the Areva site at La Hague and, to a lesser extent, the EDF nuclear power plants at Gravelines, Flamanville, Paluel and Penly.

Very low levels of residual cesium-137 dating back to Chernobyl and atmospheric nuclear bomb tests can still be measured in seawater by sampling and treating large volumes of water. The cesium-137 activity in these waters is just a few mBq/L (*Table IV.5*).

In the vicinity of nuclear power plants

The Flamanville, Paluel, Penly and Gravelines NPPs are cooled by water from the Channel. To improve the dilution of liquid effluent discharge in the sea, the Flamanville, Paluel and Penly NPPs discharge their effluent into the open sea through an underwater pipe. These outfalls dilute the discharge released to the marine environment, but do not allow the continuous use of sampling equipment. To resolve this technical problem, water samplers were installed within the outfall structure (discharge pond or channel) upstream of the point where effluent is discharged to the sea.

In all cases, the activities measured at these water samplers provide information about the average monthly radioactivity discharged by the NPPs and added to the marine environment. The design of the Gravelines NPP outfall structure is different. Discharge passes through a sea channel leading to the coast, which therefore constitutes an intermediate receiving environment for the discharge prior to its dilution in the sea. A water sampler is installed in this channel. The activity levels measured on these devices are therefore greater than those that would be measured directly in the marine environment.

Table IV.5 - Tritium and cesium-137 activity levels in water samples from the North Sea (Bq/L).

Radionuclide	Bray-Dunes	Mers-les-Bains	Wimereux
Tritium	6.7 ± 2.5	5.9 ± 2.5	4.2 ± 0.1
Cesium-137	nm	nm	0.0073 ± 0.0017

nm: not measured

The outfall structures exhibit tritium activity levels that vary, according to their type, between 5 and 150 Bq/L for most samples. The measurements taken offshore indicate values of between 5 and 20 Bq/L, depending on the location. These values are also impacted by discharge from the Areva site at La Hague and by tidal currents.

Flamanville NPP

At Flamanville (*Figure IV.27*), IRSN measures the tritium in the water of the discharge pond at a mean activity of 35 Bq/L. The measurements taken by the operator off the Channel coast are correlated and are, on average, approximately 10 Bq/L.

Paluel NPP

At Paluel (*Figure IV.28*), IRSN measures the tritium in the 0KRS/TR1 station where the mean activity of the tritium is 65 Bq/L. The measurements taken by the operator at sea are mostly below the decision thresholds. Only a few samples taken to the west of the outfall exceed 20 Bq/L.

Penly NPP

At Penly (*Figure IV.29*), IRSN measures the tritium in water samples from the discharge channel. The mean activity observed is 40 Bq/L. The measurements taken by the operator at sea are all below the decision thresholds, with the exception of one measurement (8.3 Bq/L) carried out in January 2010 on a sample in the vicinity of Varengeville-sur-Mer.

Gravelines NPP

At Gravelines (*Figure IV.30*), IRSN measures the tritium in the water of the sea channel where the mean activity detected is 15 Bq/L. The measurements taken by the operator at sea are below or close to the decision thresholds.

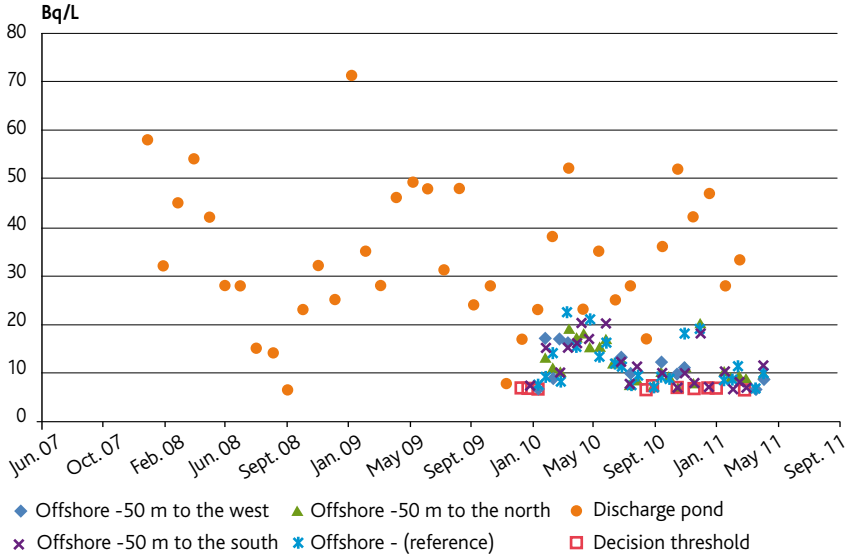

Figure IV.27 - Tritium activity measured in sea water at Flamanville (Bq/L).

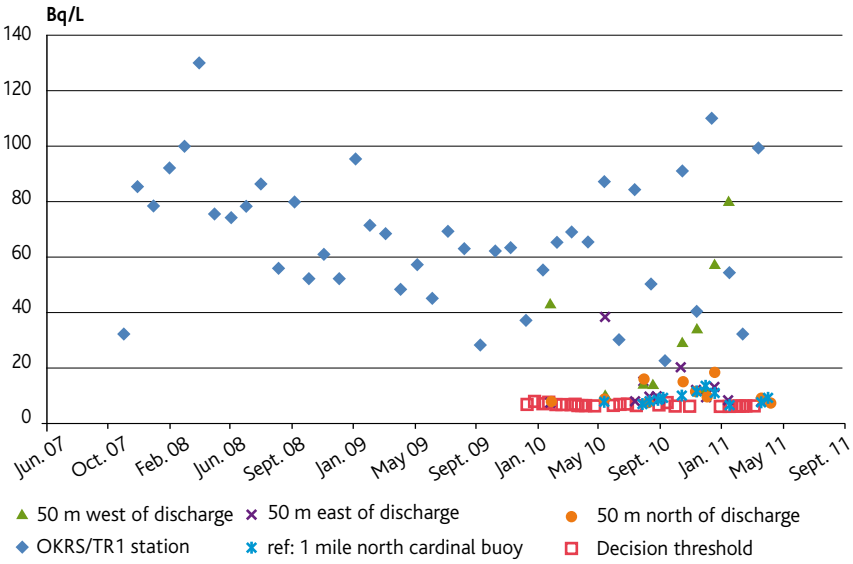

Figure IV.28 - Tritium activity measured in sea water at Paluel (Bq/L).

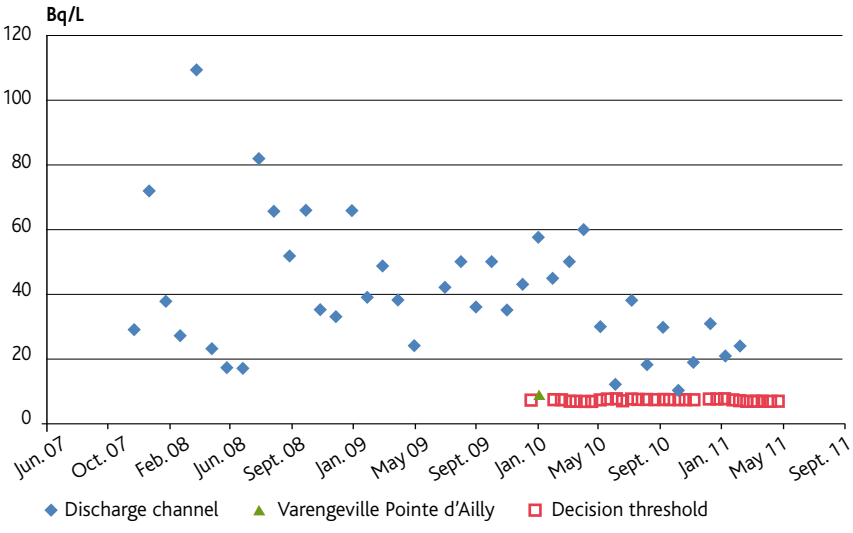

Figure IV.29 - Tritium activity measured in sea water at Penly (Bq/L).

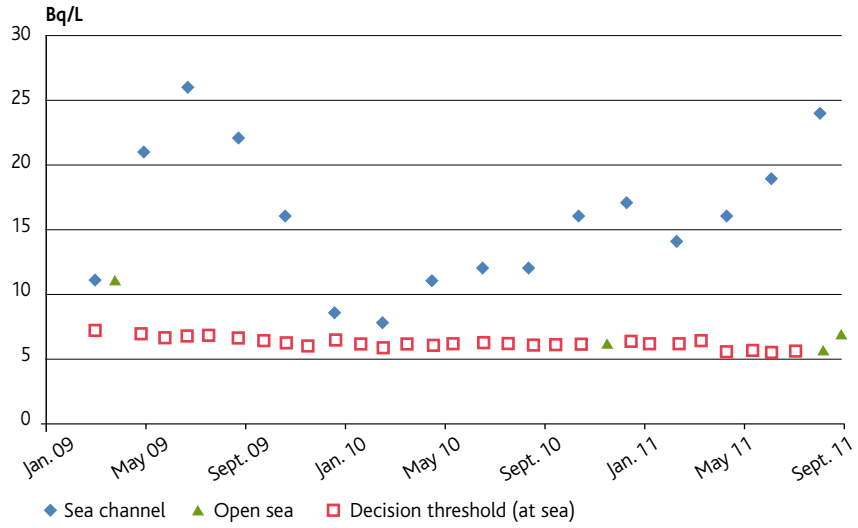

Figure IV.30 - Tritium activity measured in sea water at Gravelines (Bq/L).

Near the La Hague site

The waters of the Channel receive the liquid effluents produced by the various facilities on the La Hague plant, which, after passing through the effluent treatment stations and inspection, are discharged into the Anse des Moulinets via an underground pipe.

Iodine-129 was detected in three samples at activity levels of approximately 0.01 Bq/L taken from the port of Goury and the Anse des Moulinets, under which the liquid effluent discharge pipe from the site passes.

Since 1983, IRSN has been analyzing the sea water off the Pointe de Jardeheu. Since 1995, the improvement in liquid scintillation measuring techniques has made it possible to detect tritium at values between the decision threshold and 26 Bq/L (*Figure IV.31*). At present, the decision threshold for tritium using this technique is 1 Bq/L.

Cherbourg Naval Port

The tritium activity in the sea water collected in the vicinity of the Cherbourg Naval Port (*Figure IV.32*) was equivalent to that observed around the coast of the Cotentin peninsula.

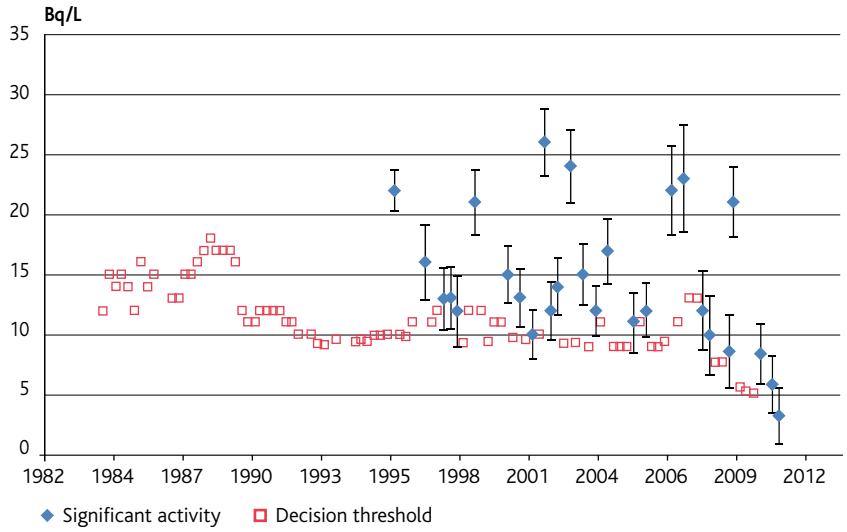

Figure IV.31 - Tritium activity measured in sea water at Pointe de Jardeheu (Bq/L).

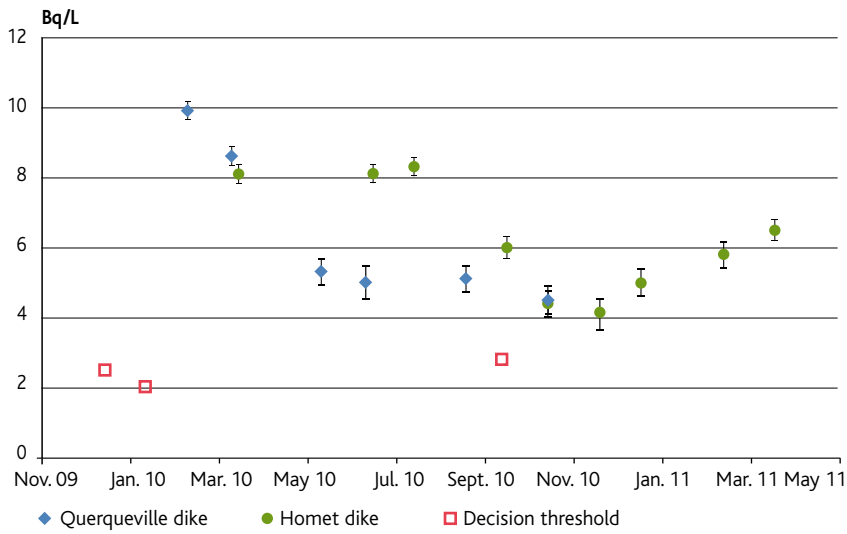

Figure IV.32 - Tritium activity measured in sea water samples from Querqueville and Le Homet dikes (Bq/L).

Sediments

Samples of marine sediments (mud, beach sand) were taken in 2010 and at the beginning of 2011 at different stations along the Channel - North Sea coast, from Roscoff to Dunkirk. The sampling frequencies varied from one station to another.

In addition to the predominantly natural radionuclides present (^{40}K, ^{228}Ac, ^{7}Be), sediment analysis indicated the presence of artificial radionuclides (^{137}Cs, ^{60}Co, ^{90}Sr, ^{238}Pu, $^{239+240}$Pu, ^{241}Am, ^{244}Cm), mainly related to past and present liquid effluent discharge from the installations at the La Hague site, as well as liquid discharge from the Sellafield site in England.

In general, the levels of activity measured remained low and did not exhibit any abnormalities. They were similar to those measured in recent years. The highest values were observed in the immediate vicinity of the outfall at La Hague. Further away, the activity levels were often close to the detection limits or the levels usually found away from any nuclear activity.

Cobalt-60 was almost systematically detected at the Penly Carteret stations with the highest activity observed in Cherbourg harbor (9.4 ± 0.9 Bq/kg dry). The activities of transuranium elements (^{238}Pu, $^{239+240}$Pu and ^{244}Cm) and strontium-90 measured in sediment samples from Cherbourg harbor and found to be slightly higher than those measured at other sampling points, confirm the sensitivity of this area with respect to discharge from the La Hague site. Cobalt-60 was no longer detected west of Granville or east of Le Tréport.

Cesium-137 was measured along the entire coast between Roscoff and Dunkirk. The highest cesium-137 activity levels were observed in the Anse des Moulinets, where the sampling station directly affected by discharge from the La Hague plant is located (maximum activity of 10.3 ± 1.2 Bq/kg dry measured in April 2010). These activity levels tended to decrease along the coast as the distance from the discharge point increased. A few dozen miles further on, the observed levels were similar to those measured in areas outside the influence of any nuclear activity. The variations observed were also related to the nature of the sediment samples taken (mud, sand), the finest having a greater tendency to bind radionuclides.

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Figure IV.33 - Collecting sediment samples.

The ^{60}Co/^{137}Cs activity ratio shown in Figure IV.34 eliminates variations in ^{60}Co and ^{137}Cs activity levels that are only related to the particle size and mineralogy of the sediment. This ratio is characteristic of the discharge from the La Hague plant, as shown in Figure IV.35, obtained in sediments from Cherbourg harbor and the Seine estuary. The discrepancy is related to the time it takes them (about ten years) to travel between Cherbourg and the Seine estuary. The wide dispersion of the values observed is explained by the short radioactive half-life of cobalt (5.27 years) with respect to cesium-137 (30.1 years).

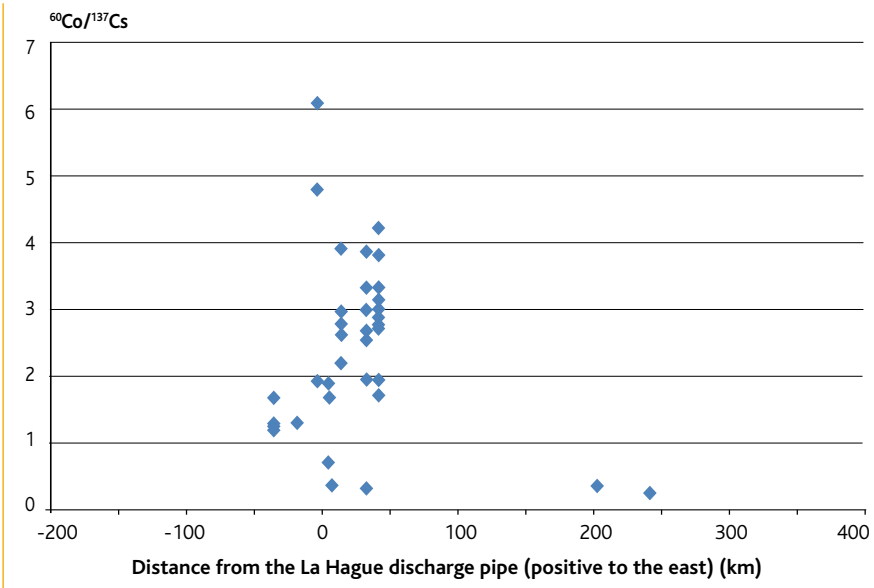

Figure IV.34 - Changes in the ^{60}Co/^{137}Cs activity ratio observed in sediment samples collected between January 2010 and May 2011 along the Channel - North Sea coast.

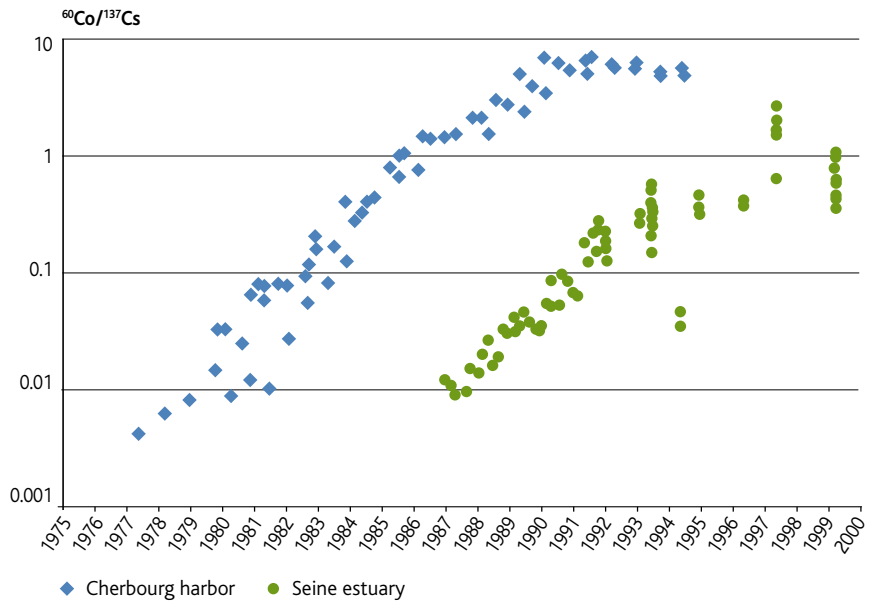

Figure IV.35 - Temporal changes in the activity ratio $^{60}Co/^{137}Cs$ observed in sediment samples from Cherbourg harbor and the Seine estuary.

Some strontium-90 activity was observed in the vicinity of the La Hague site, between 0.92 ± 0.17 at Sciotot and 2.9 ± 1.3 Bq/kg dry in Cherbourg harbor.

The alpha-emitting radionuclides (^{241}Am, ^{244}Cm, ^{238}Pu, $^{239+240}Pu$) follow a conventional distribution in the Channel and the North Sea with respect to the activities released by the reprocessing plants at La Hague and Sellafield (*Figure IV.36 to Figure IV.39*). Most of these radionuclides are no longer detected at Roscoff and Dunkirk, or exhibit very low levels of activity in the order of magnitude observed in sediment samples from areas outside the direct influence of nuclear facilities. As with cesium, the activities of transuranium elements in sediments depend on the abundance and nature of the finest fraction, often rich in argillaceous minerals. For any given site, they can vary by at least one order of magnitude between sandy and muddy sediments.

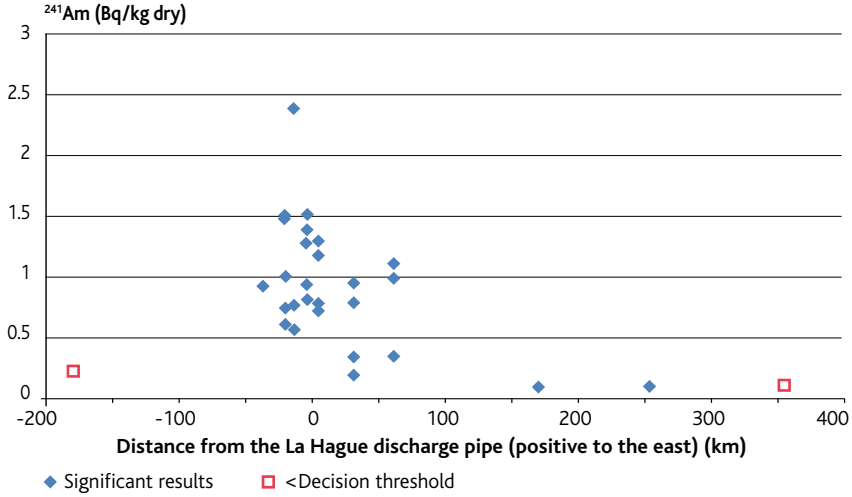

Figure IV.36 - Changes in americium-241 activity observed in sediment samples collected between January 2010 and May 2011 along the Channel - North Sea coast (Bq/kg dry).

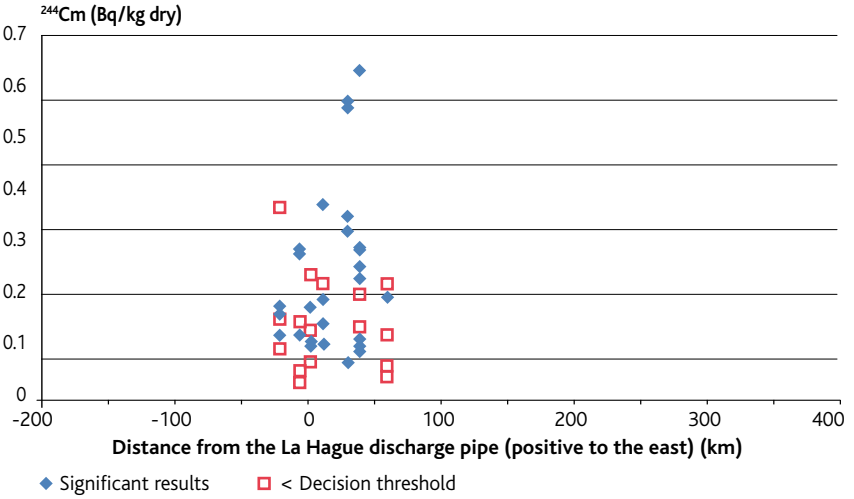

Figure IV.37 - Changes in ^{244}Cm activity observed in sediment samples collected between January 2010 and May 2011 along the Channel - North Sea coast (Bq/kg dry).

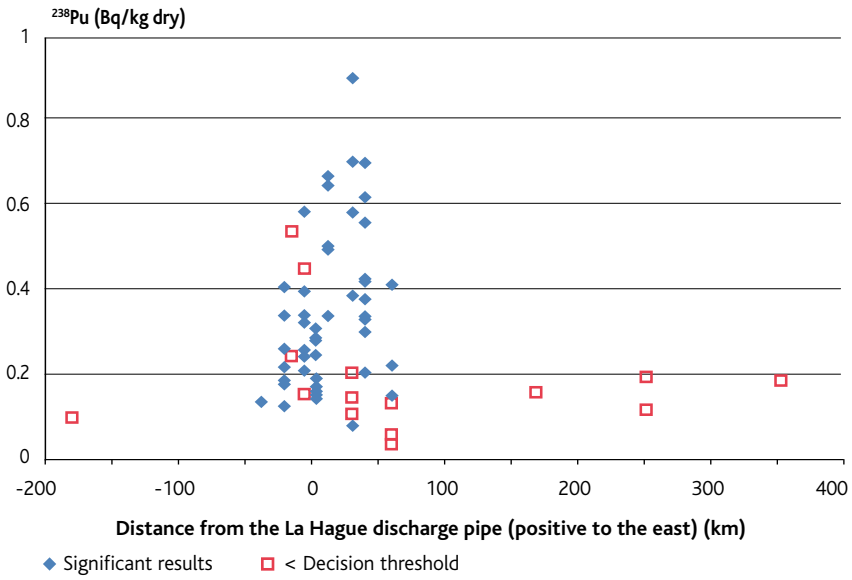

Figure IV.38 - Changes in plutonium-238 activity observed in sediment samples collected between January 2010 and May 2011 along the Channel - North Sea coast (Bq/kg dry).

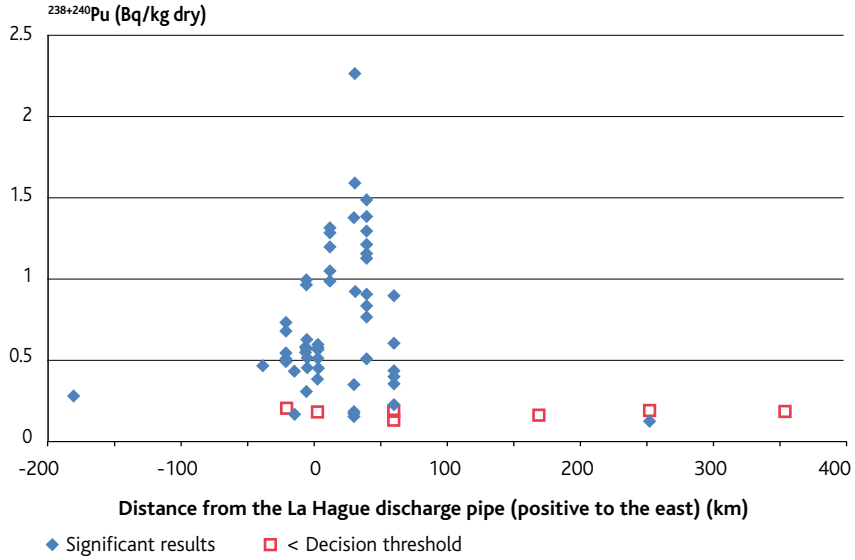

Figure IV.39 - Changes in $^{239+240}$Pu activity observed in sediment samples collected between January 2010 and May 2011 along the Channel - North Sea coast (Bq/kg dry).

In the marine environment, plutonium and americium originate from the fallout from atmospheric nuclear tests and discharge from nuclear facilities. At present, most discharge comes from spent fuel reprocessing facilities. A study of the ^{238}Pu/$^{239+240}$Pu isotope ratio identifies the sources of the plutonium: a ratio close to 0.03 is characteristic of atmospheric fallout; the Sellafield plant exhibits a ratio of approximately 0.2. The isotope ratio changes significantly in the discharge from the La Hague plant due to burnup. Figure IV.40 shows the ^{238}Pu/$^{239+240}$Pu cumulative ratio in the discharge from the La Hague plant. A maximum value close to 0.7 is currently observed in the sediments at the

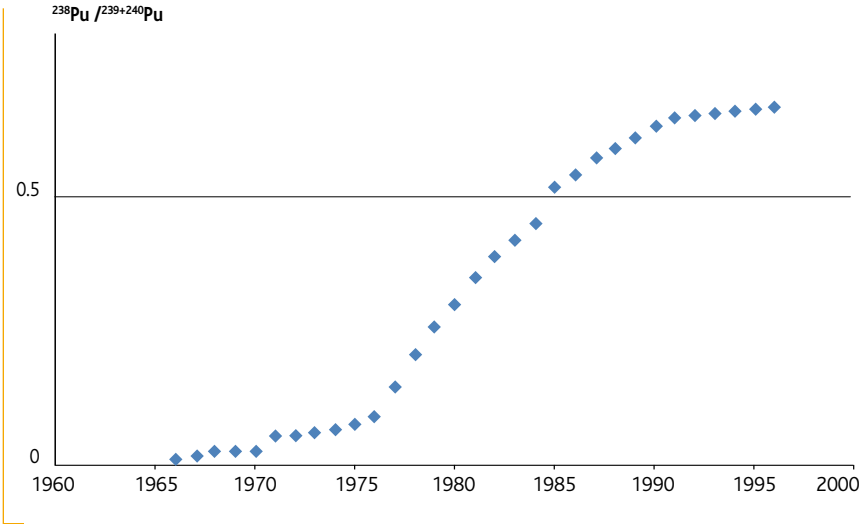

Figure IV.40 - Changes in the ^{238}Pu/$^{239+240}$Pu cumulative ratio in discharge from the La Hague plant.

center of the Channel. All the isotope ratios calculated from the measurements taken in 2010 and at the beginning of 2011 (*Figure IV.41*) revealed that the Cotentin coast showed traces of past and present liquid effluent discharge from the spent fuel reprocessing facilities at La Hague and Sellafield.

Similarly, the $^{241}Am/^{239+240}Pu$ activity ratio observed was also characteristic of discharge from the La Hague plant. The variation in the $^{241}Am/^{239+240}Pu$ cumulative ratio in the discharge from the La Hague plant (*Figure IV.42*) was close to 2 in many matrices, particularly in sediments.

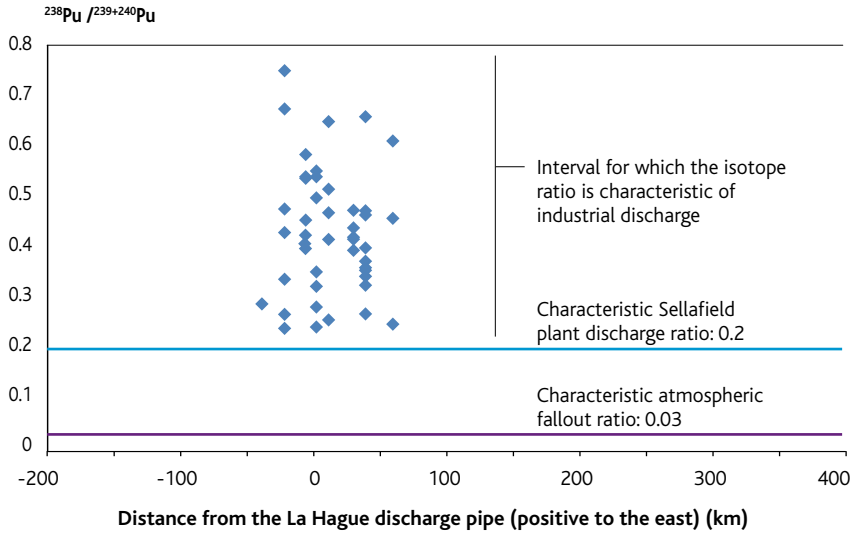

Figure IV.41 - Changes in the activity ratio $^{238}Pu/^{239+240}Pu$ observed in sediment samples collected between January 2010 and May 2011 along the Channel - North Sea coast.

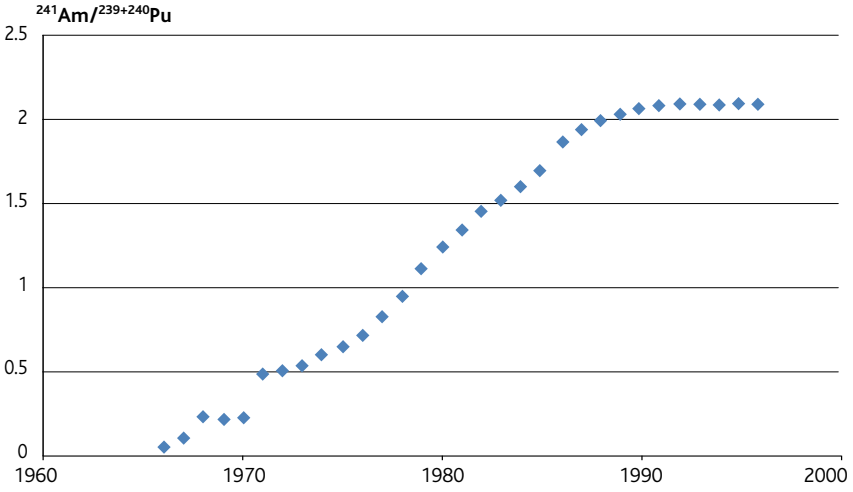

Figure IV.42 - Changes in the $^{241}Am/^{239+240}Pu$ cumulative ratio in discharge from the La Hague plant.

Seaweed

The radioactivity present in seaweed (fucus serratus, fucus vesiculosus, ulva, etc.) is regularly monitored by different stations located all along the Channel - North Sea coast, from Roscoff to Dunkirk. Apart from the fact that seaweed is used in the manufacture of products for human consumption (alginates) or can be used as a soil additive, these organisms incorporate and concentrate variations in the radionuclide content of water and are therefore a biological indicator sensitive to changes in the concentration of radioactive substances in sea water.

Figure IV.43 - Collecting seaweed samples near the La Hague plant.

Analyses of seaweed samples taken between January 2010 and April 2011 revealed the presence of different artificial radionuclides (^{137}Cs, ^{60}Co, ^{129}I, plutonium isotopes, ^{241}Am, ^{14}C, ^{3}H) with activity levels of the same order of magnitude as in recent years, which fluctuated according to the stations.

As observed on sediments, the highest values were measured at the stations closest to the La Hague outfall, in particular in the Anse des Moulinets, which is where the sampling station directly affected by discharge from the La Hague plant is located and for which maximum values were generally observed.

Cesium-137 was detected in most of the seaweed samples. Maximum activity was observed at Herquemoulin (0.78 ± 0.24 (Bq/kg dry). These low levels of activity quickly decreased as the distance from the outfall increased and reached values similar to or less than those measured in the fucus vesiculosus samples taken at Oléron, away from any nuclear facility (*Figure IV.44*).

Although its activity had decreased by a factor of more than 100 in twenty years in discharge from the nuclear facilities at La Hague, cobalt-60 was, with cesium-137, one of the few artificial gamma-emitting radionuclides that could now be detected in the marine environment west of the Cotentin (up to 3.43 ± 0.43 Bq/kg dry measured in the bay of Ecalgrain in 2010, *Figure IV.45*). The decrease in discharge activity levels was also reflected in the measurements taken. Between 1988 and 1996, the level of cobalt-60 activity measured in the fucus serratus samples from the Anse des Moulinets constantly decreased from an average of 230 Bq/kg dry in 1988 to less than 10 Bq/kg dry in 1996. From 1997 onward, the level of activity evened out (activity levels measured approximately 4 to 9 Bq/kg dry). In 2010, the levels observed in the Anse des Moulinets confirmed this trend: they varied between 0.8 ± 0.08 and 2.9 ± 0.9 Bq/kg dry. The measurement of this radionuclide in seaweed was mainly explained by the discharge from the spent fuel reprocessing facilities. Comparatively, the impact of nuclear power plants was negligible.

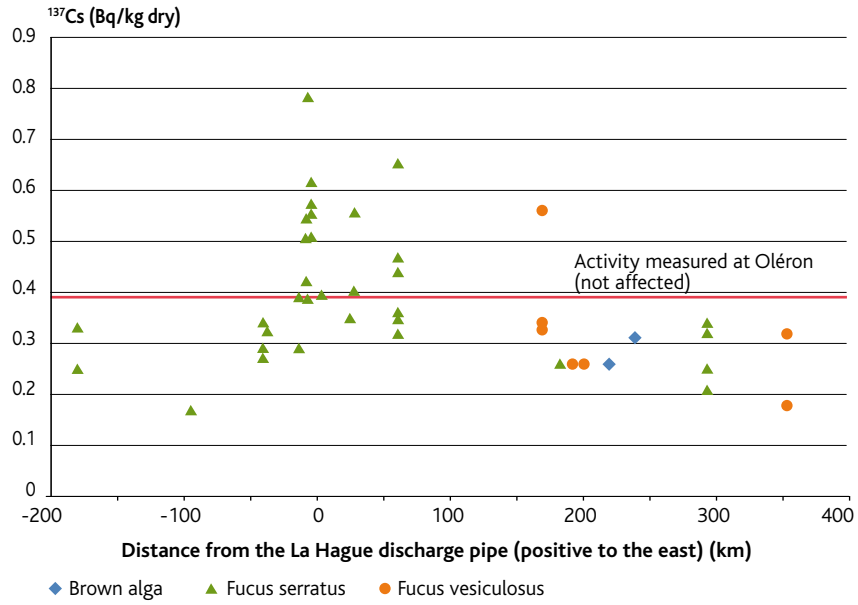

Figure IV.44 - Changes in cesium-137 activity observed in seaweed samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg dry) (values below the decision threshold are not shown on this chart).
(values below the decision threshold are not shown on this chart).

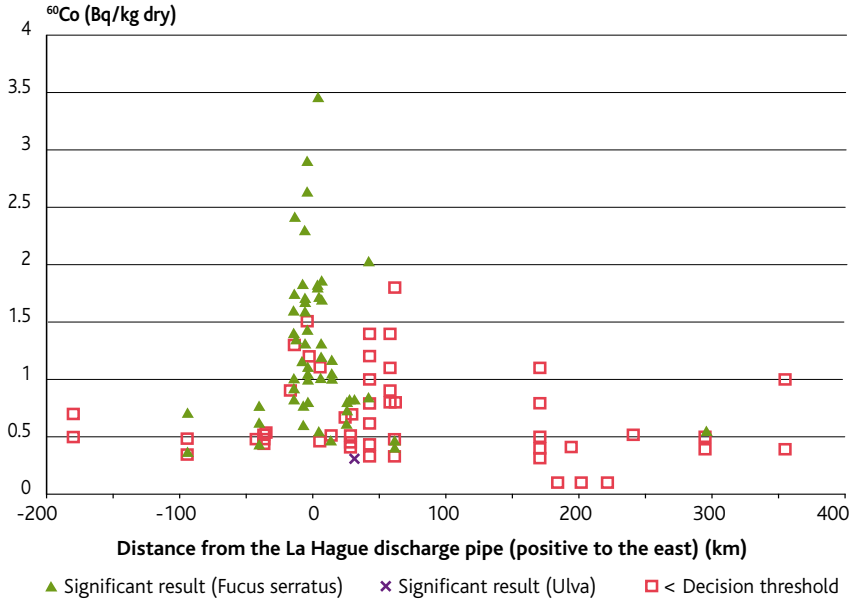

Figure IV.45 - Changes in cobalt-60 activity observed in seaweed samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg dry).

Contamination of seaweed caused by discharge from the La Hague and Sellafield plants was clearly reflected in the iodine-129 activity levels measured (*Figure IV.46*). Although less than 3.2 Bq/kg dry in seaweed samples taken west of Roscoff, the activity levels measured from Granville to Dunkirk reached 55 ± 11 Bq/kg dry at Pointe de Goury.

The slight increase in americium-241 activity levels measured in the Channel and the North Sea (between 0.025 ± 0.014 and 0.198 ± 0.049 Bq/kg dry) with respect to those measured in the Atlantic (maximum of 0.026 ± 0.01 Bq/kg dry at Concarneau) could be attributed to added concentration by discharge from the La Hague and Sellafield plants.

The same observation was made for plutonium-238, with its activity levels measured in the Channel and the North Sea varying between 0.008 ± 0.007 and 0.23 ± 0.15 Bq/kg dry (in 2010, this radionuclide was not detected in the Atlantic). Traces of ^{238}Pu were visible as far as Wimereux (0.045 ± 0.018 Bq/kg dry in May 2010).

With respect to plutonium isotopes 239 and 240, the activity levels measured in the Anse des Moulinets were more than ten times higher than those observed in the Atlantic. Figure IV.47 shows the distribution of these radionuclides along the coast, from Roscoff to Dunkirk. The ^{238}Pu/$^{239+240}$Pu isotope ratio of more than 0.2, confirmed that the radionuclides along the entire coastline came from an industrial source (*Figure IV.48*).

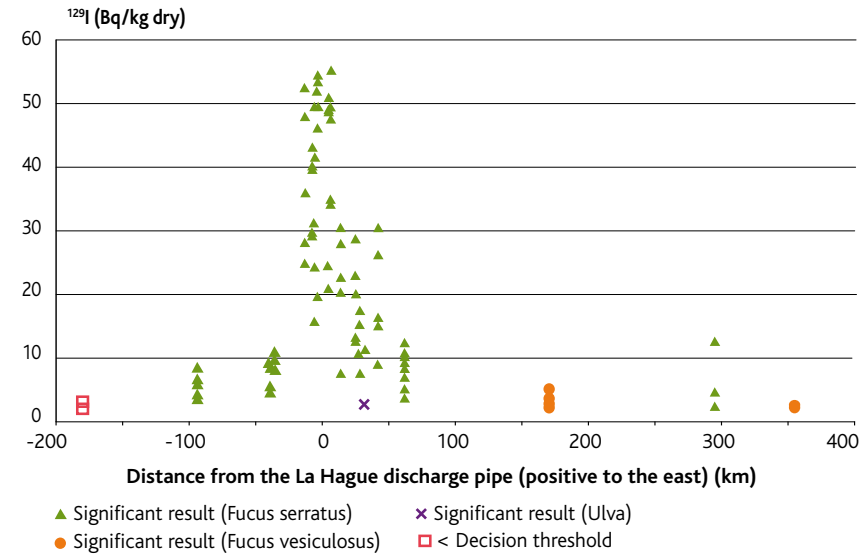

Figure IV.46 - Changes in iodine-129 activity observed in seaweed samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg dry).

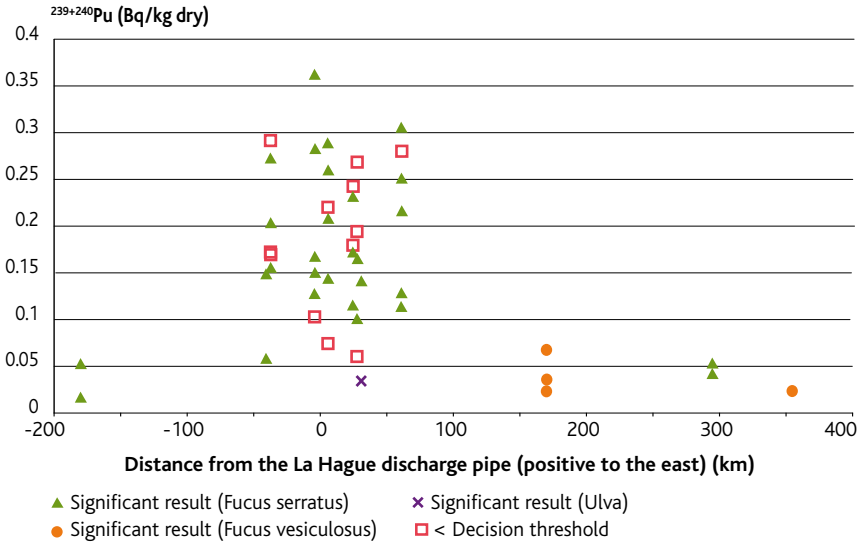

Figure IV.47 - Changes in plutonium-239+240 activity observed in seaweed samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg dry).

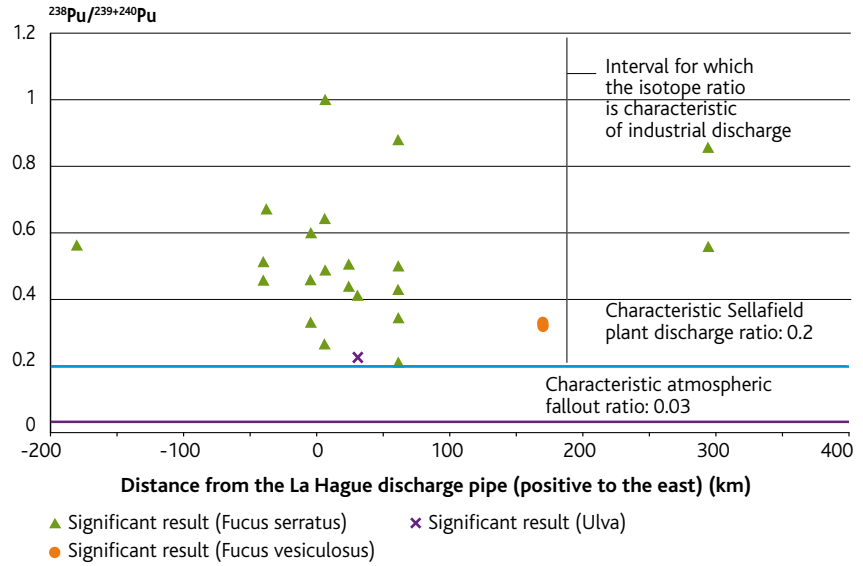

Figure IV.48 - Changes in ^{238}Pu/$^{239+240}$Pu activity observed in seaweed samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg dry).

Mollusks

Over the analysis period covered by this radiological report, measurements were performed on scallops, oysters, mussels and limpets. Among the radionuclides discharged into liquid effluents from the La Hague and Sellafield sites, the analyses revealed traces of fission products (^{137}Cs, ^{106}Ru, ^{60}Co, ^{129}I) and transuranium elements (americium and plutonium) in marine fauna (*Table IV.6*).

Cesium-137 was only occasionally detected at activity levels close to the decision thresholds, between 0.026 ± 0.009 Bq/kg wet and 0.1 ± 0.06 Bq/kg wet. Similarly, of the 141 analyses carried out along the entire Channel - North Sea coast, only two measurements exhibited traces of ruthenium-106 in limpet samples from stations particularly exposed to liquid discharge from the La Hague site: at Pointe de Goury (0.37 ± 0.16 Bq/kg wet) and Anse des Moulinets (0.94 ± 0.5 Bq/kg wet).

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Figure IV.49 - Collecting limpet samples.

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Figure IV.50 - Limpets.

Table IV.6 - Mean activity levels measured in mollusk samples collected between January 2010 and April 2011 along the Channel coast (Bq/kg wet).*

Radionuclide	West Cotentin coast		North Cotentin coast	East Cotentin coast	
	Oyster	Mussel	Scallop	Oyster	Mussel
^{40}K	62.2 ± 2.8	76.1 ± 3.8	82.6 ± 3.3	65.1 ± 3	67.7 ± 3.4
^{60}Co	< 0.08	< 0.1	0.067 ± 0.015	< 0.09	< 0.09
^{106}Ru	< 0.6	< 0.7	< 0.4	< 0.6	< 0.6
^{129}I	< 0.05	0.066 ± 0.018	0.057 ± 0.013	< 0.06	0.06 ± 0.018
^{137}Cs	< 0.06	< 0.07	< 0.045	< 0.07	< 0.07
Other gamma-emitting RNs (^{125}Sb, ^{134}Cs)	< 0.22	< 0.24	< 0.15	< 0.22	< 0.23
^{241}Am	< 0.05	< 0.06	< 0.038	< 0.05	< 0.06
^{238}Pu	0.0027 ± 0.0007	0.004 ± 0.0013	0.0076 ± 0.0016	0.0027 ± 0.0008	< 0.0049
$^{239+240}$Pu	0.0044 ± 0.0013	0.009 ± 0.0032	0.0215 ± 0.0032	0.0082 ± 0.0023	0.0152 ± 0.0044
^{14}C (Bq/kg C)	940 ± 70	470 ± 41	489 ± 33	980 ± 80	518 ± 44

** Unless otherwise stated.*

Iodine-129 and cobalt-60 activity levels measured in mollusk samples from the center of the Channel were quite typical of the discharge from the La Hague site. The highest activity levels were measured closest to the outfall at La Hague, but they quickly decreased as the distance from the site increased.

Iodine-129 was measured from Granville to Anse du Brick at activity levels of between 0.05 ± 0.022 Bq/kg wet and 1.47 ± 0.27 Bq/kg wet with the maximum value observed in the limpet samples from Anse des Moulinets (*Figure IV.51*).

The cobalt-60 activity levels observed fluctuated between 0.068 ± 0.031 and 0.77 ± 0.11 Bq/kg wet from Carteret to Barfleur (maximum observed in limpets at Siouville, *Figure IV.52*). This radionuclide was also detected in limpet samples taken near the Paluel and Penly NPPs (0.02 ± 0.01 Bq/kg wet at Saint-Valéry-en-Caux and Penly). Traces of cobalt-60 from nuclear power plant discharge added to those from spent fuel reprocessing facilities could not be excluded in the immediate vicinity of these plants (Flamanville, Paluel and Penly NPPs).

Plutonium and americium-241 activity levels were measured on mollusks (*Table IV.6*). These radionuclides were typical of the liquid effluents from the La Hague and Sellafield sites. The $^{238}Pu/^{239+240}Pu$ isotope ratio of more than 0.2, revealed that these radionuclides came from industrial sources (*Figure IV.53*).

The activity levels of these transuranium elements were significantly greater than the levels observed in the Atlantic, but nevertheless remained relatively low and in the same order of magnitude as in recent years.

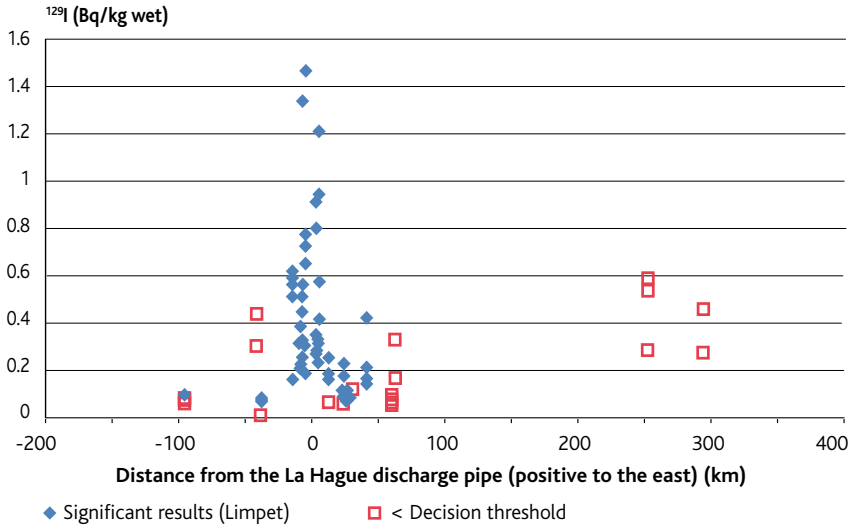

Figure IV.51 - Changes in iodine-129 activity observed in mollusk samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg wet).

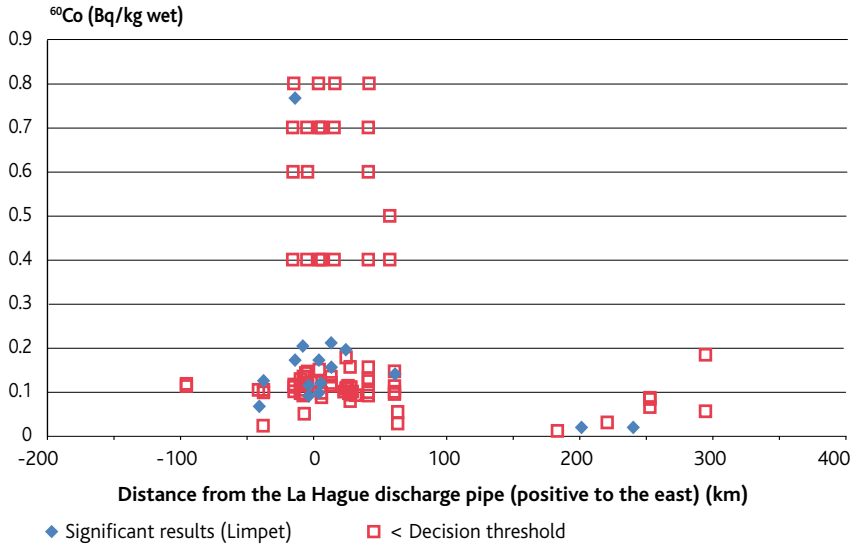

Figure IV.52 - Changes in cobalt-60 activity observed in mollusk samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg wet).

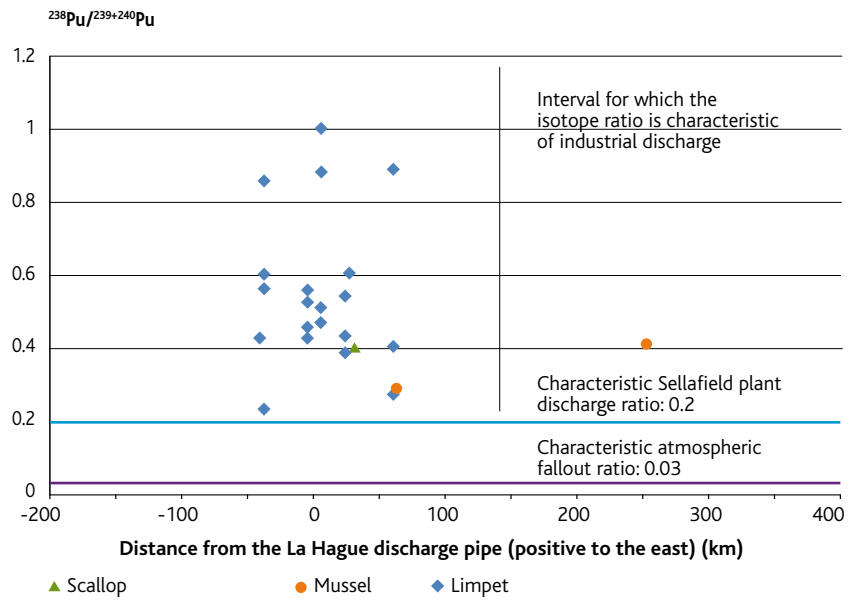

Figure IV.53 - Changes in the $^{238}Pu/^{239+240}Pu$ activity ratio observed in mollusk samples collected between January 2010 and April 2011 along the Channel - North Sea coast.

Crustaceans

Between January 2010 and April 2011, radiological analyses were performed on crustaceans (common crabs, spider crabs, lobsters) caught along the Channel coasts. They revealed the presence of artificial radionuclides (^{129}I, ^{60}Co, $^{239+240}$Pu, ^{241}Am, ^{14}C) in some samples, due to liquid discharge from the spent fuel reprocessing plants at La Hague and Sellafield (*Table IV.7*).

Iodine-129 was regularly measured at activity levels between 0.104 ± 0.048 Bq/kg wet and 1.31 ± 0.22 Bq/kg wet. Cobalt-60 and transuranium elements were only occasionally detected. Along the entire coastline, americium could only be measured twice in the 21 analyses performed (0.0065 ± 0.0025 (Bq/kg) in Carteret and 0.0057 ± 0.0031 Bq/kg wet in Urville-Nacqueville).

Table IV.7 - Mean activity levels measured in crustacean samples collected between January 2010 and April 2011 along the Channel coast (Bq/kg wet).*

Radionuclide	Roscoff	Near the La Hague site				
		Carteret harbor	Auderville Goury	West Cotentin coast		North Cotentin coast
	Common crab	Spider crab	Spider crab	Common crab	Lobster	Common crab
^{40}K	60 ± 8	83 ± 11	64 ± 8	61.3 ± 2.7	36.8 ± 1.8	60.1 ± 3
^{60}Co	< 0.1	0.144 ± 0.041	0.135 ± 0.032	0.112 ± 0.021	< 0.07	< 0.09
^{106}Ru	< 0.9	< 0.9	< 0.9	< 0.6	< 0.46	< 0.6
^{129}I	nm	< 0.17	< 0.22	0.24 ± 0.032	0.291 ± 0.03	0.097 ± 0.02
^{137}Cs	< 0.1	< 0.11	< 0.09	< 0.07	< 0.06	< 0.07
Other gamma-emitting RNs (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.98	< 0.96	< 1.07	< 0.21	< 0.17	< 0.22
^{241}Am	nm	0.0065 ± 0.0025	< 0.017	< 0.06	< 0.045	< 0.06
^{238}Pu	nm	< 0.0023	< 0.01	< 0.0034	< 0.0048	< 0.0039
$^{239+240}$Pu	nm	< 0.0023	0.018 ± 0.008	0.0049 ± 0.0012	< 0.0048	< 0.0034
^{14}C (Bq/kg C)	nm	nm	nm	491 ± 31	374 ± 20	328 ± 25

Radionuclide	Near Cherbourg naval port		Near Paluel NPP		Near Penly NPP	
	Urville - Nacqueville Hameau de Nacqueville	Tourlaville	St-Pierre-en-Port	Paluel	Vasterival	Penly
	Common crab	Common crab	Spider crab	Spider crab	Spider crab	Common crab
^{40}K	100 ± 13	62 ± 8	55 ± 8	61 ± 8	58 ± 6	65 ± 7
^{60}Co	< 0.17	< 0.09	< 0.06	< 0.05	< 0.1	< 0.03
^{106}Ru	< 1.4	< 0.8	nm	nm	nm	nm
^{129}I	0.25 ± 0.11	< 0.15	nm	nm	nm	nm
^{137}Cs	< 0.21	< 0.09	< 0.04	< 0.1	< 0.1	< 0.08
Other gamma-emitting RNs (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{54}Mn)	< 1.85	< 1.06	< 0.14	< 0.13	< 0.13	< 0.17
^{241}Am	0.0057 ± 0.0031	< 0.032	nm	nm	nm	nm
^{238}Pu	< 0.0031	< 0.01	nm	nm	nm	nm
$^{239+240}$Pu	< 0.0046	< 0.01	nm	nm	nm	nm
^{14}C (Bq/kg C)	nm	nm	nm	nm	nm	nm

** Unless otherwise stated.*
nm: not measured

Fish

Fish of different species were caught between February 2010 and April 2011 in the Channel, off Roscoff and near the main nuclear facilities along the coast (La Hague site, Cherbourg Naval Port, Paluel and Penly NPPs).

Table IV.8 shows that traces of cesium-137 were present in most samples, with low levels of activity between 0.06 ± 0.01 Bq/kg wet and 0.31 ± 0.03 Bq/kg wet. They were relatively close to those observed off the Atlantic coast. Other artificial radionuclides (^{129}I, ^{241}Am, HTO) attributable to liquid effluent discharge from the reprocessing facilities at La Hague in France and Sellafield in England were measured in some samples. Iodine-129 activity levels measured in four fish caught in the vicinity of the La Hague site were between 0.035 ± 0.018 Bq/kg wet and 0.68 ± 0.13 Bq/kg wet (38 measurements in total were carried out in the Channel over the period in question). Similarly, of the 36 samples analyzed along the entire coastline, only one sample of plaice caught in Cherbourg harbor in February 2010 exhibited traces of americium-241 (0.0033 ± 0.0027 Bq/kg wet).

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Figure IV.54 - Dissecting a plaice before analysis.

Table IV.8 - Mean activity levels measured in samples of fish caught in the Channel between February 2010 and April 2011 (Bq/kg wet).*

Radionuclide	Roscoff	Near the La Hague site					
		Carteret	Auderville	Barfleur	Cotentin west coast	Cotentin west coast	Cotentin west coast
	Skate	Dogfish	Mackerel	Spotted dogfish	Fish	Fish	Fish
^{40}K	87 ± 11	85 ± 10	120 ± 15	78 ± 9	117.4 ± 3.3	95.1 ± 3	88.9 ± 2.8
^{60}Co	< 0.022	< 0.03	< 0.024	< 0.026	< 0.09	< 0.07	< 0.06
^{106}Ru	< 0.16	< 0.23	< 0.17	< 0.19	< 0.6	< 0.43	< 0.38
^{129}I	< 0.03	< 0.04	< 0.032	< 0.037	0.065 ± 0.009	< 0.04	0.045 ± 0.007
^{137}Cs	0.151 ± 0.021	0.102 ± 0.03	0.128 ± 0.019	0.122 ± 0.019	0.086 ± 0.012	0.154 ± 0.018	0.082 ± 0.012
Other gamma-emitting RNs (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.22	< 0.35	< 0.20	< 0.24	< 0.22	< 0.16	< 0.15
^{241}Am	nm	nm	< 0.0027	< 0.007	< 0.05	< 0.041	< 0.04
^{238}Pu	nm	nm	< 0.0013	< 0.0021	< 0.0042	< 0.0038	< 0.0033
$^{239+240}$Pu	nm	nm	< 0.0013	< 0.0021	< 0.004	< 0.0031	< 0.0032
^{14}C (Bq/kg C)	252 ± 1.4	358 ± 1.7	307 ± 1.4	298.5 ± 1.7	285 ± 13	274 ± 24	270 ± 14
HTO	< 3.6	5.3 ± 1.5	< 2.9	4.1 ± 1.5	nm	nm	nm
OBT	nm	nm	1.32 ± 0.07	nm	nm	nm	nm

** Unless otherwise stated.*
nm: not measured

Table IV.8 (continued) - Mean activity levels measured in samples of fish caught in the Channel between February 2010 and April 2011 (Bq/kg wet).*

Radionuclide	Near Cherbourg naval port		Near Paluel NPP			Near Penly NPP		
	Urville - Nacqueville	Cherbourg	St-Pierre-en-Port	Paluel		Vasterival	Penly	Le Tréport
	Wrasse	Plaice	Sea bass	Sea bass	Turbot	Dover sole	Dover sole	Plaice
^{40}K	89 ± 11	92 ± 11	130 ± 14	120 ± 13	94 ± 9	140 ± 14	93 ± 9	97 ± 12
^{60}Co	< 0.038	< 0.038	< 0.01	< 0.01	< 0.02	< 0.02	< 0.01	< 0.029
^{106}Ru	< 0.31	< 0.31	nm	nm	nm	nm	nm	< 0.21
^{129}I	< 0.049	< 0.049	nm	nm	nm	nm	nm	< 0.041
^{137}Cs	0.105 ± 0.02	0.093 ± 0.019	0.31 ± 0.03	0.28 ± 0.03	0.08 ± 0.01	0.07 ± 0.02	0.06 ± 0.01	0.064 ± 0.027
Other gamma-emitting RNs (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.48	< 0.55	< 0.02	< 0.02	< 0.04	< 0.08	< 0.04	< 0.23
^{241}Am	< 0.005	0.0033 ± 0.0027	nm	nm	nm	nm	nm	< 0.006
^{238}Pu	< 0.005	< 0.004	nm	nm	nm	nm	nm	< 0.006
$^{239+240}$Pu	< 0.005	< 0.004	nm	nm	nm	nm	nm	< 0.006
^{14}C (Bq/kg C)	414.5 ± 2	287.5 ± 1.4	nm	nm	nm	nm	nm	365.2 ± 1.7
HTO	< 3.6	< 3.5	nm	nm	nm	nm	nm	< 16
OBT	0.818 ± 0.042	nm	nm	nm	nm	nm	nm	0.46 ± 0.09

Atlantic coast

The Atlantic coast was monitored between Arcachon and Brest, as described below.

Sea water

Atlantic coast

On the Atlantic coast, tritium was measured in concentrations significantly lower than those measured in the North Sea, except in the estuaries of rivers on which NPPs are located (Loire and Garonne). Very low levels of residual cesium-137 dating back to Chernobyl and fallout from atmospheric nuclear weapons tests could still be measured in the Atlantic Ocean at activity levels of just a few mBq/L (*Table IV.9*).

Table IV.9 - Tritium and cesium-137 activity levels in water samples from the Atlantic (Bq/L).

Radionuclide	Arcachon	Pornichet
Tritium	0.158 ± 0.007	6.0 ± 2.4
Cesium-137	0.0054 ± 0.0016	0.0076 ± 0.0018

nm: not measured

Brest naval port- Île Longue

No artificial radionuclide was detected in the sea water samples taken in the vicinity of the Brest naval port during the period in question.

Sediments

Atlantic coast

In 2010 and at the beginning of 2011, samples of marine sediments were taken every six months at Pornichet and Oléron and annually at Arcachon (*Table IV.10*).

Potassium-40 was the main gamma-emitting natural radionuclide measured at activities of between 168 ± 16 and 520 ± 50 Bq/kg dry. Cesium-137 and plutonium isotopes 239 and 240, attributable to fallout from atmospheric nuclear tests, were also observed in these samples. The cesium-137 concentrations measured in the samples collected were low (maximum 3.32 ± 0.32 Bq/kg dry in Oléron), or even below the decision thresholds in Arcachon. The variability observed was mainly due to the diversity of the matrices sampled (sand in Arcachon, mud in Oléron).

The plutonium-239+240 activity levels in marine sediments reached 0.12 ± 0.07 Bq/kg dry in Oléron and 0.17 ± 0.1 Bq/kg dry in Pornichet. The activity of these transuraniumelements remained below the decision thresholds in Arcachon.

Brest naval port- Île Longue

Annual, quarterly, bimonthly or monthly samples of sediments were taken from seven stations in Brest harbor (*Table IV.11*).

Table IV.10 - Mean activity levels measured in sediment samples from the Atlantic coast (Bq/kg dry).

Radionuclide	Arcachon	Oléron	Pornichet
^{40}K	188 ± 14	228 ± 15	192 ± 11
^{60}Co	< 0.2	< 0.16	< 0.12
^{137}Cs	< 0.15	0.309 ± 0.049	0.101 ± 0.028
^{228}Ac	4 ± 0.6	4.96 ± 0.48	7.7 ± 0.6
^{241}Am	< 0.1	< 0.16	< 0.21
^{238}Pu	< 0.22	< 0.11	< 0.21
$^{239+240}$Pu	< 0.22	0.12 ± 0.07	0.17 ± 0.1

The radioactivity measured was inherently natural (^{40}K, ^{228}Ac). Among the artificial radionuclides measured, only traces of cesium-137 from past atmospheric fallout were detected almost systematically in all the samples with activity levels between 0.17 ± 0.08 Bq/kg dry and 2.89 ± 0.38 Bq/kg dry.

Other artificial radionuclides were occasionally measured in samples from Anse du Fret: cobalt-60, strontium-90, americium-241 and plutonium-239+240. Cobalt-60 was detected occasionally in activity levels ranging from 0.48 ± 0.17 and 1.38 ± 0.24 Bq/kg dry (three of the 18 tests conducted between January 2010 and May 2011 had measurements above the decision thresholds). The strontium-90 activity of one of the three samples was 7.9 ± 1.1 Bq/kg dry.

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Figure IV.55 - First sieving of sediment samples on board the French Navy's Palingrin II near Brest.

Table IV.11 - Mean activity levels measured in sediment samples collected in the vicinity of Brest naval port (Bq/kg dry).

Radionuclide	Brest		Plougastel-Daoulas		Crozon	Roscanvel	
	Saint-Anne du Portzic	Rade-Abri	Kéraliou	Banc du Caro	Anse du Fret	Bay of Roscanvel	Roscanvel harbor
	Beach sand	Marine sediment	Beach sand	Marine sediment	Marine sediment	Marine sediment	Beach sand
^{40}K	415 ± 16	518 ± 10	461 ± 16	362 ± 15	273.7 ± 3.6	304 ± 8	316 ± 8
^{60}Co	< 0.17	< 0.22	< 0.09	< 0.21	0.194 ± 0.023	< 0.14	< 0.11
^{137}Cs	0.45 ± 0.16	2.77 ± 0.16	0.17 ± 0.08	1.16 ± 0.24	0.655 ± 0.045	0.92 ± 0.12	0.18 ± 0.06
^{228}Ac	13.7 ± 2	23.4 ± 1.6	21.5 ± 2.7	17.3 ± 2.5	9.1 ± 0.6	17.9 ± 2.5	18.2 ± 1.7
^{90}Sr	nm	nm	nm	nm	0.43 ± 0.12	nm	nm
^{241}Am	nm	nm	nm	nm	0.2 ± 0.08	nm	nm
^{238}Pu	nm	nm	nm	nm	< 0.14	nm	nm
$^{239+240}$Pu	nm	nm	nm	nm	0.58 ± 0.17	nm	nm

nm: not measured

Seaweed

Atlantic coast

As with sediments, the radioactivity measured in seaweed samples from the Atlantic coast was almost exclusively represented by potassium-40 (between 690 ± 70 Bq/kg dry and 1620 ± 140 Bq/kg dry) and, depending on the stations, by a few traces of artificial radionuclides such as cesium-137, americium-241 and plutonium isotopes (*Table IV.12*). The presence of these artificial radionuclides in seaweed found on French coasts was due to fallout from atmospheric nuclear weapons tests.

Brest naval port- Île Longue

Samples of seaweed (fucus serratus, fucus spiralis, fucus vesiculosus) were regularly collected from various points in Brest harbor. The natural radioactivity measured in seaweed was mainly due to potassium-40 (1,314 ± 12 Bq/kg dry on average). Cesium-137 was occasionally detected in fucus vesiculosus samples from the Sainte-Anne du Portzic and Kéraliou stations at levels very close to the decision thresholds (0.31 ± 0.21 Bq/kg dry in March 2011 and 0.42 ± 0.23 Bq/kg dry in January 2011 respectively). The activities of artificial radionuclides detected (^{134}Cs, ^{60}Co, ^{58}Co, ^{54}Mn) remained below the decision thresholds (*Table IV.13*).

Table IV.12 - Mean activity levels measured in seaweed samples from the Atlantic coast (Bq/kg dry).*

Radionuclide	Oléron	Pornichet	Concarneau
	Fucus vesiculosus	Fucus vesiculosus	Fucus serratus
^{40}K	1060 ± 60	881 ± 50	1,090 ± 50
^{60}Co	< 0.35	< 0.34	< 0.47
^{137}Cs	0.39 ± 0.06	0.38 ± 0.06	0.26 ± 0.06
Other gamma-emitting RNs (^{106}Ru, ^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{54}Mn)	<4.8	< 4.5	< 6.1
^{241}Am	< 0.016	< 0.044	0.026 ± 0.01
^{238}Pu	< 0.014	< 0.021	< 0.015
$^{239+240}$Pu	0.02 ± 0.007	0.032 ± 0.011	0.022 ± 0.008
^{14}C (Bq/kg C)	236.5 ± 0.8	241.3 ± 0.8	241.7 ± 1.7
HTO (Bq/kg wet)	< 3.8	< 4.5	< 3.5
OBT	0.216 ± 0.006	0.73 ± 0.037	nm

** Unless otherwise stated.*
nm: not measured

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Figure IV.56 - Collecting seaweed samples on board the Palingrin II near Brest.

Table IV.13 - Mean activity levels measured in seaweed samples collected in the vicinity of Brest naval port (Bq/kg dry).*

Radionuclide	Brest Sainte-Anne-du-Portzic		Plougastel-Daoulas Kéraliou		Crozon Anse du Fret			Roscanvel Roscanvel harbor	
	Fucus serratus	Fucus vesiculosus	Fucus serratus	Fucus vesiculosus	Fucus serratus	Fucus spiralis	Fucus vesiculosus	Fucus serratus	Fucus vesiculosus
^{40}K	1,440 ± 50	1,090 ± 38	1,620 ± 60	1,243 ± 44	1,445 ± 28	1,057 ± 42	1,192 ± 30	1,785 ± 43	1,231 ± 30
^{60}Co	< 0.29	< 0.34	< 0.31	< 0.28	< 0.34	< 0.3	< 0.26	< 0.32	< 0.27
^{137}Cs	< 0.25	0.31 ± 0.21	< 0.29	0.42 ± 0.23	< 0.31	< 0.27	< 0.26	< 0.29	< 0.26
Other gamma-emitting RNs (^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.55	< 0.59	< 0.29	< 0.27	< 1.42	< 0.51	< 0.26	< 0.62	< 0.54
^{14}C (Bq/kg C)	nm	nm	nm	nm	244.2 ± 1.4	nm	nm	nm	nm

** Unless otherwise stated.*
nm: not measured

Mollusks

Atlantic coast

The radioactivity measured in mollusks caught annually or biannually along the Atlantic coast was mostly natural (^{40}K, ^{210}Po). Potassium-40 activity varied between 23.4 ± 2.7 Bq/kg wet and 60 ± 5 Bq/kg wet and polonium-210 activity between 8.6 ± 0.9 Bq/kg wet and 31.4 ± 2.5 Bq/kg wet, depending on the species and sampling stations (*Table IV.14*).

Traces of americium-241 were measured in mussel samples from Oléron. Similarly, traces of plutonium-239+240 from atmospheric fallout from past atmospheric tests were present in almost all the samples analyzed

Table IV.14 - Mean activity levels measured in mollusk samples from the Atlantic coast (Bq/kg wet).*

Radionuclide	Arcachon	Oléron		Pornichet	Concarneau
	Oyster	Oyster	Mussel	Mussel	Mussel
^{40}K	26.6 ± 1.9	26 ± 2.5	50.7 ± 4.9	60 ± 5	40.1 ± 2.7
^{60}Co	< 0.029	< 0.024	< 0.05	< 0.037	< 0.04
^{137}Cs	< 0.048	< 0.02	< 0.042	< 0.033	< 0.035
Other gamma-emitting RNs (^{106}Ru, ^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.46	< 0.4	< 0.78	< 0.6	< 0.68
^{210}Po	31.4 ± 2.5	8.6 ± 0.9	31.2 ± 3.1	17 ± 2.4	14.1 ± 1.5
^{241}Am	< 0.0027	nm	0.0024 ± 0.0016	< 0.0024	< 0.002
^{238}Pu	< 0.0017	nm	< 0.0016	< 0.0013	< 0.0015
$^{239+240}$Pu	0.0014 ± 0.001	nm	0.0017 ± 0.001	< 0.0013	0.0014 ± 0.0009

** Unless otherwise stated.*
nm: not measured

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Figure IV.57 - Weighing limpet samples.

Brest naval port- Île Longue

No gamma-emitting radionuclides of artificial origin were detected in mollusk samples from Brest harbor (*Table IV.15*).

Table IV.15 - Mean activity levels measured in mollusk samples collected in the vicinity of the Brest naval port (Bq/kg wet).

Radionuclide	Brest	Plougastel-Daoulas		Logonna-Daoulas	Lanvéoc	Crozon		Roscanvel	
	Saint-Anne-du-Portzic	Kéraliou	Banc du Caro		Pointe de Lanvéoc	Anse du Fret		Bay of Roscanvel	Roscanvel harbor
	Limpet	Limpet	Scallop	Oyster	Mussel	Oyster	Limpet	Limpet	Limpet
^{40}K	66.1 ± 3.2	66.5 ± 4.7	66 ± 6	29.4 ± 4.5	36 ± 6	33.9 ± 1.3	71.1 ± 1.9	68.4 ± 5	49.4 ± 2.6
^{60}Co	< 0.046	< 0.11	< 0.14	< 0.09	< 0.1	< 0.023	< 0.07	< 0.11	< 0.042
^{137}Cs	< 0.044	< 0.1	< 0.12	< 0.08	< 0.1	< 0.022	< 0.06	< 0.12	< 0.042
Other gamma-emitting RNs (^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.09	< 0.11	< 0.13	< 0.23	< 0.4	< 0.023	< 0.11	< 0.12	< 0.09

Crustaceans

Atlantic coast

In 2010, the radioactivity measured in common crabs caught annually in Concarneau consisted predominantly of potassium-40, with specific activity of 56 ± 8 Bq/kg wet.

The activities of other gamma-emitting radionuclides were below the decision thresholds of the measuring instruments used.

Brest naval port- Île Longue

As was the case with mollusks, no gamma-emitting radionuclide of artificial origin was detected in the annual samples (*Table IV.16*):
- common crabs from Rade-Abri;
- common crabs and spider crab samples from Anse du Fret;
- spider crabs from the Bay of Roscanvel.

Table IV.16 - Mean activity levels measured in crustacean samples collected in the vicinity of Brest naval port (Bq/kg wet).

Radionuclide	Brest Rade-Abri	Crozon Anse du Fret		Roscanvel Bay of Roscanvel
	Common crab	Common crab	Spider crab	Spider crab
^{40}K	58 ± 7	30.2 ± 1.6	56.4 ± 2.1	32.3 ± 1.3
^{60}Co	< 0.08	< 0.024	< 0.08	< 0.034
^{137}Cs	< 0.08	< 0.027	< 0.08	< 0.04
Other gamma-emitting RNs (^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.39	< 0.026	< 0.14	< 0.11

Fish

Atlantic coast

In 2010, the radioactivity measured in fish caught off the Atlantic cost consisted predominantly of potassium-40, whose specific activity was approximately 100 Bq kg wet. Apart from a few traces of cesium-137 from past atmospheric fallout measured in Oléron and Concarneau, other gamma-emitting radionuclide activity was below the decision thresholds (*Table IV.17*).

Brest naval port- Île Longue

Radiological analyses of marine fauna were regularly performed at various points in Brest harbor. Apart from naturally occurring potassium-40 in all the samples, traces of cesium-137 were detected in most fish samples (*Table IV.18*). No other gamma-emitting radionuclides (^{134}Cs, ^{58}Co, ^{60}Co, ^{54}Mn) were detected.

*Table IV.17 - Activity levels measured in samples of fish caught off the Atlantic coast (Bq/kg wet)**

Radionuclide	Arcachon	Oléron	Concarneau
	Mullet	Fish	Fish
^{40}K	95 ± 12	95 ± 12	107 ± 13
^{60}Co	< 0.034	< 0.043	< 0.033
^{137}Cs	< 0.041	0.045 ± 0.016	0.22 ± 0.031
Other gamma-emitting RNs (^{106}Ru, ^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{54}Mn	< 0.57	< 0.73	< 0.57
^{14}C (Bq/kg C)	238.2 ± 1.4	237.8 ± 1.4	247.2 ± 1.7
HTO	< 3.4	< 3.5	< 3.7
OBT	0.054 ± 0.005	0.0659 ± 0.0047	nm

** Unless otherwise stated.*
nm: not measured

Table IV.18 - Mean activity levels measured in samples of fish caught in the vicinity of Brest naval port (Bq/kg wet).

Radionuclide	Brest				Plougastel-Daoulas
	Rade-Abri	Grande Digue	Bouée du Renard		Banc du Caro
	Conger	Conger	Dogfish	Cuckoo wrasse	Dover sole
^{40}K	126 ± 15	59.8 ± 2.9	108 ± 13	71 ± 9	97 ± 12
^{60}Co	< 0.034	< 0.09	< 0.05	< 0.09	< 0.07
^{137}Cs	0.087 ± 0.017	0.129 ± 0.039	0.095 ± 0.044	0.069 ± 0.03	< 0.06
Other gamma-emitting RNs (^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.14	< 0.08	< 0.23	< 0.3	< 0.23

Radionuclide	Crozon					Roscanvel
	Anse du Fret					Bay of Roscanvel
	Conger	Skate	Dogfish	Wrasse	Unidentified fish	Dogfish
^{40}K	64.2 ± 2.8	84.2 ± 4.4	67.4 ± 1.9	83.1 ± 4.7	101.1 ± 4.5	55.7 ± 2.3
^{60}Co	< 0.1	< 0.07	< 0.07	< 0.07	< 0.06	< 0.05
^{137}Cs	0.105 ± 0.03	0.09 ± 0.05	0.069 ± 0.018	0.13 ± 0.05	< 0.07	0.088 ± 0.033
Other gamma-emitting RNs (^{134}Cs, ^{58}Co, ^{54}Mn)	< 0.15	< 0.15	< 0.11	< 0.13	< 0.13	< 0.05

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Carbon-14 in the marine and coastal environment:

Carbon-14 is one of the radioactive isotopes of carbon. Its presence in the environment arises from its natural production via the action of cosmic neutrons on nitrogen atoms in the stratosphere and in the upper troposphere and also from anthropogenic activity (atmospheric nuclear explosions, nuclear industries).

Spent fuel reprocessing plants and, to a lesser extent, nuclear power plants, are today mainly responsible for anthropogenic carbon-14 discharge in the environment. Liquid carbon-14 discharge from the Areva plant at La Hague in the marine environment steadily increased between 1985 and 2000 to about 10 TBq (10^{13} Bq) in 2000. In 2010, it rose to 7.34 (TBq) (7.34×1012 Bq). In the same year, the Sellafield plant in England discharged 4.4 (TBq) (4.4×10^{12} Bq) of ^{14}C into the marine environment. In comparison, the annual worldwide production rate of natural ^{14}C was approximately 1,540 (TBq) (1.540 × 10^{15} Bq).

In the environment, carbon-14 has the same behavior as the stable isotope ^{12}C (which represents 99% of carbon): it follows the carbon cycle. It is therefore found in carbon-based living tissue.

Between January 2010 and April 2011, measurements were conducted to detect this radionuclide in different matrix samples (seaweed, mollusks, fish) collected along the coasts of metropolitan France. The measurements included both natural carbon and carbon added as a result of the activity levels of fuel reprocessing plants at La Hague and Sellafield as well as from nuclear power plants. The impact assessment had to take the natural component into account.

In general, the results showed that the traces of ^{14}C in living organism samples from the Channel and the North Sea, which are attributable to liquid discharge from the La Hague and Sellafield plants, were higher than those from NPPs along the Channel coasts (Flamanville, Paluel Penly). The highest activity levels were concentrated at the promontory of La Hague and decreased rapidly, as the distance from the liquid discharge outfall at La Hague increased, to levels close to the present background (about 240 Bq/kg of carbon). The activities measured off the Atlantic and Mediterranean coasts were broadly similar to the environmental background.

Carbon-14 in seaweed

*The impact of reprocessing plants was mainly visible in the immediate vicinity of the La Hague site, from Carteret to Barfleur. The highest values were observed in Anse des Moulinets, which is where the sampling station directly affected by discharge from the site is located and for which maximum values were generally observed (average carbon activity of 524 ± 29 Bq/kg measured in fucus serratus, more than twice the levels usually found away from any nuclear activity). In Roscoff, Honfleur, Wimereux and Dunkirk, the levels observed were similar to the background (*Figure IV.58*).*

Carbon-14 in mollusks

Between January 2010 and April 2011, the quantification of carbon-14 in mollusks focused on the annual, twice-yearly or quarterly sampling of limpets, mussels, oysters and scallops.

*The activity levels measured in mollusk samples collected near the La Hague site, from Carteret to Barfleur, were almost four times higher than those typically observed in a natural environment away from any nuclear facility, reflecting the impact of liquid discharge from spent fuel reprocessing facilities on marine aquatic fauna (*Figures IV.59 and IV.60*).*

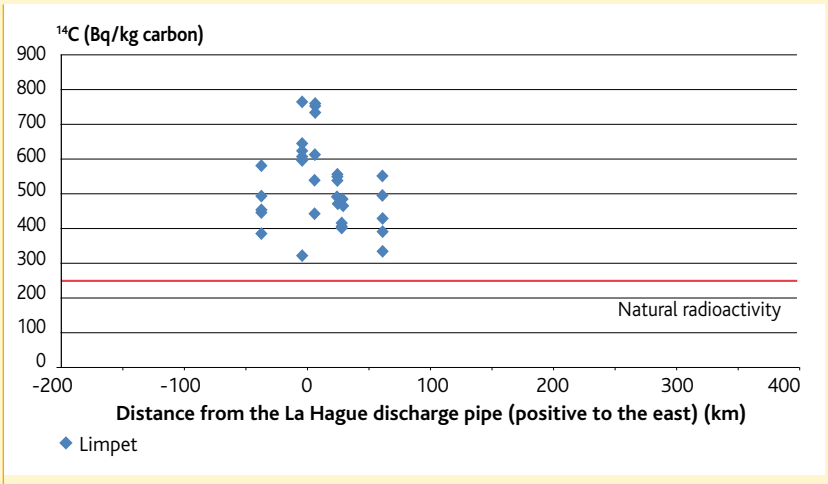

Figure IV.58 - Changes in carbon-14 activity observed in seaweed samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg of C).

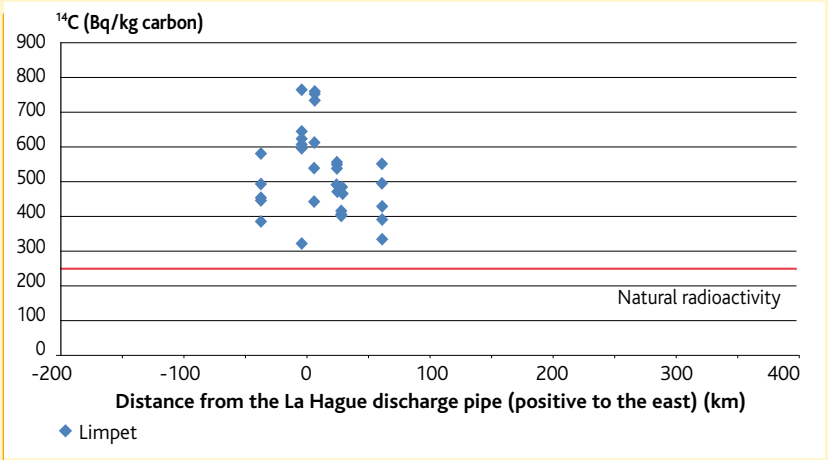

Figure IV.59 - Changes in carbon-14 activity observed in limpet samples collected between January 2010 and April 2011 along the Channel - North Sea coast (Bq/kg of C).

Among the sampling stations monitored, the highest average levels were observed at Pointe de Goury (average carbon activity of 688 ± 37 Bq/kg in limpets).

Of the different species analyzed, oysters exhibited the highest values. The average carbon levels observed reached 940 ± 70 Bq/kg in oyster samples from the west coast of the Cotentin and 980 ± 80 Bq/kg in oysters from the east coast of Cotentin (maximum 1,160 ± 210 Bq/kg in October 2010). In comparison, oyster samples from the Arcachon basin in 2010 showed an average carbon activity of 259.4 ± 1.1 Bq/kg, comparable to the present reference level.

Carbon-14 in crustaceans

Samples of common crabs collected quarterly near the La Hague site exhibited carbon-14 activity levels above the current reference levels (on average, 491 ± 31 Bq/kg of carbon on the west coast and 328 ± 25 Bq/kg of carbon on the north coast). Similarly, lobsters caught on the west coast contained traces of carbon-14, due mainly to discharge from the La Hague plant (average carbon activity measured: 374 ± 20 Bq/kg).

Carbon-14 in fish

*Radioactivity in fish is monitored annually at twelve sampling stations along the French coast. Sampling is carried out more frequently on the Cotentin coasts, closest to the outfall at La Hague. Various species, including plaice, mackerel, dogfish, spotted dogfish, wrasse, mullet, Fleury skate and sea bass were analyzed (*Figure IV.60*).*

The ^{14}C activities measured in the Channel, from Carteret to Le Tréport (414.5 ± 2 Bq/kg wet in wrasses caught in Urville-Nacqueville) are generally higher than the reference levels observed away from any nuclear facility (238.2 ± 1.4 Bq/kg wet in mullets caught in Arcachon).

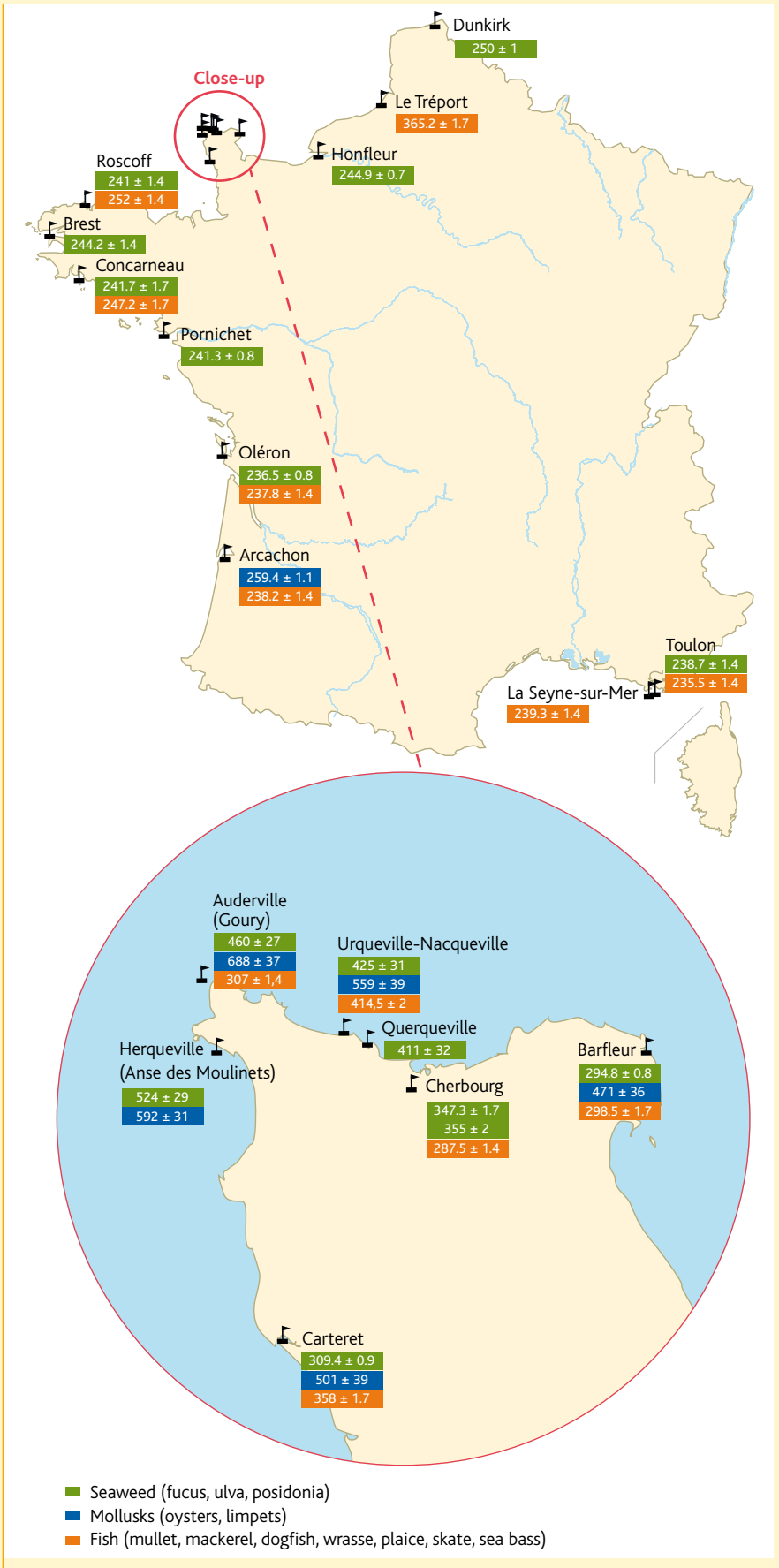

Figure IV.60 - Carbon-14 activity observed in marine aquatic plants, mollusks and fish caught between January 2010 and April 2011 along the French coast (Bq/kg of carbon).

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Bound tritium

Tritium is a natural and artificial radionuclide. "Natural" tritium comes mainly from the interaction of cosmic neutrons with nitrogen or oxygen in the air. The annual worldwide production of natural tritium is 7.4 × 10¹⁶ Bq. In the past, "artificial" tritium in the environment was mainly the result of global fallout following atmospheric nuclear weapons tests. These persistent traces tend to diminish and disappear. Tritium is also produced by most nuclear facilities. Table IV.19 lists the main artificial sources of tritium in the marine waters of metropolitan France.

As a hydrogen isotope, tritium is part of the cycle of this element in the natural environment. It is a radionuclide, which, as tritiated water, is highly mobile. In plants and animals, it is found in cell water (free tritium or HTO) and also in organic matter in the form of organically bound tritium (OBT). The first fraction quickly exchanges with the hydrogen present in the environment; its measurement can be used to characterize an environment at the time of sampling. On the other hand, bound tritium is representative of environmental contamination throughout the formation of organic matter. The measurement of tritium bound to organic matter contained in bio-indicators is a very good indicator for assessing the impact of a nuclear facility on its environment.

In 2010, seaweed and fish were sampled at different stations along the French coast. Their bound tritium activity was determined by mass spectrometry. This particularly efficient technique makes it possible to measure very low detection limits, which is useful for environmental assessment applications.

Table IV.19 - Tritium activity released into the marine environment in 2010 (TBq).*

Nuclear facilities	Discharge activity levels (TBq*)	
	Liquid discharge	Gaseous discharge
Areva La Hague	9,950	56.8
Flamanville NPP	49.3	0.68
Paluel NPP	88.6	2.11
Penly NPP	64.8	2.08
Gravelines NPP	74	3.34
Sellafield plant (England)	1,400	98

** 1 (TBq) (terabecquerel): 1,012 Bq*

Bound tritium in seaweed

*Samples of seaweed (fucus serratus and fucus vesiculosus) were collected from six stations on the Atlantic, Channel and North Sea coats. The bound tritium activity levels measured were very low, but nevertheless revealed additional concentration due to liquid discharge from the spent fuel reprocessing plants at La Hague and Sellafield (*Figure IV.62*). The impact of these facilities was measured from Carteret to Dunkirk, with the maximum activity observed in fucus vesiculosus samples from Honfleur (1.7 ± 0.26 Bq/kg dry). This activity was eight times higher than that measured in fucus vesiculosus samples from Oléron (0.216 ± 0.006 Bq/kg dry), which was outside the influence of any nuclear facility.*

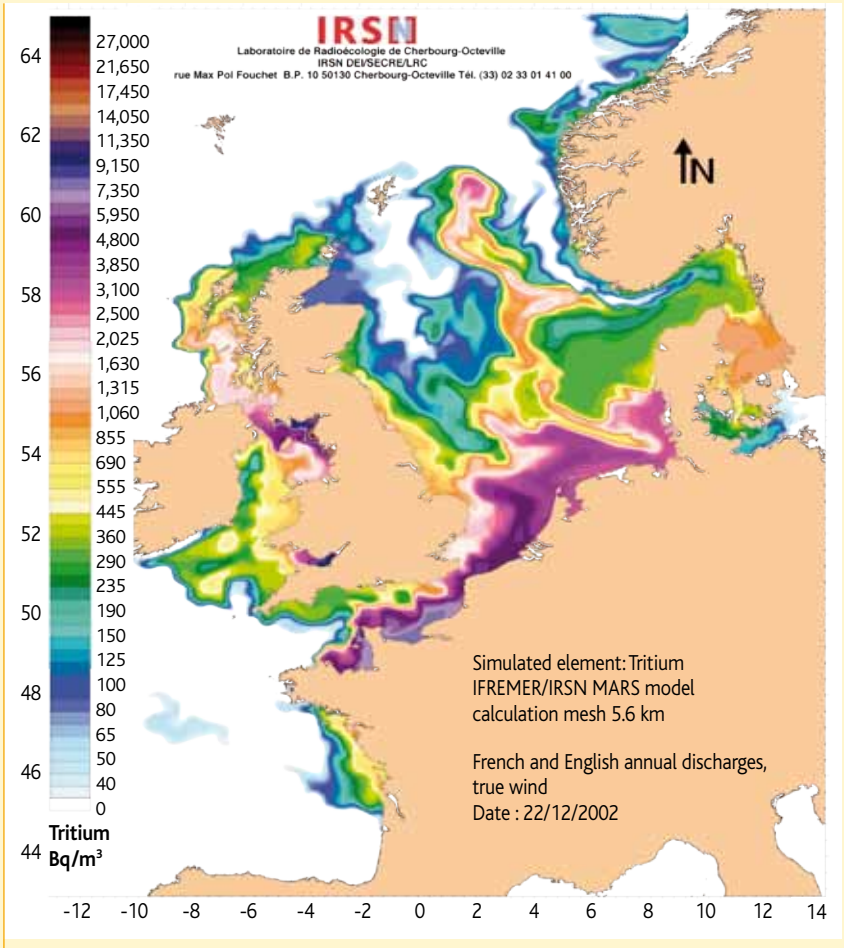

Figure IV.61 - IRSN simulation of tritium dispersion over the European northwest plateau.

The distribution of bound tritium activities measured in seaweed in the Channel and the North Sea corresponded exactly to the dispersion model of tritium released by the La Hague and Sellafield plants, thus confirming the industrial source of the tritium measured (Figure IV.61). The activity observed at Pornichet (0.73 ± 0.037 Bq/kg dry), three times higher than that measured at Oléron, indicated a slight concentration from liquid effluent discharge from NPPs upstream along the Loire.

Bound tritium in fish

In 2010, fish were caught near Arcachon, Oléron, Auderville, Urville-Nacqueville and Le Tréport. The tritium measured in the fish caught in the Atlantic mainly occurs naturally.

In the Channel, the levels measured at the three sampling stations were significantly higher than those observed in the Atlantic. A factor of 24 was observed between mullet caught at Arcachon and mackerel caught at Auderville, which is a station particularly exposed to liquid discharge from the La Hague site (Figure IV.62). Although differences between species can be observed, the discrepancy mainly indicated added tritium concentration of the marine environment by the reprocessing plants. This impact must nevertheless be weighted, as the levels recorded are extremely low.

Figure IV.62 - Bound tritium activity observed in seaweed and fish samples collected between January 2010 and April 2011 along the Channel, North Sea and Atlantic coasts (Bq/kg dry for seaweed, Bq/kg wet for fish).

The Mediterranean coast

Sea water

Following the reorganization of IRSN's monitoring strategy in the marine environment in 2009, monthly sampling of seawater by the Regional Health Agencies came to a halt. The quantity of samples collected (10 to 20 liters) did not reach satisfactory decision thresholds. A test sample of a large volume of sea water (500 liters) was taken from Toulon harbor in 2010. The dissolved cesium-137 was measured by gamma spectrometry at an activity concentration of 0.0015 ± 0.00015 Bq/L. These large-volume samples were then taken at some of the marine stations in IRSN's monitoring network.

Toulon military port

Tritium activity (5.8 Bq/L) greater than that usually measured was occasionally detected in Toulon harbor during the month of April 2010. Additional measurements were planned for 2011 to confirm this result and, if appropriate, to identify the source. No other artificial radionuclide was measured between January 2010 and June 2011.

Sediments

Toulon military port

Among the quarterly analyses of sediment samples, cesium-137 was occasionally measured at between 5.12 ± 0.52 Bq/kg dry and 8.59 ± 0.57 Bq/kg dry. Traces of plutonium-239+240 (0.059 ± 0.038 Bq/kg dry) were also detected. These radionuclides were mainly the result of past atmospheric fallout. No other artificial radionuclide was measured in sediments.

Aquatic fauna

Mediterranean coast

IRSN monitors the French Mediterranean marine environment by taking bimonthly samples of mussels (from eight stations) and fish (from four stations). The stations are distributed to ensure full geographical coverage of the French Mediterranean coast. Mussels were selected as a bioindicator due to their ability to accumulate the contaminants present in coastal waters and fish were chosen due to their higher trophic level (thus highlighting a biomagnification phenomenon).

The 2010 results highlighted the following points:

- The levels of artificial radionuclides in the coastal area were still very low, often with activities close to the decision thresholds of the best analytical techniques.
- Only cesium-137 was regularly detected by direct gamma spectrometry in samples with values less than 0.02 Bq/kg wet for mussels and less than 0.1 Bq/kg wet for fish (*Figures IV.63 and IV.64*).

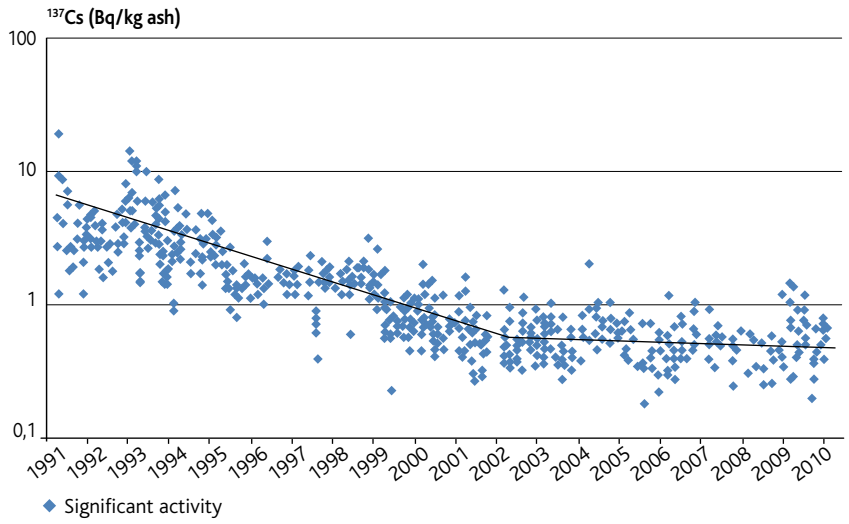

Figure IV.63 - Changes in cesium-137 activity in mussels along the Mediterranean coast from 1992 to 2010 (Bq/kg ash).

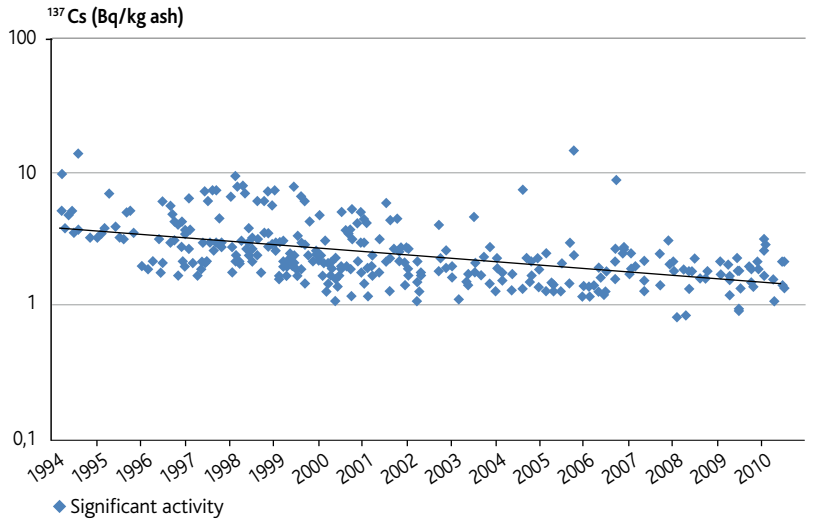

Figure IV.64 - Changes in cesium-137 activity in fish along the Mediterranean coast from 1994 to 2010 (Bq/kg ash).

Changing activity levels in mussels in recent years showed that levels were stabilizing, following a sharp decline in the 1990s.

This stabilization reflected a balance between contribution to the coastal environment, bioaccumulation in organisms and sedimentary processes (storage, partial remobilization). In fish, this decrease was less pronounced and cesium-137 activity levels in fish are now stabilizing at levels three to four times higher than those measured in mussels. This is due to the fact that fish are higher up the food chain and that they actively retain cesium in their muscles as a chemical analog of potassium. As the distribution of cesium-137 had been ecologically stabilized, the development of activity levels over the next few years, unless there is a significant new discharge, should reflect the radioactive decay of this element (half-life = 30 years).

Cobalt-60 from discharge from nuclear facilities was occasionally detected at very low levels (0.5 Bq/kg ash) in mussel samples collected west of the mouth of the Rhône, reflecting the impact of the contribution from rivers on this stretch of coastline.

Due to the relative importance of tritium and carbon-14 discharge from nuclear facilities, these two radionuclides were periodically measured in mussels and fish for all the stations. Levels of tritium in organisms were very low and less than 1 Bq/kg dry, except for stations near the mouth of the Rhône and at Toulon, reflecting a slight local impact of tritium discharge from nuclear facilities in the Rhône region. The level distribution of carbon-14 was very even, with a mean value of 235 Bq/kg of carbon.

In 2010, plutonium isotopes were analyzed by alpha spectrometry on samples of mussels recorded since 1986 for two stations: Faraman, near the mouth of the Rhône and Nice, outside the influence of the contribution from the Rhône (*Figure IV.65*). These new results indicated that the Nice station was clearly affected by the fallout from the Chernobyl accident in May 1986 and by fallout from weapons tests until the mid-1990s. The isotopic ratio ($^{238}Pu/^{239+240}Pu$) for this station varied between 0.05 and 0.03, confirming the source of this contribution. The Faraman station also showed added concentration from atmospheric fallout, contributions from the Rhône and discharge from the fuel reprocessing facility at Marcoule, as confirmed by the change in isotopic ratio from 0.3 to 0.06 over the period in question. Since the early 2000s, these two stations have shown similar, stable activity values of plutonium-239+240 of between 1 and 1.5 mBq/kg wet. Despite the limited number of measurements, this time series reflected the changes in these elements in the coastal marine environment of the Mediterranean.

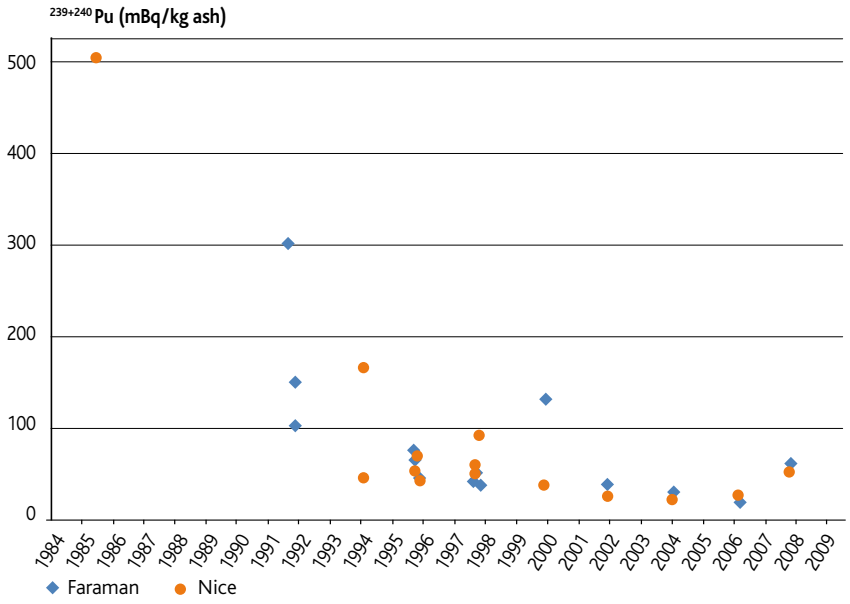

Figure IV.65 - Changes in plutonium isotope activity ($^{239+240}Pu$) in mussel samples from Faraman (mouth of the Rhône) and Nice between 1986 and 2008 (mBq/kg ash).

Toulon military port

Apart from the observations made on samples along the entire coastline, no artificial radionuclide activity above the decision thresholds was measured in samples of seaweed, mollusks and fish from Toulon harbor.

IV.4 REGIONAL RADIOLOGICAL STUDIES

Current objectives and studies

The purpose of regional radiological reports is to establish, over a wide area (several departments), an up-to-date baseline of the levels of radioactivity in certain environmental compartments, especially agricultural and livestock production typical of the area in question. This baseline must take into account the radiological "background" related to natural radioactivity and the residual material of past atmospheric fallout (nuclear weapons tests and the Chernobyl accident), and the influence of present or past discharge from nuclear facilities in this area. In the event of an accidental release, this baseline would be used as a basis for comparison and help guide the deployment of more intensive post-accident monitoring.

Developing regional radiological studies first requires an examination of all available data, including that acquired by IRSN from continuous monitoring or previous radioecological studies. This knowledge is then completed or verified through specific sampling and analyses. These reports should therefore increase the radiological knowledge of our environment both spatially and through the diversification of samples, analyses and radionuclides detected. In addition, IRSN is using the most efficient methods of collecting, processing and analyzing samples to compile this reference state.

Members of the Local Information Commissions (CLI), local governments and authorities, are invited to participate in these reports, in particular by applying their knowledge of the area during the development of sampling strategies and when results are presented. They will receive the reports published for each study.

Depending on the complexity of the area, it takes three to four years to complete studies, from beginning to delivery. A report should be updated about every five to seven years.

After the first exploratory regional radiological study conducted in the Loire valley between 2008 and 2010 (*see Focus and IRSN reports*), the strategy was improved and, generally speaking, the content of reports currently in progress increased: Rhône Valley: (2009-2012), Southwest (2009-2012) and Northeast (2010-2013).

Sampling and analysis strategy

The reports take into account the location of nuclear facilities, distinguishing between potentially affected areas (ZI) and distant areas that may be considered, under normal operating conditions, to be outside their influence (non-affected areas: ZNI).

In a terrestrial environment, the potentially affected area (ZI) does not usually exceed a few kilometers. However, it can sometimes be more extensive, such as in Marcoule, where the influence of atmospheric discharge of tritium can be seen beyond this distance. Non-affected areas (ZNI) are intentionally defined as being much further away than the distance taken into account for the potentially affected area, typically more than 15 to 20 km from each facility, in places that are therefore not normally subject to regular monitoring.

The sampling plan for a **terrestrial environment** includes several categories:

- **production that is predominantly agricultural** in terms of surface area, quantities or economic value; in this category, produce common to the Southwest and Rhône Valley reports consists, for example, of orchard fruits, wine, vegetables and regional livestock products;
- symbolically important or even emblematic production, such as olive oil, registered designation of origin (AOC) walnuts, chestnuts and rice from the Rhône valley, or garlic, honey, hazelnuts or duck from the southwest;
- samples of the same type as those collected systematically during IRSN's regular monitoring activities (leaf lettuces or milk, etc.) that allow the area under study to be compared with existing records;
- plants or animals characteristic of natural ecosystems: mushrooms, game, wild berries, etc., depending on sampling possibilities;
- **specific indicators** of certain radionuclides: tree leaves for tritium, mosses for atmospheric plutonium.

In an **aquatic environment**, the potentially affected areas are those located downstream of nuclear facilities, with non-affected areas being theoretically located upstream. However, the succession of facilities along major rivers (e.g. the Rhône) makes it more difficult to determine such areas, as upstream of a facility corresponds to downstream of the previous one. The samples consist of water, radiological indicators such as sediments, aquatic plants or filter-feeding mollusks (corbiculae in the Rhône) and foodstuffs (fish, mussels).

In the **atmospheric environment**, artificial radioactivity levels are relatively well-known throughout the areas considered. However, in the context of these studies, equipment that is more efficient than that used for routine monitoring around nuclear facilities (low-level OPERA-Air station, see Chapter IV.1) can be deployed under the prevailing winds of the site of interest.

Various analyses were performed using the best available technology on the most appropriate samples to quantify the levels of the main natural and artificial radionuclides present in measurable quantities in the environment: analyses of free and bound tritium, carbon-14, gamma spectrometry, radiochemistry and alpha and beta spectrometry for plutonium isotopes and strontium-90, ICP-MS for uranium isotopes, etc.

Rhône Valley regional study

The Rhône Valley radiological study began in mid-2009 and was completed in 2012. This report was the subject of two methodological presentation reports related to the terrestrial environment (IRSN-SESURE 2010-01) and the aquatic environment (IRSN-SESURE 2011-34). It covers the municipalities bordering the Rhône, from upstream of the Creys-Malville site to the Camargue.

Additional specific points of special interest (emblematic produce) although outlying, were also considered. This area is marked by several nuclear facilities: the four NPPs in operation (Bugey, St. Alban, Cruas and Tricastin), the Creys-Malville reactor (being dismantled), the other facilities at the Tricastin-Pierrelatte complex and those on the Marcoule site.

Figures IV.66 and IV.67 show the sampling plans respectively selected for the terrestrial and aquatic environments. In a terrestrial environment, the sampling strategy of affected and unaffected production is defined by:

- **mapping tools** (analysis of land use by a geographical information system);
- **statistical data** published by the French Regional Directorates for Food, Agriculture and Forestry (Agreste statistical database);
- **local contacts** established during sampling campaigns, who make it possible to adjust theoretical data (sometimes obsolete) to the reality on the ground.

A specific sampling and analysis plan was developed for the area around Marcoule, with the main aim of examining tritium, which is the dominant radionuclide in atmospheric discharge from this center. Samples of poplar leaves were collected from fourteen points, at increasing distances from the site, first along a north-south, then an east-west and a south-east-north-west axis, to measure the tritium.

As the Rhône aquatic environment is covered quite thoroughly as part of IRSN's regular monitoring activities (water samplers, observatory station at Arles on the Rhône) and studies are regularly conducted by IRSN in other contexts, the few additional samples taken were from generally non-typical areas. Samples of water, suspended matter and fish were therefore collected upstream and downstream of each facility. In addition, rarely sampled filter feeders were collected downstream of the NPPs and Marcoule (*Figure IV.67*).

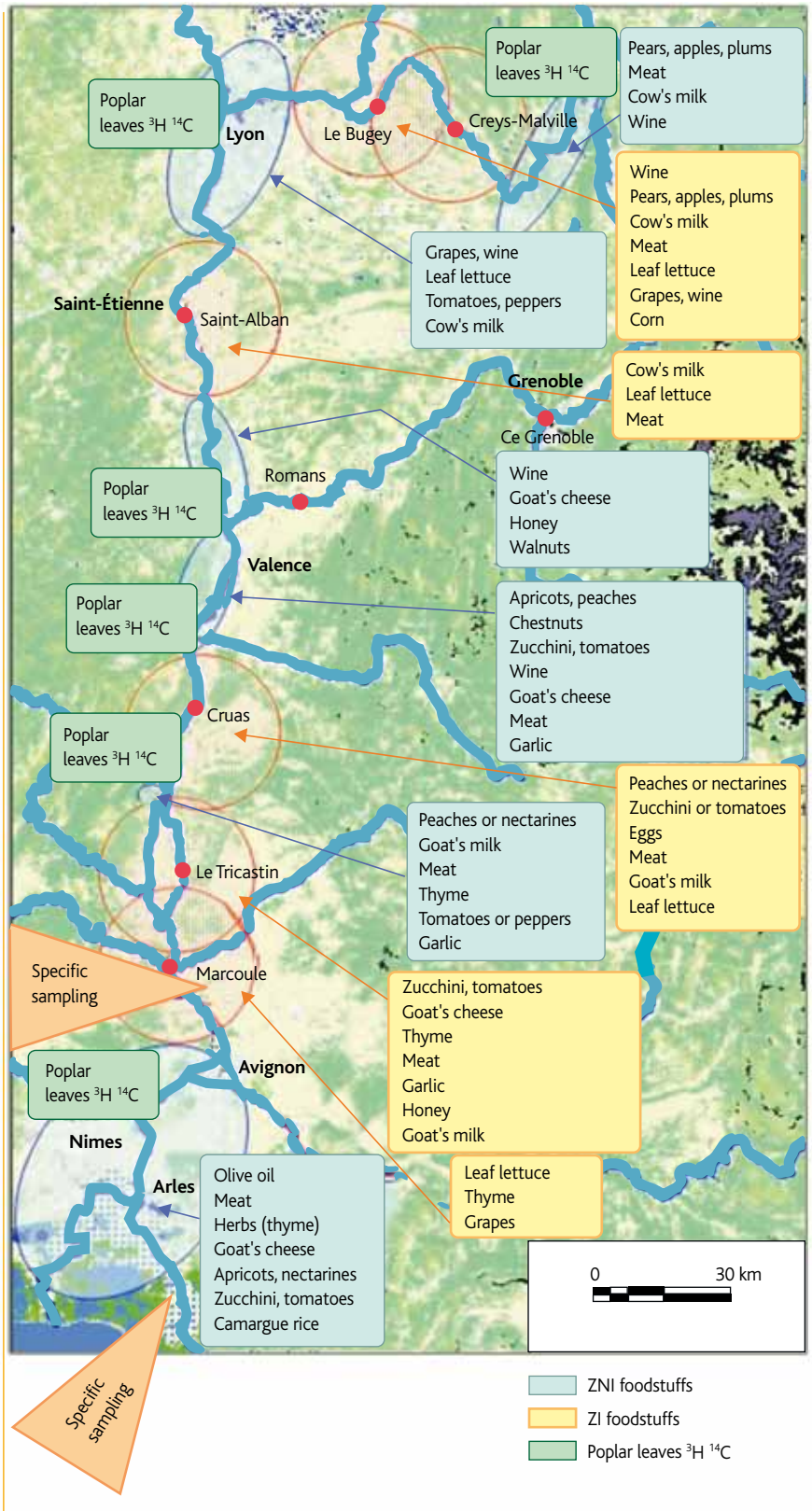

Figure IV.66 - Location of sampling areas and distribution of samples taken in the Rhône Valley study (ZI: affected area, ZNI: non-affected area)

A few specific points will be added to these samples to determine the impact of the main tributaries that dilute and possibly also carry radionuclides (for example, the Isère, which carries the discharge from the FBFC plant at Romans-sur-Isère and the CEA's Grenoble center). Finally, the study of the impact of liquid discharge from hospital radiotherapy or radiodiagnostics departments located along the river will be the subject of a subsequent additional section.

A high-volume atmospheric aerosol sampling station has been in operation under the prevailing winds of the Tricastin site since the beginning of 2012. The filters will be analyzed by gamma spectrometry (^{137}Cs, ^{60}Co, etc.), alpha spectometry (plutonium isotopes in particular) and by ICP-MS for uranium isotopes.

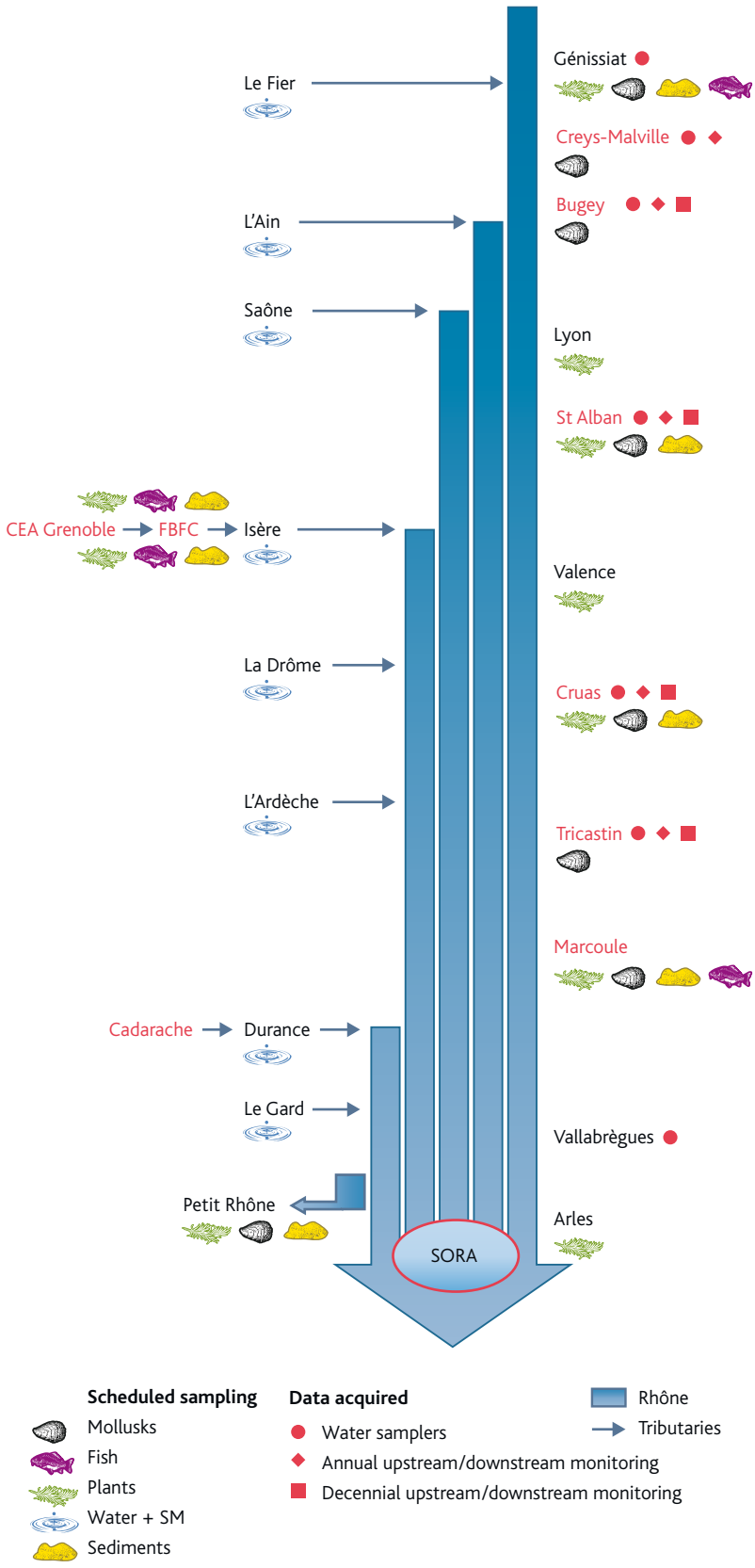

Figure IV.67 - Location of samples in the aquatic environment.

Southwest regional study

The Southwest radiological study began at the end of May 2009 and was completed in 2012. It covered a vast area of four administrative regions (Poitou-Charentes, Limousin, Aquitaine, Midi-Pyrénées) and twenty departments, bordered to the north by the Loire, to the east by the Massif Central, to the south by the Pyrenees and to the west by 700 km of Atlantic coastline.

The potential sources of radiological exposure were the liquid and atmospheric discharge from the three NPPs in operation (Le Blayais, Golfech and Civaux), liquid discharge from the nuclear medicine departments of about fifteen major cities (Pau, Bayonne, Tarbes, Bordeaux, Toulouse, Agen, Poitiers, Limoges, etc.), uranium-bearing areas, areas affected by former mining sites and other old industrial sites (residue foundry, gas production, etc.). The sampling and analysis strategy used for the Southwest report, did not, however, cover the former mining areas, which will be the subject of specific studies.

Figure IV.68 shows the sampling plan in a terrestrial environment.

A high-volume atmospheric aerosol sampling station, similar to those in the low-volume OPER-Air network, was installed in 2011 under the prevailing winds of the Golfech NPP in collaboration with the operator (*Figure IV.69*). The first samples were filtered in September 2011. They were measured by low-background gamma spectrometry. In addition, a specific campaign for measuring tritium in atmospheric water vapor was carried out in 2012.

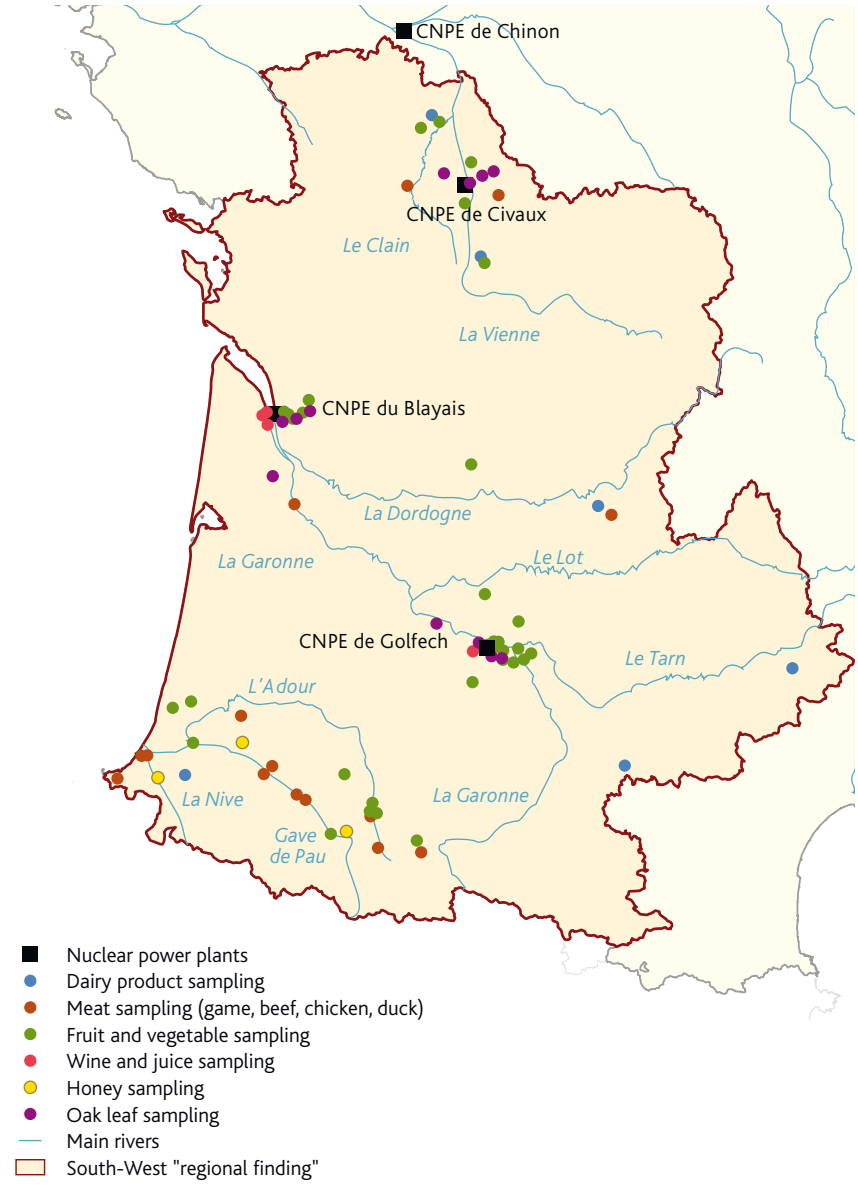

Figure IV.68 - Sampling in the terrestrial compartment within the context of the Southwest regional study.

Figure IV.69 - OPERA-Air (300 m³/h) sampler installed under the prevailing winds of the Golfech NPP.

In relation to the aquatic environment, the sampling points on major rivers (Vienna, Garonne, Adour) and their tributaries were identified during this report, taking into account the NPPs, the IRSN's regular monitoring installations (in particular, water samplers on the Garonne and the Vienne), the industrial facilities included in ANDRA's national inventory of radioactive materials and waste, major urban centers with nuclear medicine departments and the proximity of uranium-bearing areas (*Figure IV.70*). Depending on the proximity of the facilities and the diversity of the environments, the sampling focused on surface water, sediments (*Figure IV.71*) and aquatic plants (Figure IV.72). The samples were systematically analyzed by gamma spectrometry. Additional analyses were carried out, depending on the facilities located on the rivers: tritium, carbon-14, uranium, thorium, etc.

In the case of the specific study of discharge from nuclear medicine centers, samples were analyzed by gamma spectrometry as soon as possible to detect short-lived radionuclides characteristic of this activity (iodine-131, metastable technetium-99).

In total, 164 samples were collected specifically for the southwest radiological report (*Table IV.22*).

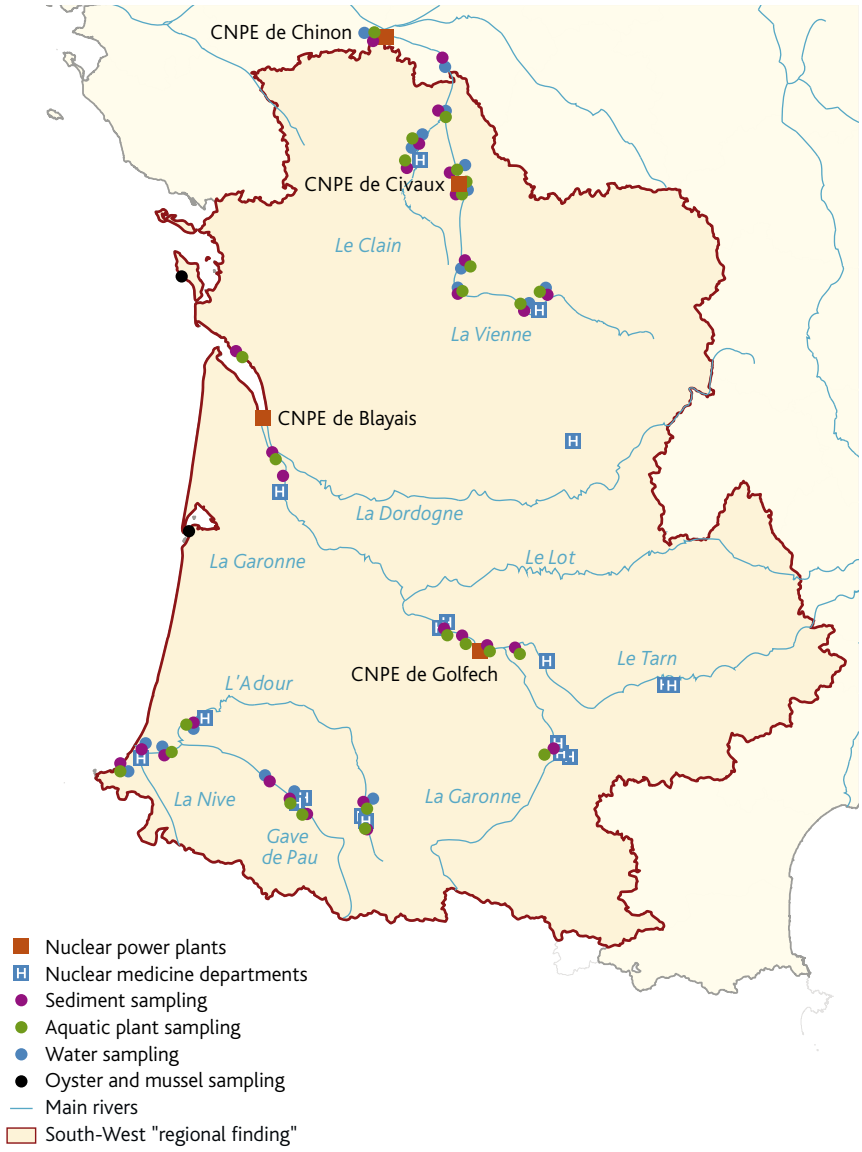

Figure IV.70 - Sampling in the aquatic compartment in the context of the Southwest regional report.

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Figure IV.71 - Sediment sampling in the Adour estuary, downstream of Bayonne, within the context of the Southwest regional study.

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Figure IV.72 - Jussie sampling in the Adour within the context of the Southwest regional study.

Table IV.20 - Number of samples taken within the context of the Southwest study.

Aquatic compartment			Terrestrial compartment				
Water	Plants and seaweed	Sediment	Fruits and vegetables	Animals	Tree leaves	Dairy products	Wines
10	26	30	46	27	13	6	6

Northeast regional study

The area covered by the Northeast radiological study includes thirteen departments that have four sites that impact the activity concentrations of their environments: the CEA's Valduc center, the Chooz, Cattenom and Fessenheim NPPs and seventeen hospital facilities (*Figure IV.73*). This assessment began in 2010 with the identification of the radionuclides to be taken into account, the collection of previously acquired data and the identification of the results to be supplemented or updated.

Essentially based on several thousand items of existing monitoring data or specific previous or concomitant studies conducted by IRSN, this study was also supported by 170 additional samples and about 300 analyses to extend the general summary report to be published. The sampling campaigns and analyses were conducted at intervals during 2011 and 2012 and this study was completed in 2013.

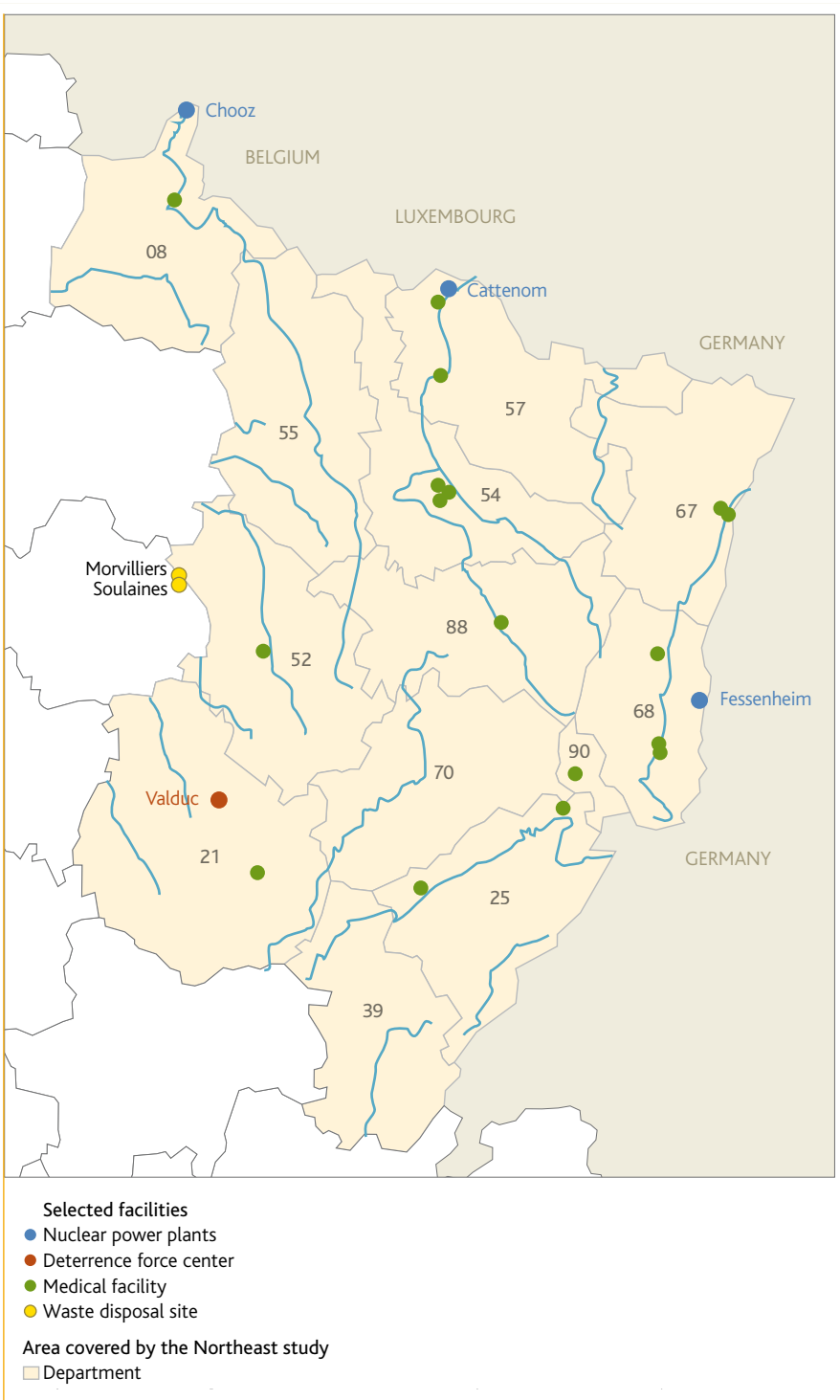

Figure IV.73 - Facilities involving radionuclides in the area covered by the Northeast study.

IV.5 RADIOLOGICAL MONITORING IN THE OVERSEAS TERRITORIES

Apart from French Polynesia, which is specifically monitored by IRSN (*see Focus on monitoring radioactivity in French Polynesia*) due to the past history of nuclear tests conducted on two French Pacific atolls (Mururoa and Fangataufa), the French overseas departments, regions and communities are outside the influence of French nuclear facilities, but may, nevertheless, be exposed to the effects of foreign nuclear facilities.

As such, IRSN's monitoring redeployment plan is intended, in the medium term, to cover only these areas, through the use of telemetry devices and by collecting samples of bio-indicators from areas not affected by a particular event. These areas will also be subject to periodic radiological reports, in the same way as all the regions of metropolitan France. IRSN began specific studies in Reunion and New Caledonia in 2012.

Between March and May 2011, these territories were more intensively monitored to track and assess the impact of the damaged Fukushima plant. These monitoring results are presented in Chapter III.

Atmospheric compartment

To assess the impact of release from the Fukushima accident on the ambient dose rate, IRSN intensified its vigilance with respect to real-time measurements from the Teleray network, particularly for areas thought to be the first in the path of contaminated air masses (in particular Saint-Pierre-et-Miquelon) and for this purpose installed passive dosimeters (RPL) at various points across the area to obtain integrated measurements of the external radiation dose during the period of exposure to contaminated air masses.

However, the predictions of concentrations in air in France (metropolitan and overseas), obtained from cesium-137 simulations performed by Météo-France, the French national meteorological service, showed levels that were too low (around 1 mBq/m^3) to cause an increase in the ambient dose rate that could be detected by the measuring devices used, given the natural background of gamma radiation of terrestrial, atmospheric and cosmic origin.

In 2010 and 2011, no abnormal measurement relative to an accidental radiological event was detected by the IRSN Teleray network probes installed in Saint-Pierre-et Miquelon, Guadeloupe (Figure IV.74), Martinique, French Guiana, La Réunion, New Caledonia and French Polynesia.

Figure IV.74 - New-generation Teleray probe installed in Saint-Claude, Guadeloupe.

Terrestrial compartment

Milk

Samples of cow's milk were collected annually in Martinique, French Guiana and Réunion (*Table IV.21*). As in metropolitan France, the radioactivity measured in 2010 and early 2011 in milk was mainly due to natural potassium-40. The activity levels observed fluctuated between 37 ± 8 Bq/L and 52.9 ± 4.9 Bq/L, depending on the source. Artificial cesium-137 was measured in the sample taken in French Guiana (0.31 ± 0.08 Bq/L). The presence of traces of this radionuclide can be explained by past fallout from previous atmospheric weapons tests. No other artificial activity was measured in milk samples from overseas regions.

Table IV.21 - Activity measured in cow's milk samples in 2010 and early 2011 in French overseas departments and regions (Bq/L).

Radionuclide	Martinique	French Guiana	Réunion
^{40}K	47.6 ± 3.9	52.9 ± 4.9	37 ± 8
^{131}I	< 0.2	< 1.2	< 1
^{134}Cs	< 0.08	< 0.08	< 0.29
^{137}Cs	< 0.1	0.31 ± 0.08	< 0.34
^{90}Sr	nm	nm	< 0.018

nm: not measured

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Monitoring in French Polynesia

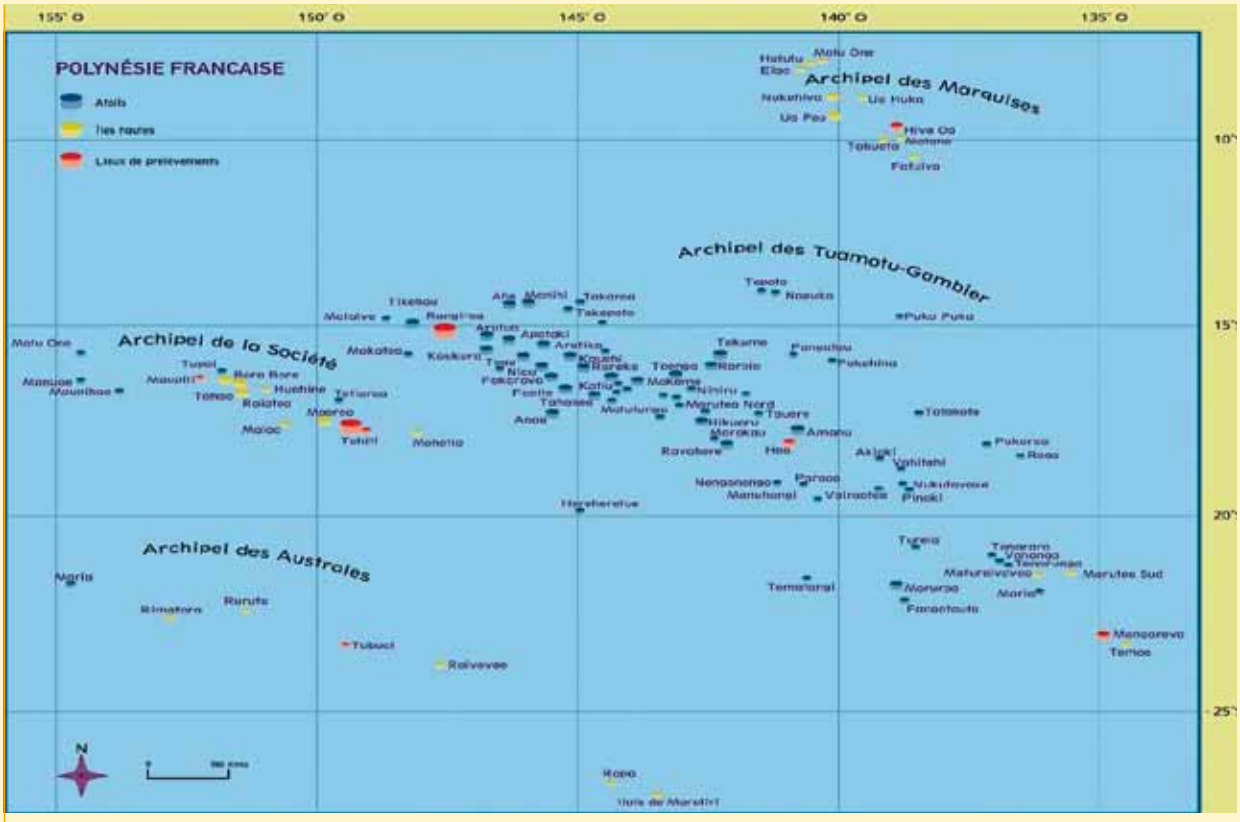

Figure IV.75 - Map of the French Polynesian archipelagoes and IRSN's sampling sites.

Since 1962, IRSN has been monitoring radiological activity in French Polynesia (Figure IV.75)*, with the exception of the Mururoa and Fangataufa atolls, where radiological monitoring comes under the authority of the French Ministry of Defense via the nuclear test center monitoring department (DSCEN) of the Arms Procurement Agency (DGA) responsible for this task in collaboration with the French Alternative Energies and Atomic Energy Commission.*

IRSN's monitoring involves taking regular samples of various kinds from different environments (air, water, soil, etc.) with which the population may be in contact, as well as local foodstuffs.

In 2010, 54 samples were taken from the physical environment (air, water and sediments) and 200 from the biological environment (deep-sea fish - Figure IV.76*, lagoon fish and other products, terrestrial samples such as vegetables, fruit, meat, milk, various drinks). The food samples were representative of the diet of Polynesians living in the five archipelagoes of the territory.*

Figure IV.76 - Mahi-mahi (or dolphin fish) caught off the coast of Tahiti.

All these samples had two objectives:

- *to discover the levels of artificial radioactivity in all the different environments and main foodstuffs;*
- *to assess the dosimetric impact of this environmental situation: for ingested doses, all the samples representative of the Polynesian diet were taken into account. For external exposure and inhalation, the dose was estimated on the basis of measurements of the physical environment.*

Focus continued

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Main results

The radioactivity measurements (gamma spectrometry for cesium-137 and cobalt-60, measurement of alpha emitters for Pu isotopes and beta emitters for strontium-90) cover most of the range of artificial radionuclides likely to be detected in Polynesia. Almost all the samples taken were measured in IRSN's Environmental Study and Surveillance Laboratory (LESE) in Vairao on the island of Tahiti.

The levels measured in 2010 did not differ from those obtained in previous years; the few variations observed were due to significant natural variability. Cesium-137 was the most frequently detected element. The maximum values detected in 2010 were less than 0.5 Bq/kg wet for fish and ten times lower for other lagoon products. The maximum value detected in the terrestrial environment was 1.8 Bq/kg wet for papaya in Rangiroa, 3.3 Bq/kg wet for pork and 8.8 Bq/kg wet for beef in Tahiti.

Where cobalt-60 and plutonium activity levels were detected, they were extremely low (Figure IV.77)*:*

- *cobalt-60 was only detected three times in 2010, in giant clam samples from Tubuai, Hao and Rangiroa;*
- *plutonium isotopes, ^{238}Pu and $^{239+240}$Pu, were only detected, at very low concentrations, in five giant clam samples (two from Tubuai, two from Hao and one from Tahiti) out of the 26 samples analyzed.*

The decline observed above can be explained by the radioactive decay of cobalt and cesium since the end of atmospheric testing.

After a steady fall in radioactivity levels since the French atmospheric tests came to an end in 1974, the radiological state observed in 2010 has been stable in recent years, and is now very low.

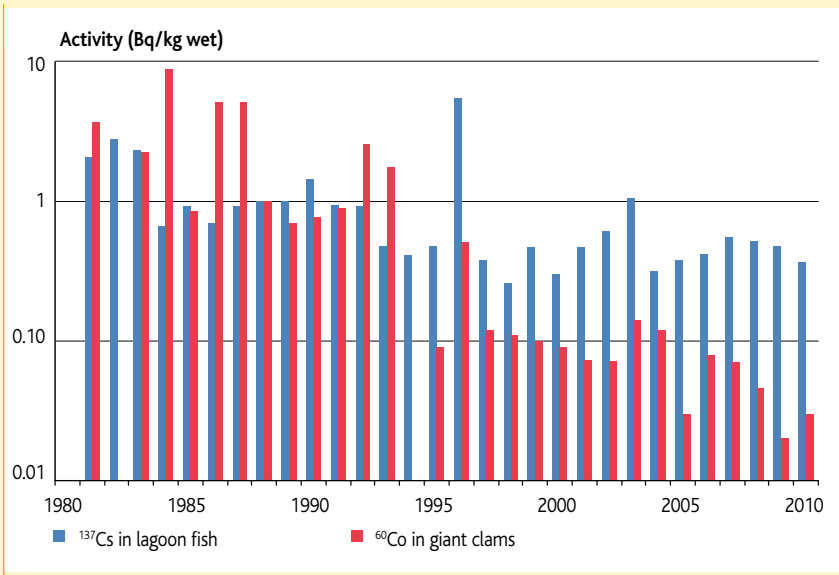

Figure IV.77 - Concentration of cesium-137 and cobalt-60 in lagoon products (all islands) (Bq/kg wet).

For more information

Assessment of radioactivity monitoring in French Polynesia in 2010 and monitoring of the impact of the Fukushima accident on French Polynesia and New Caledonia from March to May 2011 - DEI/SESURE report 2011-40

http://environnement.irsn.fr

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Figure IV.78 - Sampling sediments from a river using a Berthois cone.

V

MONITORING OF NUCLEAR FUEL CYCLE FACILITIES

V.1 ENVIRONMENTAL MONITORING NEAR NUCLEAR SITES

Until 2001, when the last operating uranium mine closed, France was the only country to have all industries of the fuel cycle on its territory, covering the following stages:

- **extraction** of uranium from mines;
- **concentration and conversion** of uranium compounds;
- **isotopic enrichment** in uranium-235;
- **fabrication and assembly** of fuel[1];
- **use** of fuel in nuclear power plant (NPP);
- **processing** spent fuel unloaded from reactors;
- **processing and disposal** of waste.

The French nuclear fuel cycle is considered "closed" or "semi-open" because part of spent fuel is processed and reused. The environments of all the fuel cycle sites *(Figure V.1)* are systematically monitored by the plant operators from the commissioning of plants and throughout their service lives, according to a program monitored by ASN, the French Nuclear Safety Authority.

The monitoring programs implemented around the fuel cycle plants take account of the type of plant being monitored and of its discharge. These programs also vary according to the geographical environment of the monitored plant and meet the objectives specified in Chapter I.

It should be noted that:

1 - The results from the French national environmental radioactivity measurement network (RNM) database used in this chapter cover the period from January 1, 2010 to June 30, 2011.

2 - The results of the regular monitoring of the plants impacted by the fallout in France from the Fukushima accident are presented separately in order to avoid interfering with the results obtained outside this period.

3 - The results of the monitoring of the marine and coastal compartment (sea water, sediments, aquatic fauna and flora) in the vicinity of nuclear facilities are presented in Chapter IV (Marine and coastal environment).

1 – The fuel may be a mixed oxide fuel (MOX fuel), i.e. consisting of a mixture of uranium and plutonium oxides produced by reprocessing.

- Uranium conversion (Comurhex Malvési and Pierrelatte)
- Uranium enrichment (Eurodif Tricastin)
- Fuel assembly fabrication (FBFC Romans-sur-Isère)
- Nuclear power plants (EDF, 22 sites of which 19 in operation)
- Processing of spent fuel unloaded from reactors and recycling (Areva La Hague) and R&D in these fields (CEA Marcoule)
- Surface disposal of radioactive waste (ANDRA, CSM, CSFMA and CSFTA waste disposal facilities)

Figure V.1 - Main fuel cycle plants in France (excluding former mining operations, shown on the map in Section V.2)

4 - In order to be able to use all the results transmitted to the RNM database and produce understandable summary information while minimizing the number of units of measurement, IRSN has in some cases applied conversion factors to the raw results (Bq/kg wet <-> Bq/kg dry, for example).

V.2 ENVIRONMENTAL MONITORING AROUND FORMER MINING SITES

In France, uranium was mined on an industrial scale for nearly 50 years. Many former mining sites (*Figure V.2*) are now under the responsibility of Areva. IRSN has undertaken an exhaustive inventory of all the former uranium ore prospecting, mining and processing sites as part of a program called MIMAUSA (memory and impact of the uranium mines: summary and archives) at the request of the Ministry of Ecology. All available data is accessible through a map interface on the IRSN website (http://mimausa.irsn.fr).

Uranium ore prospecting, mining and processing activities and the disposal of processing tailings involved some 230 sites in France, located in 25 departments. The sizes of these sites and the quantities of ore mined vary greatly, ranging from simple survey sites to major plants that produced several thousand metric tons of uranium. Mining and processing of uranium ore generated two types of material or waste: waste rock and processing tailings.

- **Waste rock**, rock excavated to access the ore, differs from the other rock in the areas concerned only by its location close to ore-bearing areas. It is generally richer in uranium than the neighboring rocks, with uranium contents ranging from a few tens to a few hundred g/t, with a total activity from a few Bq to a few tens of Bq/g. The waste rock was stored in dumps at the mines, used in the construction of processing tailings disposal facilities, or used in the rehabilitation of the sites. Some has also been reused in public works.

- **Processing tailings** are industrial waste obtained after processing the uranium ore. They differ from the initial rock by physical (crushing) and mineralogical alterations caused by the chemical treatments. Their total activity, all radionuclides combined, is approximately a hundred to several hundred Bq/g. Consequently they are categorized as low- and very-low-level long-lived radioactive waste. More than 50 million metric tons of tailings are currently stored in 17 disposal facilities on 16 sites. After they were closed down, all the sites were rehabilitated to make them safe, reduce their radiological impact and re-integrate them into the surrounding landscape. Underground mine works were partially backfilled and then flooded. Tunnel entrances were blocked up and shafts were sealed. Open pit mines were flooded, creating artificial lakes, or backfilled with waste rock, or used as disposal sites for processing tailings.

Figure V.2 - Locations of French mining areas (Mimausa program)

All the radionuclides initially present in the ore are found in the tailings except the uranium, most of which has been extracted and concentrated in the form of "yellow cake". They include in particular all the decay products of uranium-238, such as ^{230}Th (half-life: of 7,000 years) and ^{226}Ra (half-life of 1,600 years). The specific activity levels of the uranium ore processing talings are compared with those of various types of rock or ore in Table V.1.

Table V.1 - Radioactivity levels observed in several major rock types, ores and mining tailings (Bq/g)

	Radium activity	Total activity
Uranium ores	10 - 70	180 - 900
Mine tailings	10 - 70	100 - 700
Waste rocks	0.05 - 5	1 - 100
Granitic rocks	0.04 - 0.3	0.7 - 6
Basalts and certain sedimentary rocks	0.0003 - 0.03	0.005 - 0.5

The management of uranium ore processing tailings is subject to the regulations on environmentally regulated facilities (ICPE). These tailings are a potential source of environmental contamination and of exposure to radioactivity as they may lead to radon release, and, above all, because of their leaching by rainwater or runoff water. At some mining sites, the characteristics of the collected water means that it requires treatment before it can be discharged into the environment.

Areva is still operating a number of water treatment plants. Despite treatment, the permitted water discharge from certain sites may result in an increase in the radioactivity in downstream watercourses, and in the deposition of sediments that may contain high levels of uranium on the beds or banks of bodies of water. In order to be able to assess the radiological impact of the disposal sites for these tailings on populations and verify the effectiveness of the measures implemented by Areva, checks on the outlet water before discharge and monitoring of the various compartments of the environment (including the air) are required by prefectorial order for each disposal site.

In addition to the monitoring by Areva, which meets the regulatory requirements and is often reinforced by the company, checks are made by the Regional Directorates for the Environment, Town and Country planning and Housing (DREAL), including unannounced inspections with sampling for analysis. These periodic measurement campaigns are also conducted by several bodies, including IRSN. These measurements may be made following questions from the public, elected representatives, local or national associations, or in response to requests from the authorities. In addition to these periodic measurements, IRSN carries out regular monitoring of the environment around some of the leading former mining sites in terms of tonnage of uranium mined or of ore tailings in disposal facilities. This monitoring focuses essentially on the aquatic environment and external exposure.

This chapter covers only the results of water monitoring (surface water, ground water). Air measurements are covered in Chapter IV (Atmospheric compartment). Over the period analyzed in this report, nearly 1,300 measurements were made on water samples collected by IRSN and Areva (*Figure V.3*) around former French mining sites subject to regulatory environmental monitoring.

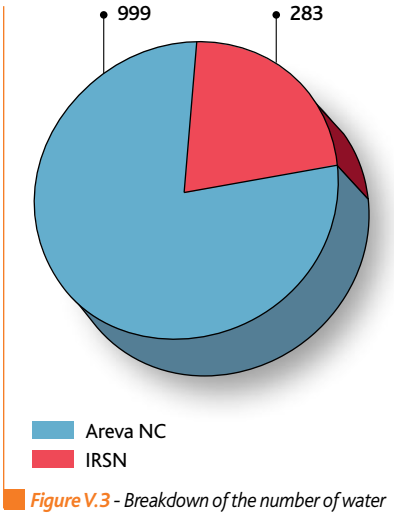

Figure V.3 - Breakdown of the number of water samples by providers of mining site monitoring data

Bertholène mining site (Aveyron mining area)

Located in southern France, Bertholène was the site underground mines and an open pit mine from 1977 to 1994. The ore was processed by static leaching, generating the tailings now stored on the site. The facilities have been dismantled and the site, which has a water treatment plant, is being rehabilitated.

The radium-226 measurement results at the water monitoring points on this mining site in 2010 varied between the decision threshold (< 0.01 Bq/L) and a maximum value of 0.07 Bq/L for the analyzed ground water. These activity levels are equivalent to the natural background. The significant values of uranium-238, between 141 and 247 µg/L, showed an influence of the mining site on the receiving environment, which has natural levels of approximately a few µg/L.

Rophin mining site (Ambert mining area)

The Rophin mining site, in Lachaux (central France), was worked underground from 1949 and 1955 and its uranium ore processing plant operated from 1950 to 1955. The solid tailings from processing are stored on the site. The facilities have been dismantled and the site has been rehabilitated.

Of the five surface water monitoring points, only the activity levels of radium-226 (1.94 Bq/L) and uranium-238 (251 µg/L) at one sampling point at Lachaux showed that they were affected by the mining site. Activity levels of radium-226 (between 0.02 Bq/L and 0.12 Bq/L) and uranium-238 (between < 5 and 6 µg/L) at the other monitoring points were equivalent to the natural background of this site.

Saint-Pierre mining site (Cantal mining area)

In operation from 1958 to 1981, the Saint-Pierre mining site included an open pit mine and a uranium processing and concentration plant. The tailings are stored on the site. The installations have been dismantled and the site has been rehabilitated.

The radium-226 activity levels measured in surface water samples from the two monitoring points varied between the decision threshold (< 0.01 Bq/L) and a maximum value of 0.22 Bq/L. These activities are moderate, and most of them are linked with the naturally high background in this uranium-bearing area. Nevertheless, the maximum values are evidence of added concentration levels related to past activity of the site. The measured uranium concentrations (weight/volume), between 4 and 52 µg/L at one monitoring point and between 75 and 489 µg/L at the other, confirm this observation.

Bernardan mining site (Benaize mining area)

Société des mines de Jouac owned a dozen sites worked in the Benaize mining area at Jouac, Cromac, Saint-Léger-Magnazeix and Mailhac-sur-Benaize in central France. The uranium ore was worked in open pit mines (quarries) or underground mines, depending on the characteristics of the deposits.

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Figure V.4 - Pond for drain water from the uranium mine tailings disposal facility at the Bessines-sur-Gartempe site

The Bernardan mining site was the largest of these sites. It was operated as an open pit mine (1978-1987) and an underground mine (1983-2001). The site accommodated experimental static heap leaching facilities (1978-1987) and an ore processing plant (1979-2001). Mining of deposits ended on May 30, 2001 and the processing plant was shut down in December 2001 and then dismantled. The installations were dismantled and the site, which has a water treatment plant, has been rehabilitated.

In 2010, the radium-226 measurement results at the six surface water monitoring points of this mining site varied between the decision threshold (< 0.01 Bq/L) and 0.08 Bq/L. These activity levels are equivalent to the natural background. The uranium concentrations (weight/volume), near 30 µg/L, were higher than those generally observed in surface water in similar geological contexts not influenced by mining.

Crouzille mining area (central France)

From 1948 to 1995, the Crouzille mining division worked a series of granitic uranium-bearing deposits which produced 23,324 metric tons of uranium. The ore was extracted by open pit mining for deposits close to the surface and by underground mining for deep deposits. The area comprises 24 mining sites located within the boundaries of four concessions. Between 1958 and 1993, all the mined ore was processed at the Bessines-sur-Gartempe processing plant (*Figure V.4*). The site, now rehabilitated, accommodates the center for research and follow-up of former mining activities (CESAAM) and a depleted uranium storage facility.

The surface of the area occupied by the mining sites of the Crouzille mining division can be divided into drainage basins on the basis of its hydrological characteristics. The major drainage basins in terms of the number of sites are those of the Gartempe (9 sites), the Vincou (2 sites), the Ritord (5 sites) and the Couze (4 sites not discussed below). The Couze, the Ritord and the Vincou are all left-bank tributaries of the Gartempe. The largest mining sites in terms of the geographic extent of the works and their production are at Bessines (SIB) on the Gartempe, Fanay-Augères on the Ritord and Margnac-Pény on the Vincou.

Vincou drainage basin

The Vincou flows from the monts d'Ambazac hills through the Crouzille division. This stream is notable with regard to the study and the understanding of radioactivity in the vicinity of the mining sites, as it flows through several mining sectors at Margnac (*Figure V.5*).

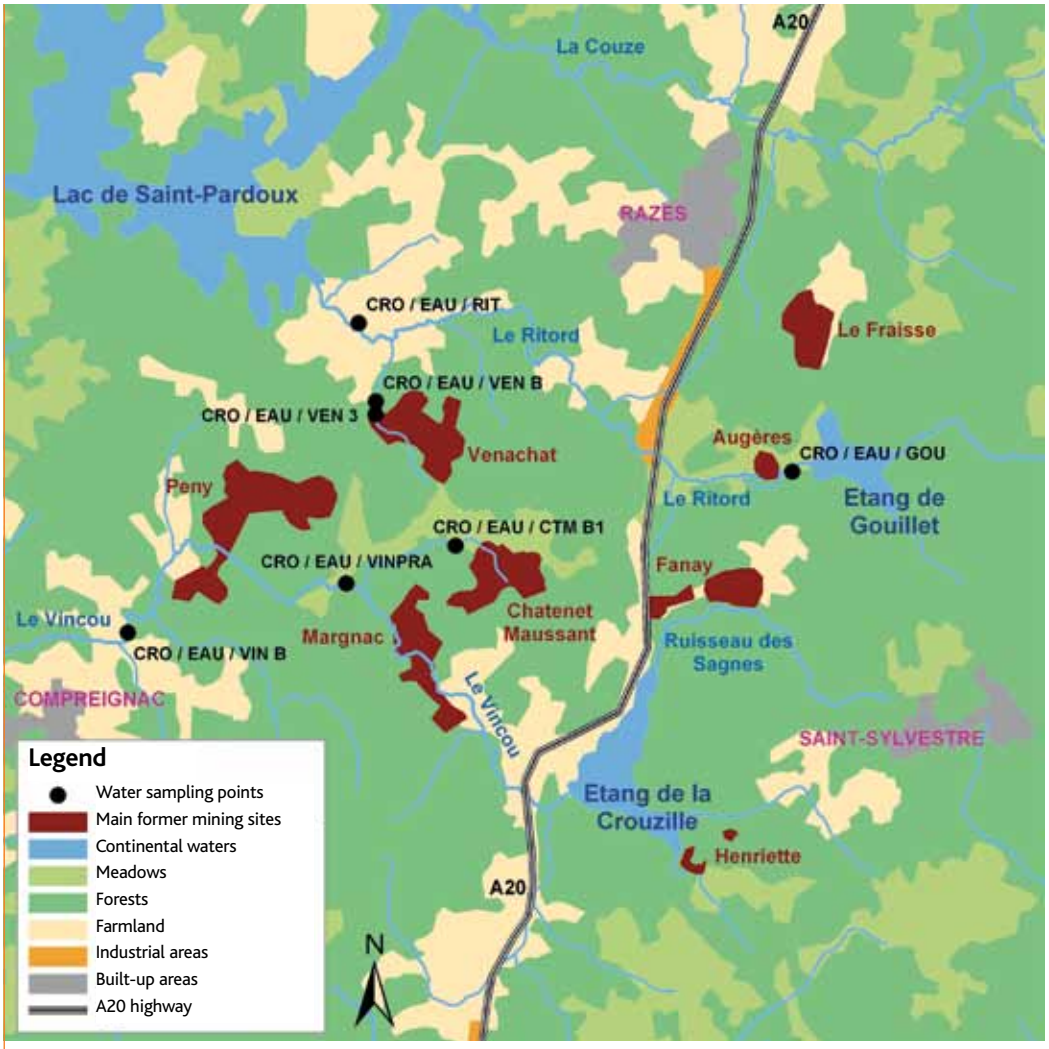

Figure V.5 - Main rivers and mining areas of the Vincou and Ritord drainage basins

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Figure V.6 - Crouzille Pond

Downstream of Crouzille Pond (*Figure V.6*), IRSN has been collecting water samples from the Vincou since 1966. The samples have been used for historical monitoring of radioactivity during the different phases of operation of the mines.

The operating and subsequent monitoring phases of the site can be observed in the gross alpha activity and the radium-226 activity of the water samples from the Vincou (*Figure V.7*). During the operating period of the mining sites (1948-1995), the average annual gross alpha activity varied between 1 and 11 Bq/L according to the industrial operations on the sites and to the improvement in effluent treatment techniques. The maximum value measured was 33 Bq/L in June 1978. Since the shutdown of the mine in 1995, the average annual gross alpha activity has not

exceeded 1.13 Bq/L and has decreased steadily to reach 0.45 Bq/L in 2010. Radium-226 activity was close to 0.1 Bq/L.

These observations agree with those obtained in 2010 by Areva at the water monitoring points on the Vincou downstream of Crouzille Pond (radium-226 activity between 0.02 and 0.14 Bq/L). The maximum uranium-238 level in the water of the Vincou downstream of all the mining sites (point VIN B – *see Figure V.5*) was 24 µg/L. These values are slightly higher than those generally observed in surface water in similar geological contexts not influenced by mining. They are similar to the results obtained at point CTM B1 (*Figure V.5*) in a stream receiving water from the Châtenet Maussant site which flows into the Vincou.

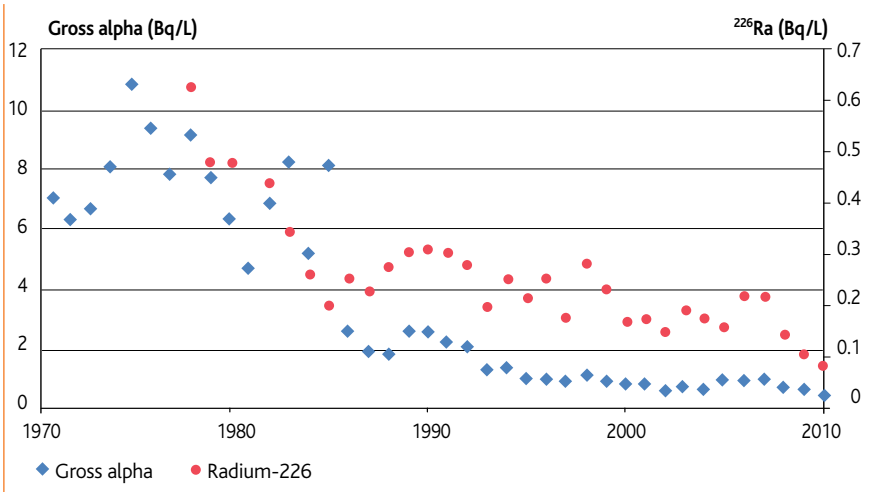

Figure V.7 - Gross alpha and radium-226 activity levels in water downstream of the Vincou basin mining sites – IRSN data (Bq/L)

Ritord drainage basin

Le Gouillet Pond feeds a small stream, the Ritord (*Figures V.5 and V.8*), which receives discharge from five mining outlets over a distance of five kilometers. The stream receives discharge from the main outlet of the Fanay-Augères site and then secondary discharge from other mining sites (Vénachat, etc.). It flows into Saint-Pardoux Lake, an artificial lake created in 1976 on the river Couze.

Overall, no difference is observed between measurements made on the Ritord upstream of all the sites (outlet from Le Gouillet Pond) and the point downstream of all the mining sites (where the Ritord flows into Saint-Pardoux Lake). Activities of approximately 0.1 Bq/L of radium-226 and 5 µg/L of uranium-238 were measured in 2010. Only the gross alpha measurements showed activity levels, close to 0.4 Bq/L, higher than the guideline values recommended by the public health code for water intended for human consumption (0.1 Bq/L).

Lower down the drainage basin, the mining signature was observed in the water flowing into the natural environment immediately downstream of the Vénachat mining site (0.2 Bq/L of radium-226 and between 15 and 32 µg/L of uranium-238 at points VENB and VEN3), with a maximum gross alpha activity of 1.05 Bq/L measured at point VENB in 2010. However, additional concentrations in the water of the stream could no longer be observed where the Ritord flows into Saint-Pardoux Lake.

Figure V.8 - The Ritord at Razès, between Le Gouillet Pond and Saint-Pardoux Lake

Gartempe drainage basin

With a length of 206 km and a drainage basin covering an area of 3,922 km², the Gartempe is the main tributary of the river Creuse. Its source is near the small village of Lépinas in the Creuse department, and it receives water from various mining sites (including Puy Teigneux, Puy de l'Age and Bellezane) and from the Bessines industrial site (*Figure V.9*). These sites are subject to monitoring of the radiological quality of surface water and ground water carried out by Areva.

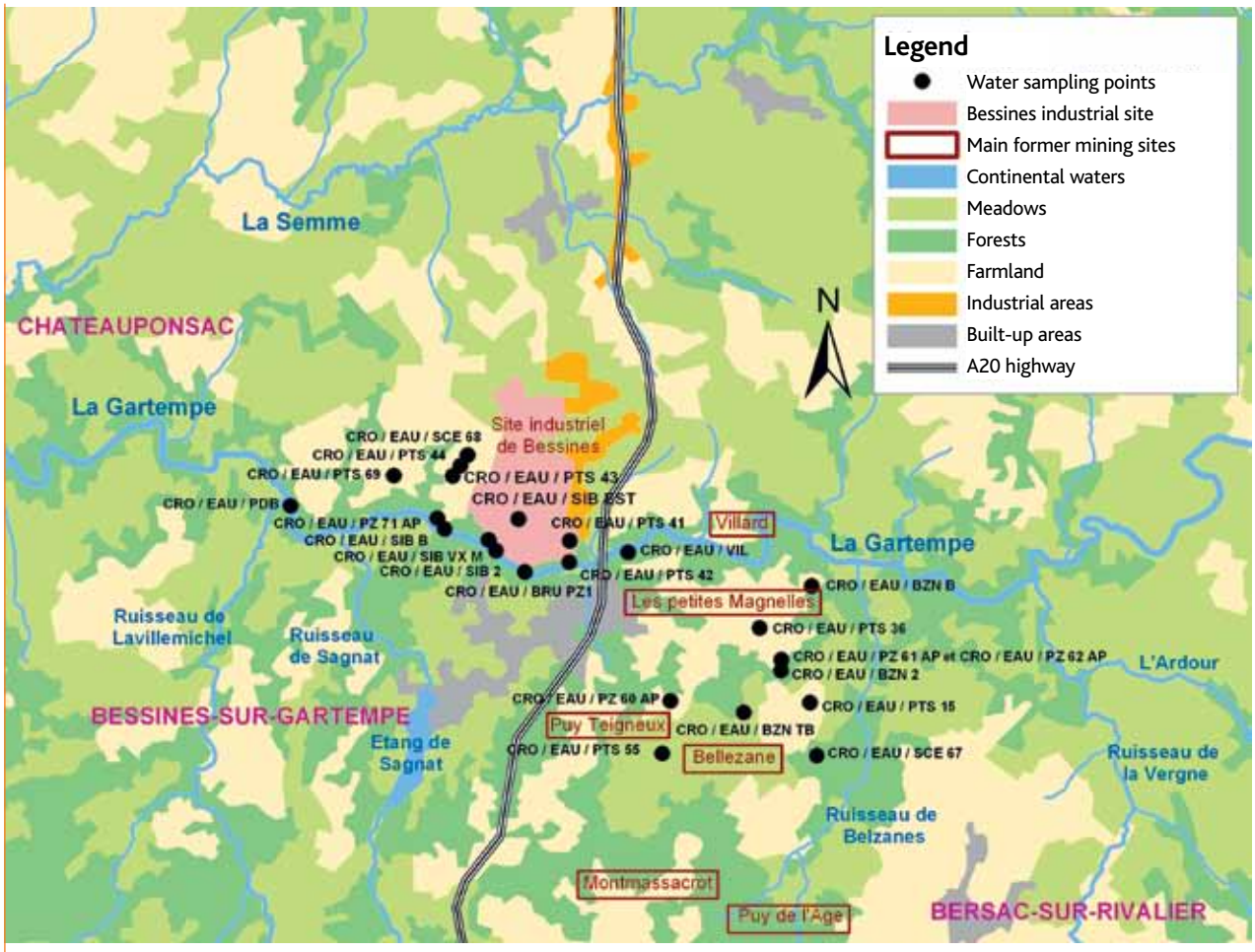

Figure V.9 - Main rivers and mining areas of the Gartempe drainage basin and Areva sampling point locations

The activity levels measured at the dozen ground water monitoring points showed no added uranium concentrations (between the decision threshold at 0.5 µg/L and 6 µg/L). A natural level of radium-226 was observed in all samples, ranging from 0.1 to 0.3 Bq/L. The gross alpha activity levels (0.16 and 0.37 Bq/L) and gross beta activity levels (1.6 and 1.9 Bq/L) at points PTS 42 and PTS 43 were slightly higher than the reference values recommended by the public health code for water intended for human consumption (gross alpha 0.1 Bq/L and gross beta 1 Bq/L).

The water discharged from the uranium ore tailings disposal sites (Le Brugeaud and Lavaugrasse on the Bessines industrial site, Bellezane, Montmassacrot), undergoes radium insolubilization treatment, and had low concentrations of radium-226 (approximately 0.1 Bq/L). The uranium-238 content of the surface water samples collected from the receiving stream immediately downstream of the Bellezane site (point BZN 2) was between 187 and 375 µg/L, indicating added concentrations in discharge in this stream with its low flow rate and consequent low dilution factor. The radium-226 and uranium activity levels measured in the water of the Gartempe upstream (point VIL) and downstream (point SIB B) of the Bessines industrial site were equivalent to the natural background. The impact of this site and the mining sites of this drainage basin on the water of the Gartempe consequently cannot be quantified because of the dilution of the discharge (the annual average flow rate of the Gartempe is about 30,000 m³/h upstream of the mining sites).

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The joint expert group (GEP) on the Limousin uranium mines

*The joint expert group (GEP) on the Limousin uranium mines submitted its final report (*Figure V.10*) to the Minister of Sustainable Development and to the Chairman of ASN on September 15, 2010. The report provides the first interdisciplinary assessment throwing light on a complex matter: the legacy of uranium mining in France. This legacy involves 230 sites in 12 regions and 25 departments. It is associated with a number of issues, including the ore processing tailings disposal facilities and their future, the risks related to the reuse of waste rock, the accumulation of radionuclides in the sediments of watercourses downstream of the sites, and the possibility of radon transfer from the sites to inhabited areas. Members of the public are often in direct contact with these sites, raising questions regularly, and the sites are still sources of potentially significant exposure for the public.*

Figure V.10 - Final report of the joint expert group (GEP) on the Limousin uranium mines

Among the various actions undertaken by the public authorities to deal with these issues and answer these questions, the setting-up of the GEP by the Ministers of Sustainable Development, Industry and Health in 2006 was a completely original initiative. The many competencies brought together in the group meant that it could explore the different technical facets of the topic. The group also and above all was notable in involving members from different backgrounds and with different outlooks in long-term work. Experts from public bodies (including IRSN and InVS), the academic world, Areva, regulatory authorities and foreign bodies, but also from local and national associations, were brought together to take a critical look at the monitoring of the rehabilitated mining sites and clarify for the authorities and the operator the management options to be implemented for the long term. As a public expert, IRSN played a critical role in setting up and completing this novel approach, for example by running the scientific secretariat of the GEP and co-chairing its four working groups.

In its work, the GEP conducted a methodological analysis based on the in-depth assessment of the situation of a number of Limousin sites. This analysis led the GEP to emphasize a movement towards openness and progress, increasingly taking account of the concerns raised by the associations, but also to stress the need to pursue the work already undertaken in greater depth and more systematically, in order to cover all the sites and situations and ensure the long-term continuity of the approach initiated by public authorities. The aim is both to make progress in the management of the current impacts and to anticipate future impacts, by taking possible changes in the sites into account more systematically. To this end it has put forward a number of recommendations, grouped into 15 major recommendations and organized around six priorities:

- ***institutional viewpoint*** *and the regulatory framework for post-uranium mining;*
- ***knowledge*** *of the sites and the need for studies and research to plan their future;*
- ***assessment*** *of the radiological and chemical impacts on population and on the environment;*
- ***measures*** *for upgrading monitoring;*
- ***robustness*** *of rehabilitations over the long term;*
- ***information*** *and participation of local bodies and communities.*

Among its various recommendations, the GEP has emphasized the importance of informing the public and encouraging its participation in the implementation of rehabilitation work on former uranium mining sites. It has therefore recommended that the collection and release of information on the location and other details of these sites should be continued, along with site monitoring activities. In particular, it called for extension of the work undertaken through the Mimausa program to summarize and archive the memories and the impact of the uranium mines.

With regard to the current regulatory monitoring of the mining sites, it considered that the systems deployed for monitoring discharge sources, transfers to the environment and potential impacts did not always appear appropriate in view of the needs and the prioritization of the issues. For example, the GEP considered that it was necessary to reinforce the

Focus (continued)

Focus (continued)

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measurements made downstream of the main waste rock dumps, in the potential accumulation areas for substances released by the sites (measurements on the sediments, for example) or in farm wells located within their area of influence. It also called for continuation of the work on obtaining knowledge of water circulation on the scale of a site and on assessment of the ecotoxicity of the substances contained in mine discharge.

The group also noted that the monitoring currently in place was mainly focused on exposure indicators and, in certain cases, would benefit from being supplemented by monitoring focused on these effects (monitoring of the ecosystems).

The GEP stressed the importance of ensuring the quality and the credibility of monitoring by further reinforcing joint acquisition, checking and accessibility of data. For this it emphasized the importance of the site checks conducted by authorities, including through unannounced inspections, and invited IRSN to take account of the impacts associated with the former uranium mining sites when rolling out its new monitoring strategy. With the aim of giving visibility to the monitoring of the sites and promoting the accessibility of results, the GEP suggested that marking of field measurement points and their identification in documents be improved, and also that access to data, including via Internet, be facilitated, emphasizing in this context the considerable progress represented by the creation of the national environmental radioactivity measurement network (RNM).

Bois Noirs Limouzat mining site (Forez mining area)

Located at Saint-Priest-la-Prugne in south-central France, the Forez mining division site covers an area of 88 hectares, of which 18 hectares are occupied by a water-filled storage basin and 3 hectares are the site of former processing plants. It was worked as an open pit mine and an underground mine between 1955 and 1980. It included an ore processing and separation plant which was in operation from 1960 to 1980. Ore processing tailings are stored under water in the basin, behind a homogeneous earth dam, located on the river Besbre, the course of which was diverted by a canal. Part of the tailings were reused to backfill the underground mine workings. The facilities were dismantled in 1981 and demolished in 2006. The site, which has a water treatment plant, has been rehabilitated.

The radium-226 measurement results at the ten surface water monitoring points of this mining site in 2010 varied between the decision threshold (< 0.01 Bq/L) and 0.16 Bq/L. These activities are equivalent or close to the natural background. The uranium contents (between < 0.5 µg/L and 8 µg/L) were in the range of values observed in water in contact with uranium-bearing rocks, except for water collected by drain no. 40, located upstream of the Besbre discharge, on the right bank. Samples from this drain had uranium contents greater than background (between 107 and 165 µg/L), indicating additional concentrations related to the site's mining activities.

Bosc mining site (Lodève mining area)

In 1975, the first ore was mined from the underground mine of the main site of Mas Lavayre in southern France (Le Bosc). The open pit mines at Mas d'Alary began operation in 1978, and continued until 1984. Between 1989 and 1992, other small mines were also in operation (Rabéjac, La Plane, Puech Bouissou). From 1994 to 1997, only the Mas Lavayre underground mine was still being operated. The plant was dismantled in 1999 and rehabilitation works were completed in 2001.

The main site is now home to a team tasked with monitoring the environment and treating water from the mine (completely flooded) and the rehabilitated quarries containing processed ore tailings. Areva monitors the surface water of the drainage system around the mining site. Water samples are collected from the Riviéral stream draining the whole of the industrial area and the cap of the disposal facility for the plant dismantling waste, from the Mas d'Alary stream draining the whole of the mining area and the cap of the processing tailings disposal facility, and from the river Lergue upstream and downstream of the discharge point.

The results of the uranium-238 measurements for the two streams draining water from the mining area showed added concentrations due to mining activity (between 530 µg/L and 1,930 µg/L). In the Lergue, the uranium content upstream and downstream of discharge was equivalent to the natural background (between < 0.5 and 10 µg/L). The activity levels of

Table V.2 - Minimum and maximum activity levels measured in the surface water and ground water samples collected in 2010 on the Mas Lavayre site and in its close environment (in Bq/L for ^{226}Ra and µg/L for ^{238}U)

Water type	Sampling point	^{226}Ra (Bq/L)	^{238}U (µg/L)
River water	Lergue (upstream)	< 0.01 - 0.08	< 0.5 - 1
	Lergue (downstream)	0.02 - 0.06	3 -10
Stream water	Mas d'Alary stream	0.03 - 0.09	833 - 1,930
	Riviéral stream	0.05 - 0.23	530 - 760
Ground water	Piezo Hydro 34	0.89 - 1.17	3 -14
	Piezo P37	0.26 - 0.30	3,090 - 3,240
	Piezo PZ 1	0.01 - 0.06	162 - 188
	Piezo PZ 2	0.03 - 0.04	19
	Piezo PZ 3	0.03 - 0.07	6 - 30
	Piezo PZ 4	0.04 - 0.05	371 - 368
	Piezo PZ 6	0.04 - 0.08	1,250 - 2,030
	Piezo PZ 7	0.01	11,100
	Piezo PZ 8	0.61 - 0.62	111 - 135
	Piezo PZ FS	0.35 - 0.62	73,000 - 164,000

radium-226 in the surface water varied between < 0.01 and 0.23 Bq/L. These concentrations are in the range of values observed for water in contact with uranium-bearing rocks. Ground water quality is monitored by Areva using ten piezometers located at various points over the whole site. The radium-226 and uranium-238 measurements on the water samples show a substantial effect on the site ground water. The highest radium-226 activities were observed at points Hydro 34 and PZ 8 located between the mining area and the area west of the Lergue (between 0.61 and 1.17 Bq/L). The highest uranium-238 contents were observed at point PZ FS (between 73,000 and 164,000 µg/L), located near the dismantling material storage facility. Points PZ7 (11,100 µg/L), P37 (3240 µg/L) and PZ 6 (2030 µg/L) also showed high uranium-238 contents due to the past mining activities of the site (*Table V.2*).

Gueugnon site (Saône-et-Loire mining area)

In 1954, a uranium ore processing plant was built at Gueugnon in the Saône-et-Loire department in east-central France. Operating from 1955 to 1980, the plant produced nearly 10,000 metric tons of uranium before it was dismantled in 1980-1981. A disposal facility for waste and tailings generated by the operation of the plant was also opened in 1955. Converted from disused sand pits, it now contains 225,000 metric tons of ore processing tailings and plant dismantling waste, and is monitored by Areva.

Since 1981, works and rehabilitation have been carried out on the areas of the former plant and the disposal facility. As part of this program, in 2010 Areva carried out rehabilitation work at the former plant and around the disposal facility, including the laying of special surfacing on the south car park of the Jean-Laville stadium. Following these works, in 2010 IRSN was commissioned by the Directorate General for Risk Prevention (DGPR) to determine whether the dose rates in the rehabilitated areas were at a level equivalent to that of the surrounding natural environment (further information at www.irsn.fr).

Surface water and ground water samples were monitored at six sampling points. Only one piezometer showed radium-226 (0.4 Bq/L) and uranium (836 µg/L) levels substantially higher than the surrounding background. The surface water showed activity levels of radium-226 (between 0.02 and 0.08 Bq/L) and uranium (between < 0.5 and 9 µg/L) equivalent to the natural background.

Bauzot mining site (Saône-et-Loire mining area)

The Bauzot site, located at Issy-l'Évêque, also in the Saône-et-Loire department, consisted of an underground uranium mine, an open pit mine and a low-level industrial waste disposal facility. It was in operation from 1950 to 1985. The pit of the open pit mine was backfilled, and the disposal facility was covered with a layer of impermeable material and a layer of topsoil. The site was then rehabilitated and fenced off.

Surface water (river, lake, waste water) and ground water are sampled by Areva to monitor the disposal facility. The radium-226 and uranium-238 measurements made in 2010 on the samples generally showed added concentration levels related to past activities of the site. The highest radium-226 activity levels were close to or slightly greater than 1 Bq/L, and the highest uranium content was greater than 2,000 µg/L at the "fosse" sampling point. The other points showed uranium contents close to 100 µg/L, greater than the surrounding background.

Vendée mining area

The Vendée mining area in western France was in operation from 1954 to 1990. Until 1991, an ore processing plant was also located on the Écarpière site. Rehabilitation work was carried out on the site from 1989 to 1996. The Écarpière site is now the base of an Areva team tasked with environmental monitoring of 25 sites operated by the Vendée mining division and 18 former mining sites in Brittany.

IRSN monitoring of surface water samples from the vicinity of the Écarpière site has not revealed any anomalies with regard to the uranium and radium-226 concentrations.

V.3 ENVIRONMENTAL MONITORING OF INDUSTRIES IN THE FRONT END OF THE NUCLEAR FUEL CYCLE

The processing and concentration plants located close to the mines mainly produced uranates (containing approximately 70% uranium) and in some cases oxides (containing up to 80% uranium). Today, UO_2 low-enriched to 3-5% uranium-235 is the end material of pressurized water reactor (PWR) fuel. In the current plants, enrichment is carried out on an ultrapure chemical compound, uranium hexafluoride (UF_6), obtained by conversion of mining concentrates.

In France, two Comurhex (Areva group) plants work in series to produce UF_4 and UF_6. At Malvesi, in southwest France, the ore concentrates are converted to UF_4. At Pierrelatte, in the Rhone valley, the second Comurhex plant converts the UF_4 to UF_6.

The uranium is then transferred to the George Besse enrichment plant operated by Eurodif (also at Pierrelatte) in the form of solid UF_6. The three isotopes of uranium present in the natural state (uranium-234, -235 and -238) are separated selectively by passing UF_6 gas through porous membranes (gaseous diffusion barrier). The lighter isotopes pass through the barrier more easily than the heavier ones, so the process produces selective and progressive enrichment. Uranium enrichment technology is changing from gaseous diffusion to centrifugation, offering higher performance, and the Georges Besse plant is to be replaced by a new facility. The *Société d'Enrichissement du Tricastin* (SET) is the owner of this project and the operator of the Georges Besse II plant, where production will increase gradually until 2016.

After enrichment, the UF_6 is delivered to the Franco-Belgian Fuel Fabrication (FBFC) plant at Romans-sur-Isère, which converts it to uranium oxide (UO_2), pelletizes it (production of UO_2 pellets), then fabricates the fuel assemblies for light water nuclear power plants.

Comurhex plant at Malvési

Based 3 km north of Narbonne in southern France since 1959 (*Figure V.11*), the Comurhex Malvési plant produces 14,000 metric tons of uranium tetrafluoride (UF_4) each year, a quarter of worldwide production, from uranium concentrates (yellow cake).

The industrial process used leads to uranium discharge into the air via stacks on the site and into the Tauran canal through the liquid waste discharge pipe. Between 1960 and 1980, the site also used uranium recovered from irradiated nuclear fuel processing activities at the Marcoule plant (southern France). Waste produced during this period, with contents including plutonium, americium-241 and technetium-99, was stored in ponds on the plant site and is still there.

Lastly, since the plant was opened, changes in the outfall have been made and different events have occurred (discharge outlet pond overflows, flooding due to poor weather).

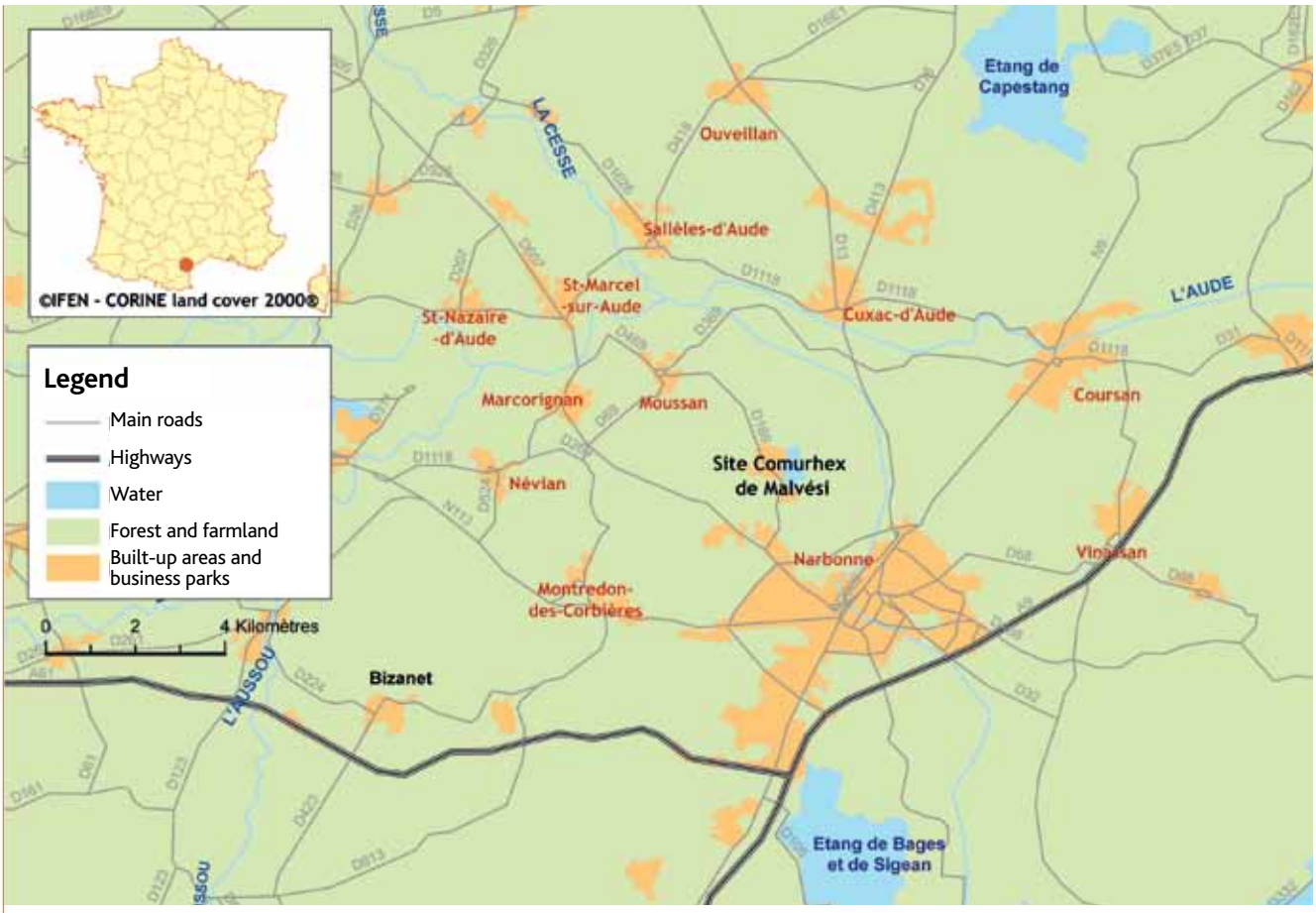

Figure V.11 - Geographical location of the Comurhex Malvési site

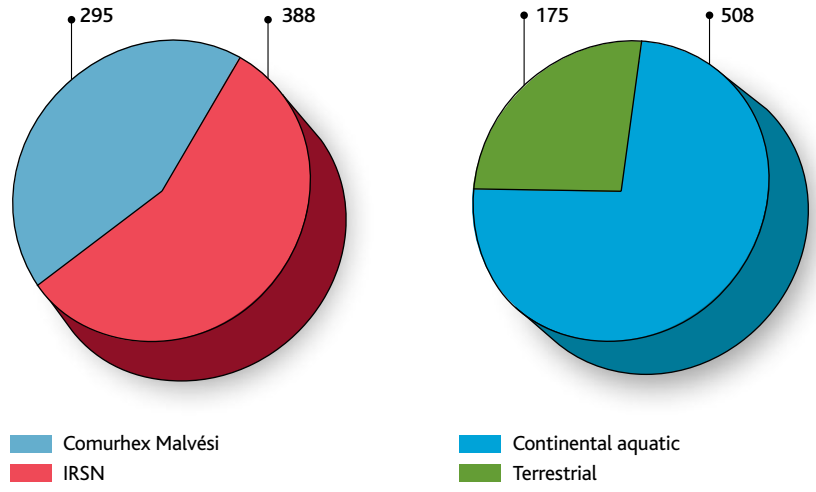

Figure V.12 - Comurhex Malvési site: breakdown of the number of samples by data provider and per compartment

Atmospheric compartment

Atmospheric aerosols

In the environment of the Comurhex Malvési plant, atmospheric aerosol monitoring has not detected any artificial radionuclides, as shown by the tracking of gross alpha and beta activity levels (*Table V.3, Figures V.13 and V.14*).

Table V.3 - Activity levels measured in atmospheric aerosol samples collected in the environment of the Comurhex Malvési plant (mBq/m³)

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Gross activity indices	Alpha activity	0.055 ± 0.001
	Beta activity	0.39 ± 0.01

Only two unusual values were observed, in the sample from October 25 to November 2, 2010: 12.56 ± 6.66 mBq/m³ for the gross alpha activity and 7.14 ± 1.78 mBq/m³ for the gross beta activity. No particular event was recorded during this period at the Comurhex plant.

Terrestrial compartment

Terrestrial flora

Terrestrial plants are sampled regularly in the area potentially affected by discharge, i.e. to the east of the plant, and in the areas not potentially affected.

Among the plant samples, cypress leaves showed the highest activities of uranium isotopes (*Table V.4*). In this bioindicator, the $^{235}U/^{238}U$ isotope ratio expressed by weight (0.68 ± 0.02%), which is significantly lower than the ratio measured in naturally occurring uranium ($^{235}U/^{238}U$ = 0.72%), indicates depletion of ^{235}U. This means that the predominant source of the uranium measured in these plants is uranium discharged by the Malvési plant.

In the sampled foodstuffs (wheat ears and lettuce leaves), the uranium isotope activity levels were generally lower than in the cypress leaves, but were highly variable. In these matrices, the $^{235}U/^{238}U$ isotope ratio expressed by weight is similar to the ratio measured in naturally occurring uranium ($^{235}U/^{238}U$ = 0.72%).

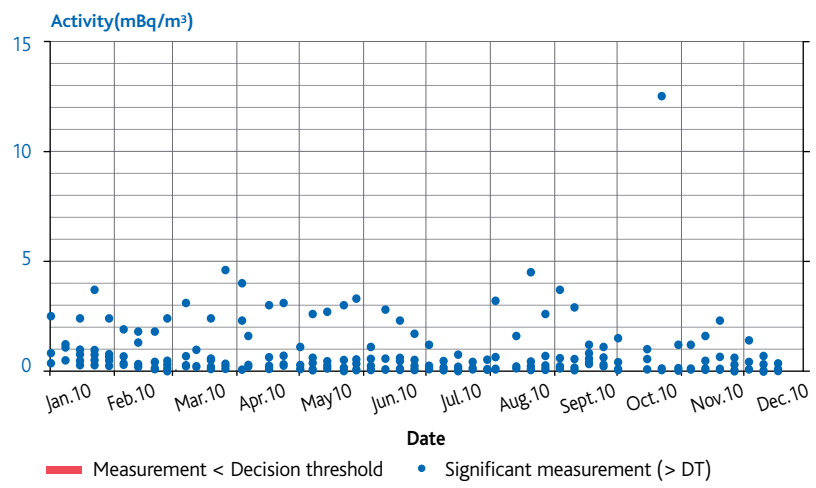

Figure V.13 - Time plot of gross alpha activity in atmospheric aerosol samples collected in the vicinity of the Comurhex Malvési facility (mBq/m³)

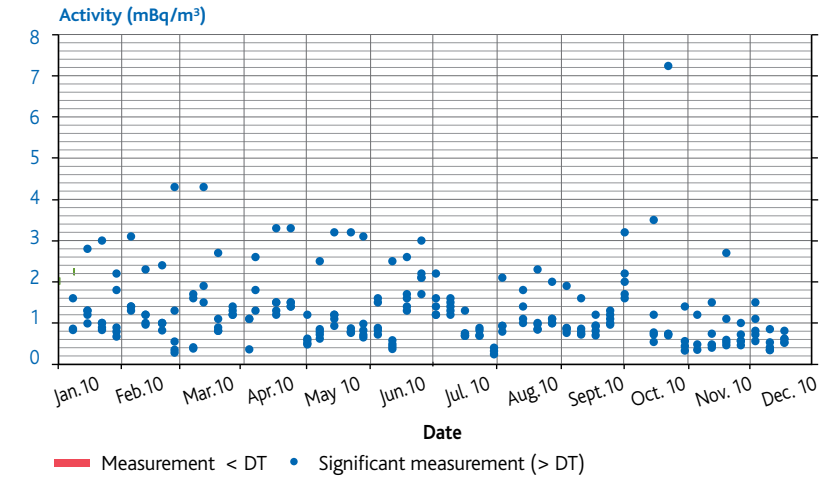

Figure V.14 – Time plot of gross beta activity in atmospheric aerosol samples collected in the vicinity of the Comurhex Malvési facility (mBq/m³)

Table V.4 - Uranium isotope activity levels in cypress leaf samples collected in the environment of the Malvési site in 2011 (Bq/kg dry)

Station	Type	^{234}U	^{235}U	^{236}U	^{238}U	$^{235}U/^{238}U$ by weight (%)
Malvési East	Cypress leaves	34 ± 4	1.6 ± 0.1	< 0.02	37 ± 3	0.68 ± 0.02

In the terrestrial environment, analyses by IRSN in 2007 (***Étude radioécologique de l'environnement du site de Malvési*** – report IRSN/DEI/SESURE 2008-20) emphasized the effect on cypress leaves (*Figure V.15*) and wheat ears of uranium from atmospheric discharge through the stack, and for ^{230}Th, ^{241}Am and the plutonium isotopes, the source of which was diffuse releases from the site ponds.
The results obtained by ASN during a radiological inspection conducted in June 2011 in the environment of the Comurhex plant show a decrease in concentration levels in the terrestrial environment (and in the aquatic environment) by discharge from this facility. In the terrestrial environment, the effect on cypress needles and foodstuffs (wheat and lettuce) of uranium discharged into the atmosphere by the plant decreased compared with 2007, when the previous radioecological study was carried out by IRSN. In addition, these matrices show, over the

same period, a greater decrease in concentration levels radionuclides from storage ponds (plutonium isotopes) or settling ponds (^{230}Th) on the site.

Farm produce and foodstuffs

Fruit and vegetables

The impact of the atmospheric discharge from the Malvési site decreases very rapidly away from the prevailing wind direction and with distance from the plant. Fruit and vegetables grown more than 4 km from the site showed uranium-234 and 238 activity levels compatible with a natural origin (*Table V.5*).

The average activity levels measured in France, except for plants from uranium-bearing areas, are around a few millibecquerels per kilogram of wet matter, with significant variability depending on soil type.

Aquatic compartment

The Malvési site is located in the 6,000 km² drainage basin of the river Aude. The hydrology near the site is characterized by a major system of irrigation canals fed by the Aude, which flows through an alluvial plain. The following irrigation canals are located near the site:

- **Robine canal**, which runs almost 1.7 km to the east of the plant;
- **Cadarièg canal** and its feeders flowing into the Mayral stream;
- **Tauran canal**, which is to the east of the plant, also flows into the Mayral.

Measurements in water samples from the Tauran canals showed a gross alpha activity in the region of 0.15 Bq/L in 2009-2010 (*Figure V.16*).

IRSN has been measuring gross alpha activity in the Cadarièg canal since 1975. In the water of this canal, the gross alpha activity is correlated with the uranium concentration (w/v) (*Figure V.17*).

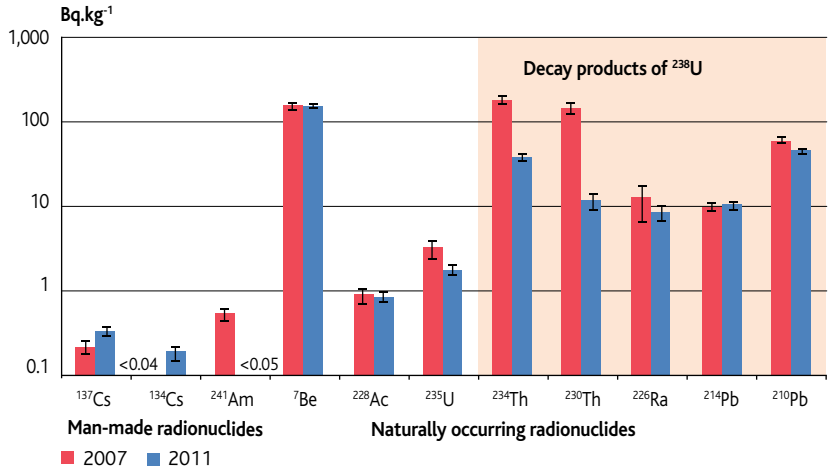

Figure V.15 - Comparison of the specific activity levels of the main artificial and natural gamma-emitting radionuclides in cypress leaves in 2007 and 2011 (Bq/kg)

Table V.5 - Activity levels measured in fruit and vegetables grown in the vicinity of the Comurhex Malvési site (Bq/kg wet)

Location	4 km to the west, under the secondary prevailing winds	9.5 km to the northwest, outside the area of influence of the prevailing winds
Radionuclide	Lettuce	Peach
^{210}Pb	< 0.56	< 0.62
^{226}Ra	0.029 ± 0.009	< 0.0043
^{234}U	0.04 ± 0.01	< 0.0086
^{235}U	< 0.008	< 0.0052
^{238}U	0.018 ± 0.006	< 0.0074

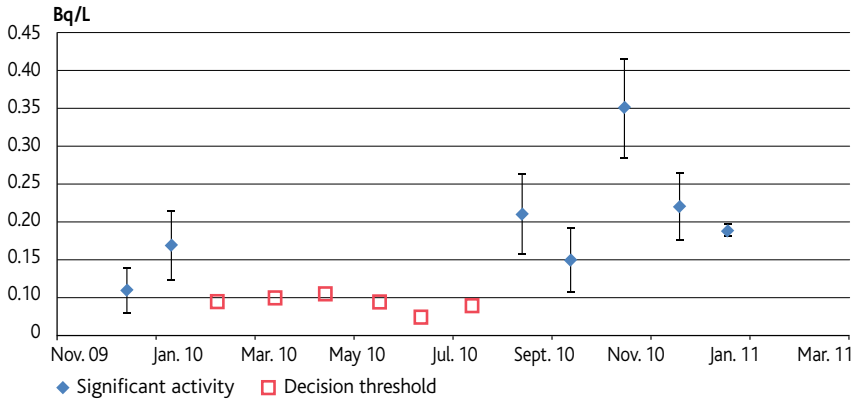

Figure V.16 - Gross alpha activity measured in the Tauran canal (Bq/L)

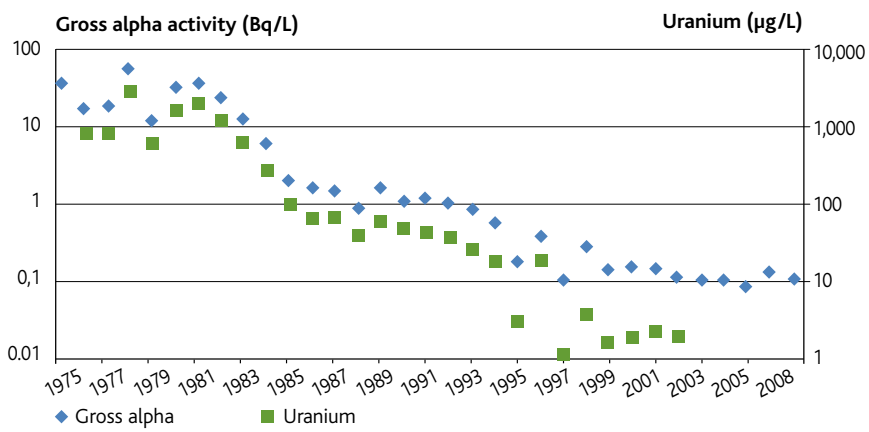

Figure V.17 - Gross alpha activity (Bq/L) and uranium concentration (µg/L) measured in the Cadarièg canal (IRSN measurements)

Grouped monitoring of the Areva Tricastin facilities

Since the 1960s the Tricastin industrial site has accommodated several activities related to the fabrication of nuclear fuel (by companies such as Comurhex, Eurodif, FBFC, Socatri) and use (by companies such as Areva, CEA, EDF). This section presents the results of specific monitoring of facilities operated by Areva (Comurhex, Eurodif, SET, Socatri and Areva NC), industries in the front end and back end of the nuclear fuel cycle *(Figure V.18)*. The results of monitoring of nuclear power plants, including the Tricastin NPP, are given in section V.4.

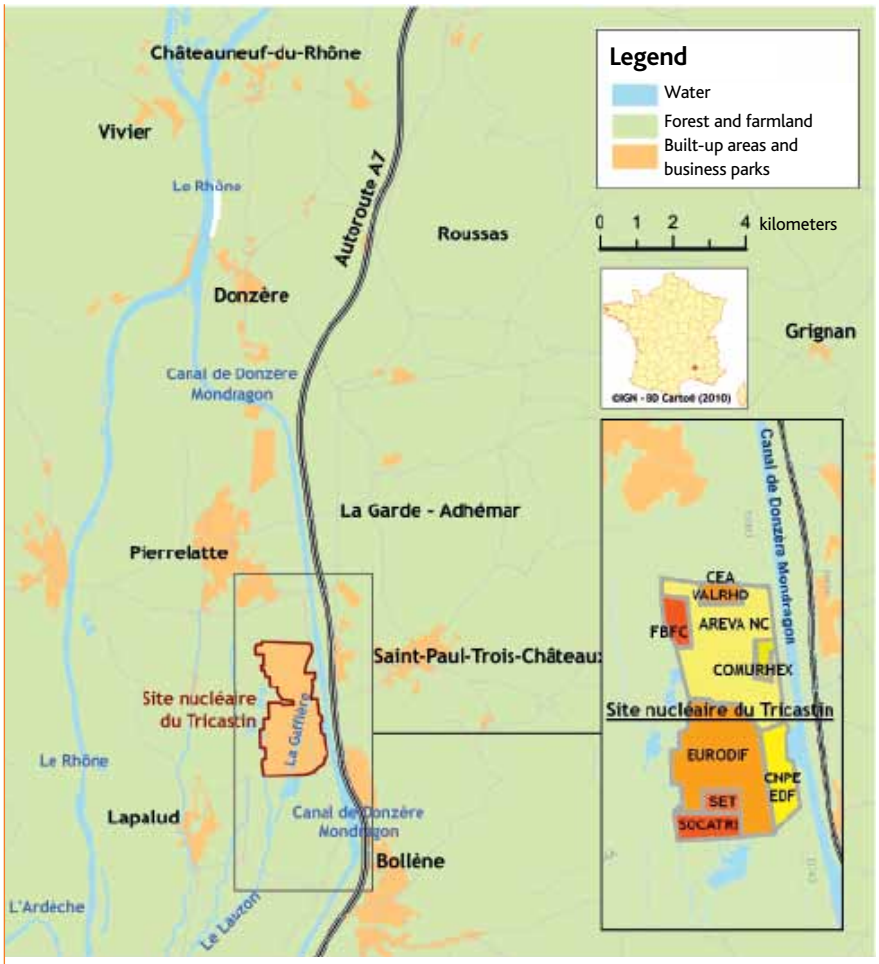

Figure V.18 - Geographical location of the Tricastin nuclear site

Comurhex Pierrelatte plant

The Comurhex Pierrelatte plant converts uranium tetrafluoride (UF_4) to uranium hexafluoride (UF_6), a transformation step between the mining of ore and the enrichment of uranium.

Eurodif Production plant

The Eurodif Production plant is also known as the Georges Besse plant. Since 1982, using a gaseous diffusion process, it has produced uranium enriched in uranium-235 to a level sufficient for use in nuclear reactors.

Areva Pierrelatte plant

The Areva Pierrelatte site is involved in several industrial steps of the nuclear energy cycle, and in particular in uranium chemistry. This plant also carries out other work: maintenance of uranium transport containers, and dismantling of gaseous diffusion plants.

SET Georges Besse II plant

The *Société d'Enrichissement du Tricastin* (SET), part of the Areva group, operates the new centrifugation uranium enrichment plant on the Tricastin nuclear site. Inaugurated in 2010, it will gradually replace the Eurodif plant.

Socatri plant

Socatri is a uranium purification and recovery facility. It deals with maintenance and dismantling of nuclear equipment, and the treatment of liquid effluents and nuclear waste.

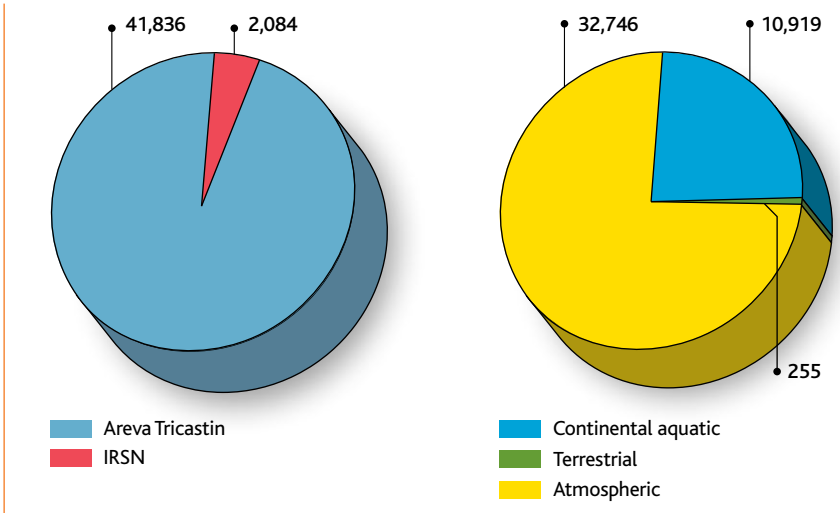

Figure V.19 - Tricastin nuclear site: breakdown of the number of samples by data provider and by compartment

Atmospheric compartment

Atmospheric aerosols

In the environment of the Tricastin site, atmospheric aerosols are monitored daily by measuring gross alpha and beta activity levels, by gamma spectrometry measurement, and by additional analyses if an anomaly is observed.

Uranium isotope activity levels above the customary values have been measured in samples collected by Areva and IRSN at Pierrelatte (*Table V.6*). This occasional anomaly was due to an incident that occurred on August 1, 2010, involving uranium release through the gaseous effluent outlet of plant W on the Areva site (this plant is specialized in the deconversion of depleted uranium hexafluoride (UF_6)).

This event was reported by Areva to ASN on August 3, 2010.

Table V.6 - Activity measured in the sample collected between August 1 and August 2, 2010 by an IRSN monitoring station at Pierrelatte (mBq/m³)

Radionuclide	Activity (mBq/m³)
Uranium-234	0.14 ± 0.05
Uranium-235	0.011 ± 0.009
Uranium-236	< 0.0064
Uranium-238	0.83 ± 0.2

In a check by Areva, an abnormal gross alpha activity value was observed in an aerosol sample collected at Bollène between February 3 and 4, 2010 (1.7 ± 0.5 mBq/m³). Additional investigations by spectrometry led to the conclusion that this unusual value was not due to artificial radionuclides (absence of plutonium isotopes and normal activity levels of uranium isotopes) (*Table V.7*).

Other than these observations, no abnormal activity was detected (*Figures V.20 and V.21*).

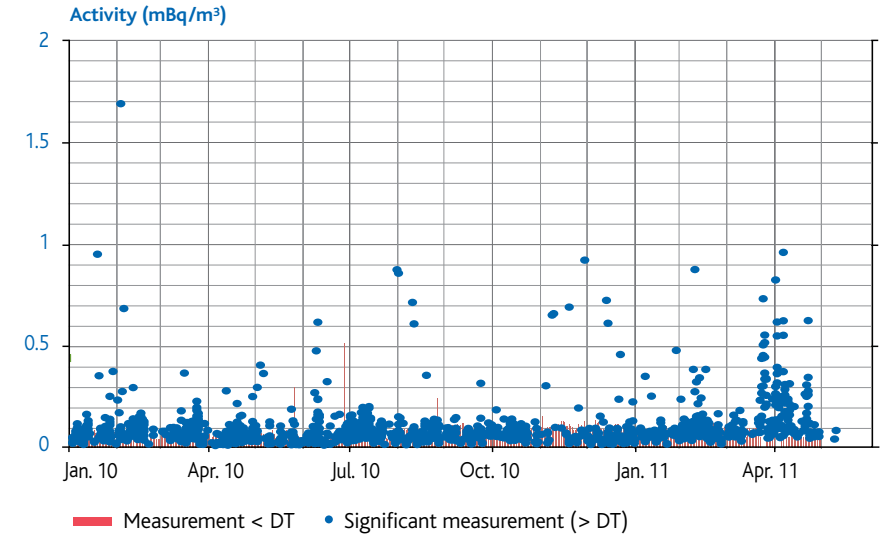

Figure V.20 - Time plot of gross alpha activity in atmospheric aerosol samples collected in the environment of the Tricastin site (mBq/m³)

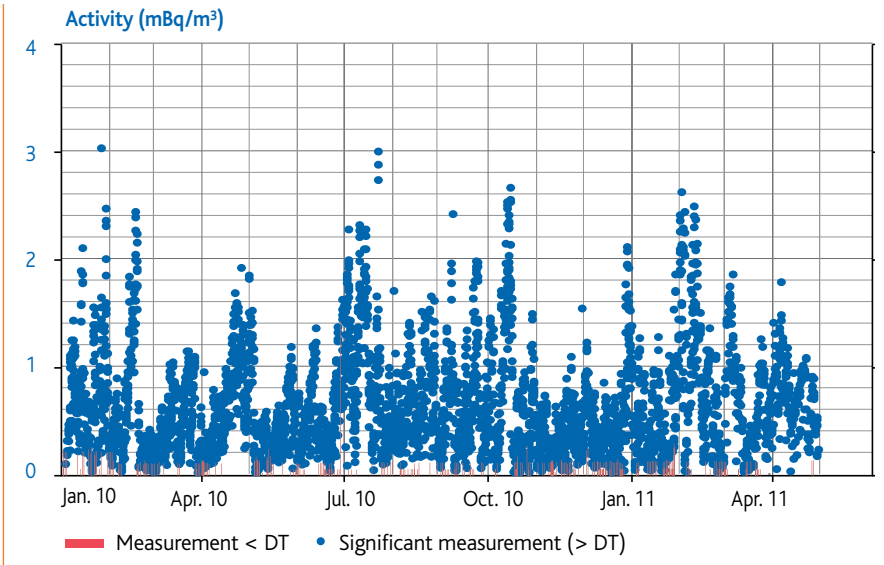

Figure V.21 - Time plot of gross beta activity in atmospheric aerosol samples collected in the environment of the Tricastin site (mBq/m³)

Table V.7 - Activity measured in the sample collected between February 3 and 4, 2010 by one of the Areva monitoring stations at Bollène (mBq/m³)

Radionuclide	Activity (mBq/m³)	Radionuclide	Activity (mBq/m³)
Plutonium-238	< 0.063	Uranium-234	0.098
Plutonium-239	< 0.0081	Uranium-235	< 0.012
Plutonium-240	< 0.0081	Uranium-238	0.021

An increase in gross beta activity was also observed between the end of March and the end of April 2011 (*Table V.8*). This increase is attributed to the presence of artificial radionuclides linked with atmospheric fallout from the Fukushima accident.

For more information

Chapter III – Fukushima accident

Gases sampled by bubblers

Atmospheric tritium collectors are installed to the north (Pierrelatte) and south (Bollène) of the Tricastin site, along the axis of the prevailing winds. Tritium in the form of water vapor was measured in 20% of the air samples at values between 0.19 and 0.87 Bq/m³ (*Figure V.22*). The mean activity of all the samples, taking decision thresholds into account, was approximately 0.15 Bq/m³.

Rainwater

The rainwater collected near the Tricastin NPP had tritium activity levels between the decision thresholds and 7.8 Bq/L between 2009 and 2011 (*Figure V.23*).

Table V.8 - Gross alpha and beta activity levels of atmospheric aerosols collected in the environment of the Tricastin site (mBq/m³)

Facility	Radionuclide	Mean activity (mBq/m³)
Areva NC Pierrelatte Comurhex Pierrelatte Eurodif Production Société d'enrichissement du Tricastin Socatri	Gross alpha activity	0.011 ± 0.001
	Gross beta activity	0.25 ± 0.01 0.54 ± 0.01*

** Measurements taken during the period of the nuclear accident at the Fukushima nuclear power plant between March 22 and May 6, 2011.*

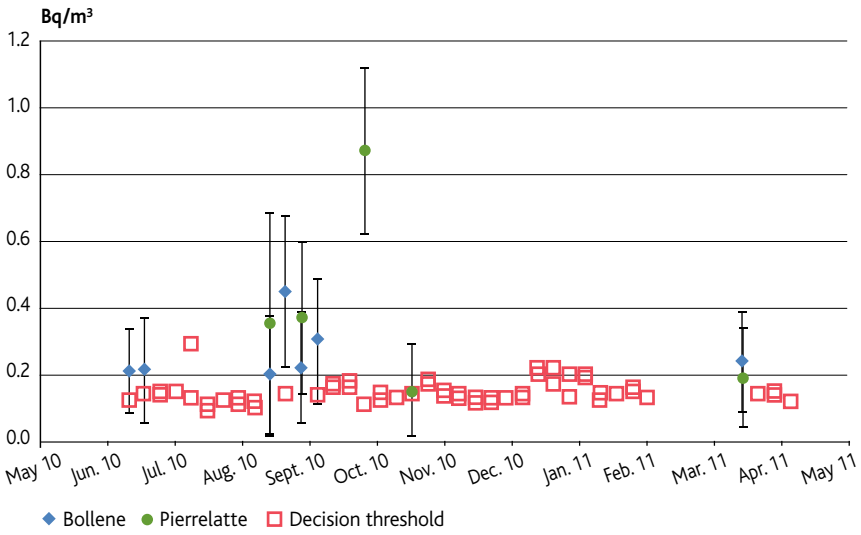

Figure V.22 - Activity of tritium in the form of water vapor in ambient air (Bq/m³)

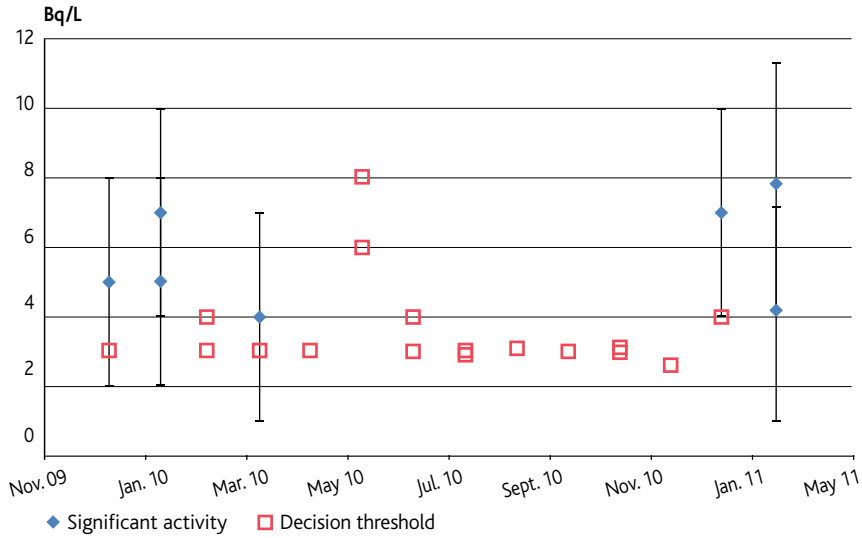

Figure V.23 - Tritium activity in rainwater collected in the vicinity of the Tricastin site (Bq/L)

Terrestrial compartment

The terrestrial environnement of the Tricastin site is subject to regular monitoring consisting of sampling grasses and plant produce under and away from the areas of influence of the prevailing winds.

Terrestrial flora

Six-monthy grass samples are collected in the vicinity of the Tricastin site on a north-south axis. Uranium was measured in most of the samples, with the same ranges of activity levels as those of grasses collected away from the potential effect of discharge (*Table V.9*). Activity levels of plutonium, americium and free tritium remained below decision thresholds. Similarly, the artificial gamma-emitting radionuclides (^{137}Cs, ^{134}Cs, ^{131}I, ^{54}Mn, ^{58}Co, ^{60}Co, etc.) were not detected by the measuring instruments used.

Carbon-14 results did not differ from the activity levels measured in the same matrices in areas outside the influence of discharge from nuclear plants.

Farm produce and foodstuffs

Cereals

The analysis results for uranium by weight and isotopes were lower than the decision thresholds in all three maize samples collected in 2010 near the Tricastin site (*Table V.10*).

No artificial gamma-emitting radionuclide was detected in the wheat sample collected at Chantemerle-lès-Grignan, about 12 km northeast of the Tricastin site. Uranium isotope analysis was not performed on this sample.

Leafy vegetables

In 2010, a lettuce sample collected 4 km northwest of the Tricastin complex, in an area located outside the influence of gaseous discharge, was subjected to radiological analyses. The results showed that the major activity was due to naturally occurring potassium-40 (*Table V.11*). Traces of uranium were measured, giving activity levels similar to those that can be observed in the natural environment. Cesium-137, measured at a specific activity of 0.078 ± 0.036 Bq/kg wet, comes from persistent effects of the Chernobyl accident.

*Table V.9 - Mean activity levels measured in grass samples collected in the vicinity of the Tricastin site (Bq/kg dry)**

Radionuclide	La Garde-Adhemar 4 km north of the site, outside the area of influence	Lamotte-du-Rhône 4 km south of the site, under the prevailing winds
^{137}Cs	< 1.6	< 1.6
^{238}Pu	< 0.005	< 0.006
$^{239+240}$Pu	< 0.005	< 0.006
^{241}Am	< 0.0075	< 0.011
^{234}U	0.5 ± 0.12	0.6 ± 0.14
^{235}U	< 0.18	< 0.27
^{238}U	< 0.35	0.3 ± 0.14
HTO (Bq/kg wet)	< 2.2	< 2.5
^{14}C (Bq/kg C)	235.2 ± 1	234.8 ± 1.1

** Unless otherwise indicated*

*Table V.10 - Mean activity levels measured in maize samples collected around the Tricastin site (Bq/kg dry)**

Radionuclide	Pierrelatte 2.5 km north of the site, outside the area of influence	Bollène 1.5 km south of the site, under the prevailing winds
U (mg/kg dry)	< 0.006	< 0.0021
^{232}U	< 0.023	< 0.008
^{234}U	< 0.015	< 0.008
^{235}U	< 0.015	< 0.008
^{236}U	< 0.015	< 0.008
^{238}U	< 0.015	< 0.008

** Unless otherwise indicated*

Table V.11 - Mean activity levels easured in the lettuce sample collected at Pierrelatte (Bq/kg wet)

Radionuclide	Lettuce
^{137}Cs	0.078 ± 0.036
^{40}K	99 ± 13
Other gamma-emitting RNs (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{60}Co, ^{54}Mn, ^{106}Ru, ^{131}I)	< 1
HTO	2.8 ± 1.8
^{234}U	0.06 ± 0.008
^{235}U	0.0033 ± 0.0015
^{238}U	0.06 ± 0.008

Continental aquatic compartment

Surface water

The right-bank counter-ditch (*Figure V.25*), which runs along the edge of the Tricastin site, is intended to collect runoff water and drain losses from the Donzère-Mondragon canal. The counter-ditch collects water from the left bank through three different siphons combined with a division box which divides the water between the counter-ditch and the starting point of the Gaffière stream.

The Gaffière flows north to south and crosses the eastern part of the Tricastin site, with a spreading area in the middle forming a pond. Immediately downstream of the site, the Gaffière flows alongside the Trop Long pond, where an overflow has been built in the left bank for flood control. The Gaffière continues alongside the Trop Long past this overflow and joins the Mayre Girarde stream to form the Lauzon.

The Donzère-Mondragon canal is a diversion canal for the river Rhône running for 24 km between Donzère and Mondragon. Located to the east of the Rhône, the canal improves navigation on the river, controls the flow and supplies cooling water to the Tricastin nuclear site.

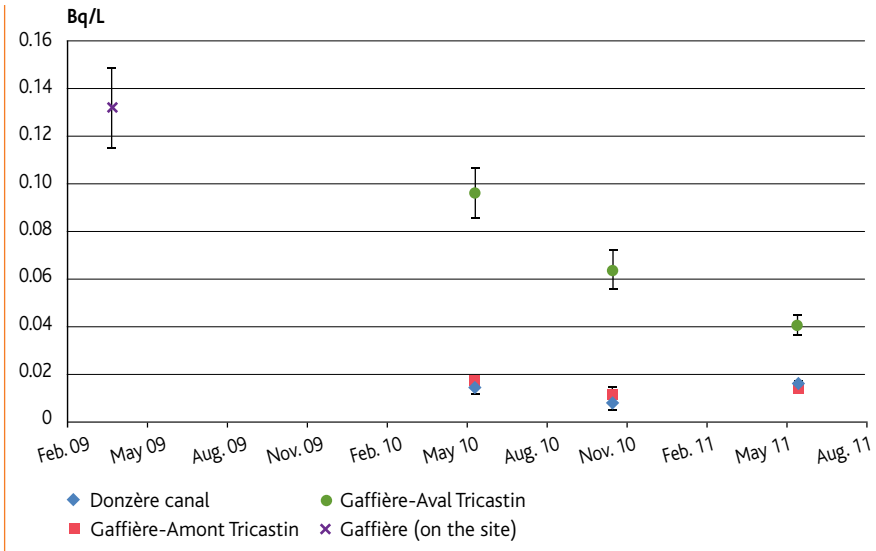

Figure V.24 – Uranium-238 activity in water from the Gaffière and the Donzère-Mondragon canal (Bq/L)

Uranium-238 concentrations in the water of the Gaffière are observed on the Tricastin site (0.13 Bq/L) and downstream of the site (0.06 Bq/L). The upstream part of the Gaffière and the Donzère-Mondragon canal have activity levels of approximately 0.015 Bq/L (*Figure V.24*).

Figure V.25 – Right-bank counter-ditch upstream of the Tricastin nuclear site

Sediments

Sediment samples are collected regularly from the watercourses located in the vicinity of the Tricastin nuclear complex for radiological analyses. Sampling takes place annually at five sampling stations: two upstream of the site (Gaffière and Donzère-Mondragon canal -*Figure V.26*) and three downstream (Gaffière, Lauzon and Donzère-Mondragon canal).

The activity levels of cesium-137, the only artificial radionuclide measured in all the sediment samples, showed no difference between samples taken upstream and downstream of the site (*Table V.12*). The presence of cesium-137 can be linked to atmospheric fallout from nuclear weapons testing and from the Chernobyl accident; the variation of activity levels measured in the different samples can be explained by mineralogy and physical characteristics, in particular the granulometry, of the sediments. Other gamma-emitting artificial radionuclides (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{60}Co, ^{54}Mn, ^{106}Ru) were not detected by the measuring instruments used.

Sediment sampling downstream of the site in the Gaffière showed uranium concentrations more than three times higher than those measured upstream, resulting from current discharge of reprocessed uranium by the site. Despite the dilution, the uranium concentration is still high in the Lauzon, 3.5 km downstream of the nuclear complex.

The detection of traces of americium and plutonium downstream of the Gaffière can be linked to past nuclear operations at the Tricastin site.

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Figure V.26 - Sediment sampling in the Donzère-Mondragon canal upstream of the Tricastin nuclear site

*Table V.12 - Mean activity levels measured in freshwater environment sediments in the vicinity of the Tricastin site (Bq/kg dry)**

Radionuclide	Donzère-Mondragon canal		Gaffière		Lauzon
	3.2 km upstream of Tricastin	5 km downstream of Tricastin	1.5 km upstream of Tricastin	100 m downstream of Tricastin	3.5 km downstream of Tricastin
^{137}Cs	nm	2.07 ± 0.43	2.8 ± 0.6	6.8 ± 2.4	4.5 ± 0.9
^{131}I	nm	< 4.3	< 4.3	< 5	< 4.9
^{40}K	31 ± 6	47 ± 8	310 ± 50	76 ± 10	106 ± 15
^{210}Pb	nm	51 ± 31	nm	nm	nm
Other gamma-emitting RNs (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{60}Co, ^{54}Mn, ^{106}Ru)	nm	< 19	< 17	< 21	< 21
^{90}Sr	nm	< 18	nm	nm	nm
^{241}Am	nm	< 0.15	< 0.017	0.29 ± 0.12	< 0.017
^{238}Pu	nm	< 0.16	< 0.11	0.11 ± 0.07	< 0.15
$^{239+240}$Pu	nm	< 0.16	< 0.11	0.11 ± 0.07	< 0.16
Calculated U content ** (mg/kg dry)	nm	0.93 ± 0.11	0.62 ± 0.07	1.97 ± 0.2	1.83 ± 0.19
^{234}U	nm	12.2 ± 1.3	7.7 ± 0.9	27.1 ± 2.7	24.1 ± 2.4
^{235}U	nm	0.8 ± 0.17	0.51 ± 0.13	2.18 ± 0.31	1.94 ± 0.29
^{238}U	nm	11.5 ± 1.3	7.6 ± 0.8	24.2 ± 2.4	22.5 ± 2.3

** Unless otherwise indicated*
*** U by content calculated from the measured uranium isotopes*
nm: not measured

Continental aquatic fauna

In 2010, uranium was measured in fish caught upstream and downstream of the Tricastin nuclear site. The analysis results were below decision thresholds (*Table V.13*).

Additional analyses were performed on eels caught in the Donzère-Mondragon canal, downstream of the Tricastin complex. The eels showed activity levels of the isotopes uranium-234 and -238 compatible with a natural origin (*Table V.14*).

Added concentrations of carbon-14 were also observed in these samples. This can be attributed to liquid discharge from the nuclear power plants in the Rhône valley (*Section V.4*).

Continental aquatic flora

Four pondweed samples are collected every six months in the vicinity of the Tricastin nuclear complex: two upstream of the site and two downstream in the Gaffière and the Donzère-Mondragon canal. One sample is also collected once a year from the Lauzon, downstream of waste discharge from the Tricastin site (*Table V.15*).

Analysis of these aquatic phanerogams shows activity of approximately 620 Bq/kg dry, due mainly to potassium-40. Traces of cesium-137 from atmospheric fallout from nuclear weapons testing and the Chernobyl accident are detected both upstream and downstream of the site. The presence of iodine-131 observed in the sample from upstream of the Tricastin site can be attributed to discharge from nuclear medicine services, which use this radionuclide for diagnosis or radiotherapy. Other gamma-emitting radionuclides investigated (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{60}Co, ^{54}Mn, ^{106}Ru) in the various watercourses upstream and downstream of the Tricastin site were not detected by the measuring instruments used.

The isotopic uranium activities measured were significantly higher downstream of the site than upstream, and result from discharge of reprocessed uranium by the site. These differences were greater in plants collected from the Gaffière, which receives this discharge.

Table V.13 - Mean uranium concentrations measured in fish caught in the environment close to the Tricastin site (mg/kg wet)

	Donzère canal 3.2 km upstream	Donzère canal 5 km downstream	Gaffière 100 m downstream	Lauzon 3.5 km downstream
Eel	< 0.007	< 0.006	< 0.0046	< 0.0035
Chub	< 0.008	Not sampled	< 0.007	< 0.009

Table V.14 - Specific activity levels measured in eels caught downstream of the Tricastin site in the Donzère-Mondragon canal (Bq/kg wet)

Radionuclide	Activity
^{14}C	128 ± 42
^{137}Cs	< 0.1
^{40}K	65 ± 13
^{90}Sr	< 0.045
^{232}U	< 0.01
^{234}U	0.01 ± 0.01
^{235}U	< 0.01
^{236}U	< 0.01
^{238}U	0.02 ± 0.01
Other gamma-emitting RNs (^{125}Sb, ^{144}Ce, ^{134}Cs, ^{58}Co, ^{60}Co, ^{129}I, ^{54}Mn, ^{95}Nb, ^{106}Ru, ^{95}Zr, ^{233}Pa)	< 0.8

The aquatic plant samples collected downstream of the site from the Donzère-Mondragon canal and from the Gaffière showed traces of activity levels of americium and plutonium slightly higher than the activity levels measured in the upstream sample in the canal, suggesting a mild impact from the site's discharge.

The free tritium activity measured in the plants collected from the Donzère-Mondragon canal in November 2010, around 6 Bq/kg wet upstream and downstream of the Tricastin complex, indicates slight contamination of the water of the Rhône by liquid discharge from the nuclear facilities located upstream (Bugey, Saint-Alban and Cruas NPPs in particular). The tritium activity in plants collected at the same time from the Gaffière, fed by the canal, was 3.6 ± 1.8 Bq/kg wet. In June 2010, the observed concentration level was lower: the activity measured upstream of the Tricastin site was 1.9 ± 1.6 Bq/kg wet.

Lastly, traces of carbon-14 were observed in all the aquatic plants collected upstream and downstream of the Tricastin complex *(Table V.15)*. These can be attributed to liquid discharge from the nuclear power plants of the Rhône valley.

*Table V.15 - Mean activity levels measured in the aquatic phanerogams (pondweed) collected from surface water near the Tricastin site (Bq/kg dry)**

Radionuclide	Donzère-Mondragon canal		Gaffière		Lauzon
	5 km upstream of Tricastin	5 km downstream of Tricastin	1.5 km upstream of Tricastin	100 m downstream of Tricastin	3.5 km downstream of Tricastin
^{137}Cs	< 1.1	1.44 ± 0.46	1.7 ± 0.6	< 2.4	nm
^{131}I	6.5 ± 1.4	< 9	< 7	< 9	nm
^{40}K	570 ± 60	420 ± 60	680 ± 70	820 ± 100	nm
Other gamma-emitting RNs (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{60}Co, ^{54}Mn, ^{106}Ru)	< 18	< 17	< 25	< 36	nm
^{238}Pu	< 0.015	< 0.024	nm	< 0.026	nm
$^{239+240}$Pu	0.015 ± 0.006	0.049 ± 0.021	nm	0.027 ± 0.011	nm
^{241}Am	0.018 ± 0.009	0.026 ± 0.019	nm	0.063 ± 0.022	nm
^{90}Sr	nm	< 0.31	nm	nm	nm
U content (mg/kg dry)	1.05 ± 0.21 (3.2 km upstream of site)	0.76 ± 0.16	nm	1.49 ± 0.23	0.64 ± 0.13
^{234}U	4.22 ± 0.29	8.8 ± 0.8	10 ± 0.7	23.5 ± 1.6	nm
^{235}U	0.31 ± 0.041	0.59 ± 0.11	0.73 ± 0.09	2.61 ± 0.22	nm
^{238}U	3.85 ± 0.26	8.8 ± 0.8	9.7 ± 0.6	20.3 ± 1.4	nm
HTO (Bq/kg wet)	3.8 ± 1.2	6.2 ± 1.7	nm	3.8 ± 1.3	nm
^{14}C (Bq/kg C)	251.4 ± 1.2	267.2 ± 1.7	nm	258.7 ± 1.4	nm

** Unless otherwise indicated*
nm: not measured

Ground water

Ground water flows in the sandy gravel alluvium of the Rhône. The alluvium is some ten meters thick and highly permeable. The aquifer is bounded at its base by an impermeable marl layer. The ground water is drained by many streams and by the Rhône river. The flow is from northeast to southwest, and from east to west at the site.

The piezometers at and near the Tricastin site showed an average uranium concentration of 2.2 µg/L *(Figure V.27)*. A number of individual points occasionally showed concentrations greater than 30 µg/L.

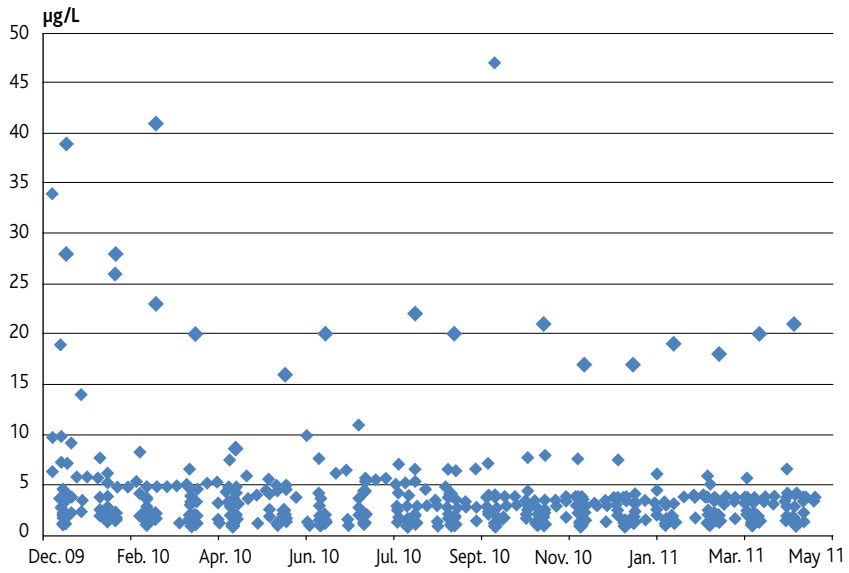

Figure V.27 - Uranium concentration in the ground water sampled at and near the Tricastin site (µg/L)

FBFC plant at Romans-sur-Isère

Located south of Lyon in the Rhône valley (*Figure V.28*), FBFC at Romans-sur-Isère operates two basic nuclear installations: the research reactor fuel fabrication unit (INB 63) and the PWR reactor nuclear fuel fabrication unit (INB 98). The site also accommodates an environmentally regulated facility (ICPE 6 bis), the "Cavities" facility, where specific components of the LHC (Large Hadron Collider), such as cavities and collimators, are manufactured for the European Organization for Nuclear Research (CERN).

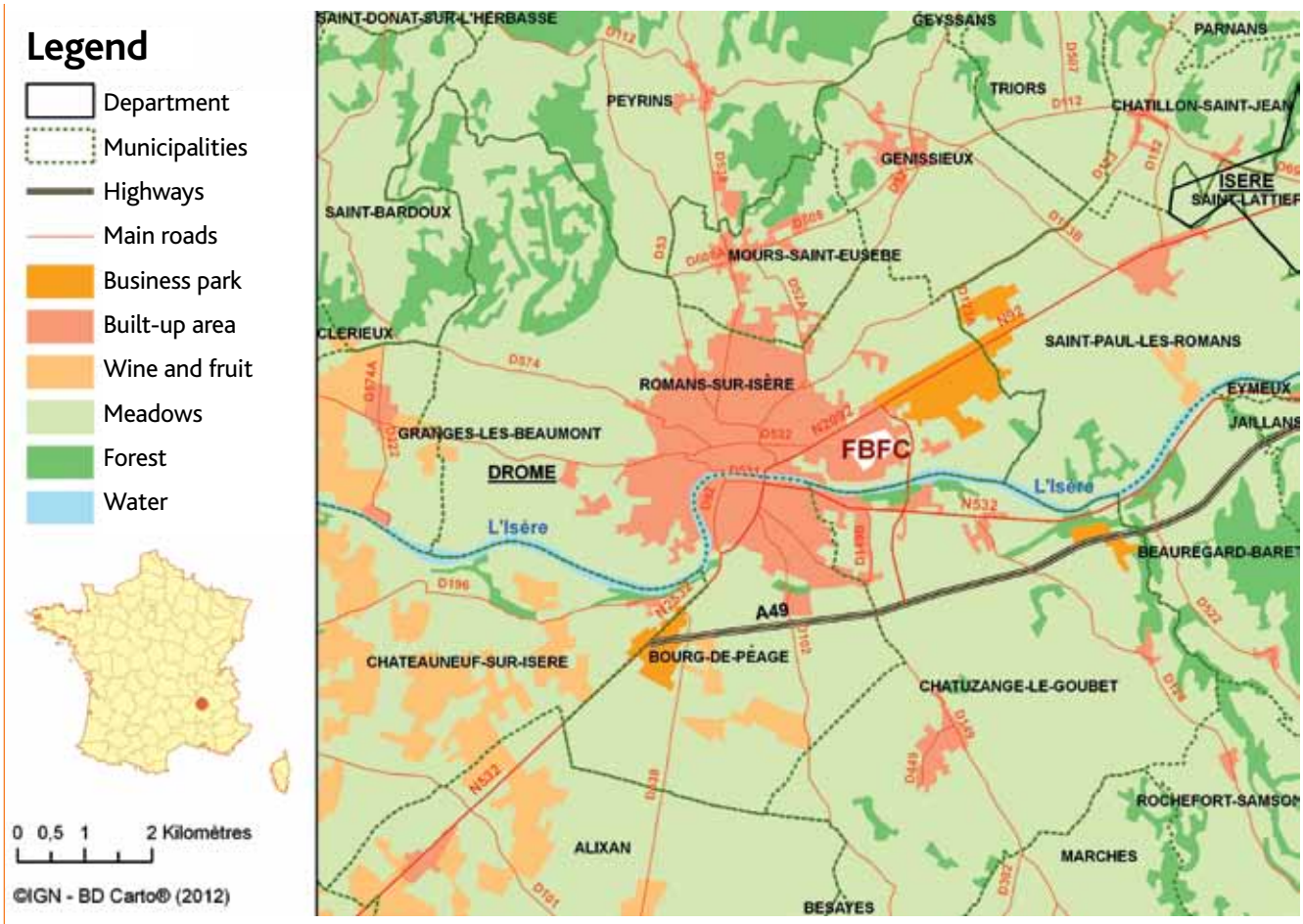

Figure V.28 - Geographical location of the FBFC Romans-sur-Isère site

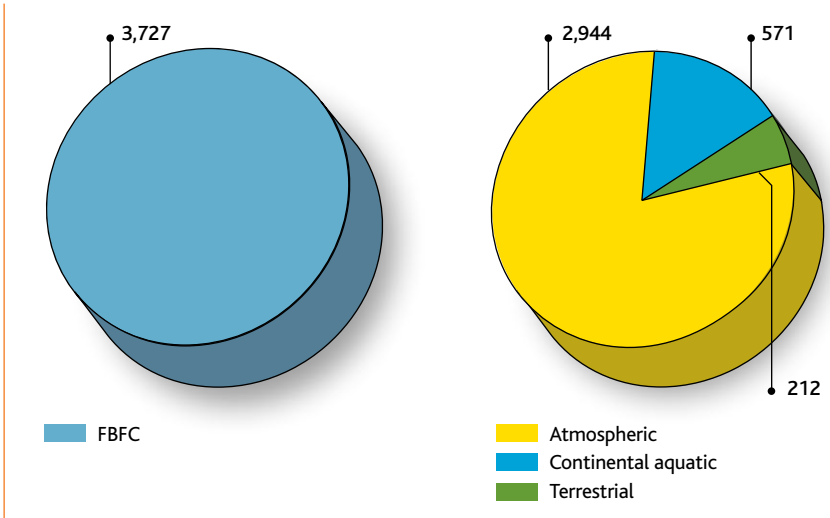

Figure V.29 - FBFC Romans-sur-Isère plant: breakdown of the number of samples by data provider and by compartment

Atmospheric compartment

Atmospheric aerosols

In the environment of the FBFC site at Romans-sur-Isère, atmospheric aerosols are monitored (*Figure V.30*) daily by determination of the gross alpha and beta activity levels (*Table V.16*) followed by additional analyses if an anomaly is observed, by systematic detection of radionuclides using gamma spectrometry , and by analyses using inductively coupled plasma mass spectrometry (uranium isotope measurement).

These checks showed a significant level of niobium-95 in aerosols collected between January 1 and 31, 2010 at Romans-sur-Isère (0.034 ± 0.018 mBq/m³). However, given the uncertainty associated with this measurement and the absence of any significant measurement for zirconium-95 (parent of niobium-95), the actual presence of traces of niobium-95 is highly unlikely.

Table V.16 - Gross alpha and beta activity of atmospheric aerosols collected in the environment of the FBFC Romans-sur-Isère site (mBq/m³)

Facility	Radionuclide	Mean activity (mBq/m³)
FBFC Romans-sur-Isère	Gross alpha activity	0.047 ± 0.001
	Gross beta activity	0.60 ± 0.01

Table V.17 - Uranium isotopes measured in atmospheric aerosols collected in the environment of the FBFC Romans-sur-Isère site (mBq/m³)

Facility	Radionuclide	Mean activity (mBq/m³)
FBFC Romans-sur-Isère	Uranium-234	0.015 ± 0.001
	Uranium-235	0.00040 ± 0.00002
	Uranium-236	0.00032 ± 0.00002
	Uranium-238	0.0015 ± 0.0001

Other than this observation, no other abnormal value of gross beta activity or gross alpha activity was obtained. The gamma spectrometry and mass spectrometry analyses showed that, apart from naturally occurring radionuclides, no artificial radionuclide was detected in the environment. In particular, the results of the uranium isotope measurements showed activities compatible with natural origin (*Table V.17*).

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Figure V.30 - Recovery of the filter used for sampling atmospheric aerosols on the FBFC Romans-sur-Isère site

Terrestrial compartment

Any radioactive element content due to atmospheric discharge from the nuclear facilities of the FBFC plant at Romans-sur-Isère is determined following plant sampling campaigns, monthly at four points on the site and annually at fourteen points around the site. The plants (Austrian pine, oak, mulberry, plane, grasses, mosses and cereals) are chosen according to their capacity to fix discharged substances and how representative they are in the environment of the nuclear site (*Table V.18*).

In general, the southern area of the FBFC Romans site, directly under the prevailing winds, showed the highest uranium concentrations, indicating a slight impact on the immediate environment of the facility (*Figure V.31*). At distances greater than a few hundred meters, measurements in and outside areas influenced by the prevailing winds showed similar and very low values.

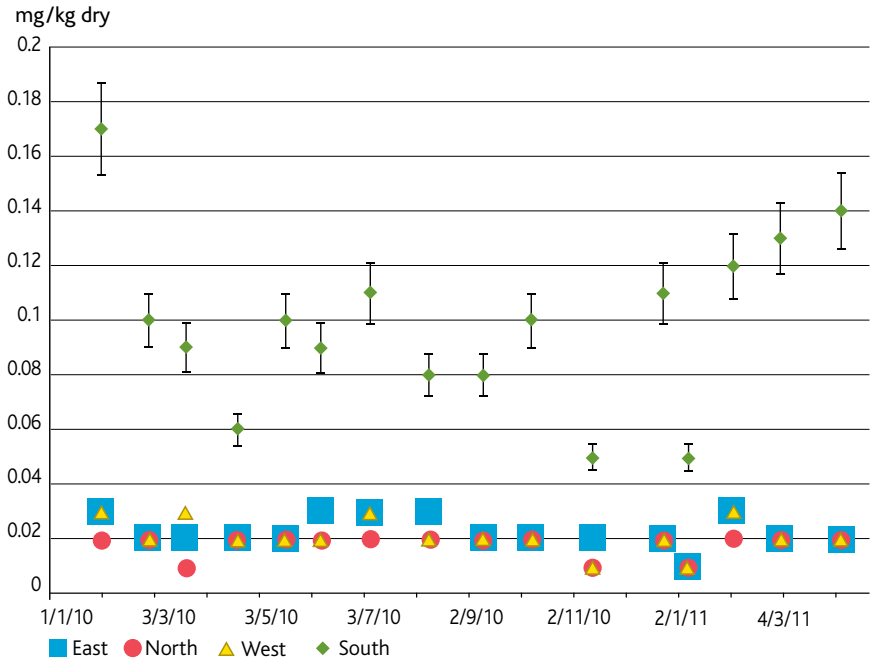

***Figure V.31** - Uranium concentration in pine needles collected on the FBFC Romans-sur-Isère site (mg/kg dry)*

***Table V.18** - Mean uranium concentrations measured in terrestrial plants collected in the vicinity of the FBFC Romans-sur-Isère site (mg/kg dry)*

Sampling locality		North	East	South	West
Pine needles	Distance	On site	On site (northeast)	On site	On site
	mg/kg dry	0.0152 ± 0.0004	0.0189 ± 0.0005	0.0782 ± 0.0021	0.01685 ± 0.00045
Oak leaves	Distance	750 m	1,000 m	500 m	ns
	mg/kg dry	0.011 ± 0.0022	0.006 ± 0.0012	0.026 ± 0.0049	ns
Mulberry leaves	Distance	ns	ns	ns	750 m
	mg/kg dry	ns	ns	ns	0.00219 ± 0.00042
Grass	Distance	200 m	200 m (southeast)	750 m	1,200 m
	mg/kg dry	< 0.002	0.011 ± 0.0011	< 0.004	< 0.001
Terrestrial moss	Distance	750 m	1,000 m	1,250 m	ns
	mg/kg dry	0.237 ± 0.047	0.38 ± 0.08	0.198 ± 0.04	ns
Cereals	Distance	1,200 m	200 m (southeast)	2,000 m	ns
	mg/kg dry	0.003 ± 0.0006	< 0.002	0.004 ± 0.0008	ns

ns: sampling not specified in the monitoring plan

Continental aquatic compartment

Surface water

Discharge from the FBFC Romans-sur-Isère plant are governed by the order of June 22, 2000, which defines the nature and characteristics of the liquid radioactive discharge. The water discharge includes industrial and chemical water potentially contaminated by uranium (nuclear workshop floor washing water, process water, laundry water, etc.) and other liquid waste from chemical processes collected around the site's treatment plant. After physical-chemical treatment to trap suspended solids, this liquid waste is discharged into the Isère. Rainwater and domestic wastewater are drained off by the domestic wastewater system of the town of Romans and directed towards the municipal treatment plant under a discharge agreement.

The uranium concentrations measured in the water of the Isère above the Pizançon dam or in downtown Romans were low, approximately 1.5 to 2 µg/L.

Sediments, fauna and flora

The impact of liquid discharge on the natural aquatic environment is monitored by annual sampling and measuring of fish, aquatic moss, aquatic plants and sediments from the Isère, at various points upstream and downstream of the outfall. The main measurement results for 2010 are given in Table V.19.
The measured samples had uranium-234 and -238 activity levels of the same order of magnitude for each matrix and isotope ratios ($^{235}U/^{238}U$) compatible with natural sources. The lack of difference between upstream and downstream samples means that any impact of liquid discharge from the site on the environment is too small to be quantified. The uranium measured comes from natural erosion. The Isère carries away about 16 metric tons of suspended solids annually.

Traces of uranium-236, a radionuclide characteristic of discharge from the FBFC site, were nevertheless observed in all fish caught in the Isère.

Table V.19 - Activity levels measured in the sediments, aquatic flora and fauna of the Isère.

Radionuclide		Upstream Outfall 1.5 km	Upstream Outfall 250 m	Downstream Outfall 2.5 km	Downstream Outfall 6 km	Downstream Outfall 9 km
		Upstream Pizançon dam	Pizançon dam	Downtown Romans	Downstream Romans treatment plant	Beaumont-Monteux dam
Reed (Bq/kg dry)	^{137}Cs	2 ± 0.9	ns	2.1 ± 0.8	2.6 ± 0.9	ns
	^{234}U	< 0.8	ns	< 0.67	< 0.54	ns
	^{235}U	0.004 ± 0.001	ns	0.0027 ± 0.0008	0.0027 ± 0.0006	ns
	^{236}U	< 0.008	ns	< 0.0074	< 0.0054	ns
	^{238}U	0.047 ± 0.01	ns	0.054 ± 0.012	0.054 ± 0.013	ns
Common water moss (Bq/kg dry)	^{137}Cs	ns	< 0.47	ns	ns	< 1.2
	^{234}U	ns	< 8.4	ns	ns	< 2.8
	^{235}U	ns	0.62 ± 0.13	ns	ns	0.31 ± 0.047
	^{236}U	ns	< 0.022	ns	ns	< 0.022
	^{238}U	ns	16.4 ± 3.5	ns	ns	5.6 ± 1.1
Sediment (Bq/kg dry)	^{137}Cs	3.5 ± 2.1	ns	4 ± 1.5	3.3 ± 2	ns
	^{234}U	20.2 ± 4.5	ns	15.8 ± 4	75 ± 14	ns
	^{235}U	0.88 ± 0.16	ns	0.66 ± 0.13	4.2 ± 0.9	ns
	^{236}U	< 0.07	ns	< 0.062	< 0.073	ns
	^{238}U	18.7 ± 3.7	ns	12.3 ± 2.5	84 ± 17	ns
Fish (Bq/kg wet)	^{137}Cs	0.093 ± 0.039	ns	0.1 ± 0.035	0.056 ± 0.025	ns
	^{234}U	< 0.12	ns	< 0.13	< 0.11	ns
	^{235}U	0.000067 ± 0.000019	ns	0.000061 ± 0.000019	0.00006 ± 0.000011	ns
	^{236}U	< 0.0012	ns	< 0.0013	< 0.0012	ns
	^{238}U	0.00043 ± 0.00006	ns	0.00031 ± 0.00006	0.00068 ± 0.00008	ns

ns: sampling not specified in the monitoring plan

SICN Annecy

Established in 1957, the *Société Industrielle de Combustible Nucléaire* (SICN) at Annecy in eastern France produced fuel for graphite-moderated gas-cooled reactors (GCR). SICN (part of the Areva group) fabricated this fuel until 1990, using natural and reprocessed uranium. It also manufactured metal parts on an industrial scale for non-GCR nuclear fuel elements. In 2002, following its final withdrawal from the nuclear market that led to the termination of its aluminum metallurgy business, the SICN Annecy plant was renamed Gemma. The site now focuses exclusively on mechanical and machining subcontracting for sectors including aircraft, electronics and mechanical engineering.

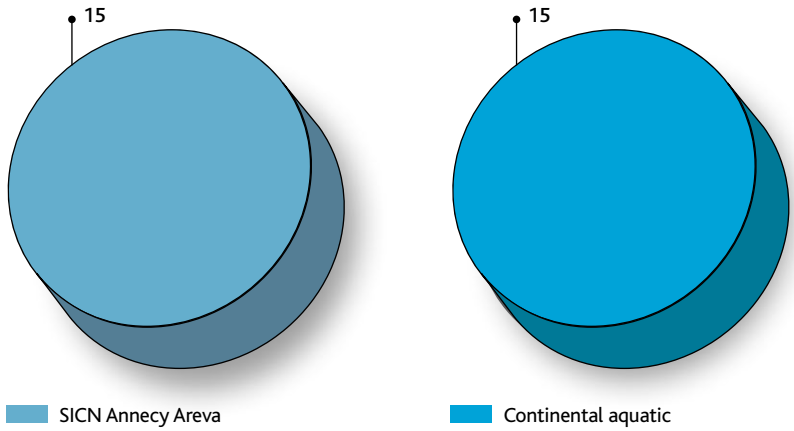

Figure V.32 - SICN Annecy: breakdown of the number of samples by data provider and by compartment.

Areva monitors radioactivity in the ground water on the SICN Annecy site. In piezometer no. 3, the measured uranium concentrations were close to the ambient background (between 3 and 10 µg/L). In contrast, the uranium concentration averaged approximately 80 µg/L in the water of piezometer 2, and 20 µg/L in piezometer 1, with a maximum value of 100 µg/L measured in February 2010 (*Figure V.33*). The uranium levels measured in piezometers 1 and 2 indicate added concentrations in ground water related to past operations on the SICN Annecy site.

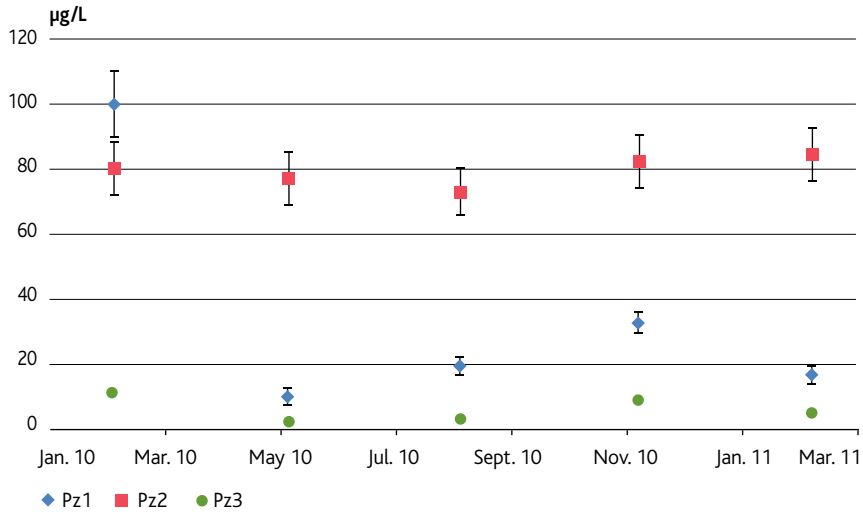

Figure V.33 - Uranium concentrations in ground water samples collected on the SICN site at Annecy (µg/L)

SICN Veurey-Voroize

Located at Veurey-Voroize in eastern France, this SICN site was set up in 1960 as a backup to the Annecy site. It consists of two nuclear facilities (a nuclear fuel fabrication plant and a pelletizing unit) that were shut down in the early 2000s. The end-of-operation procedures were carried out between 2000 and end-2005. Permits for the dismantling operations were approved in February 2006, allowing dismantling to begin.

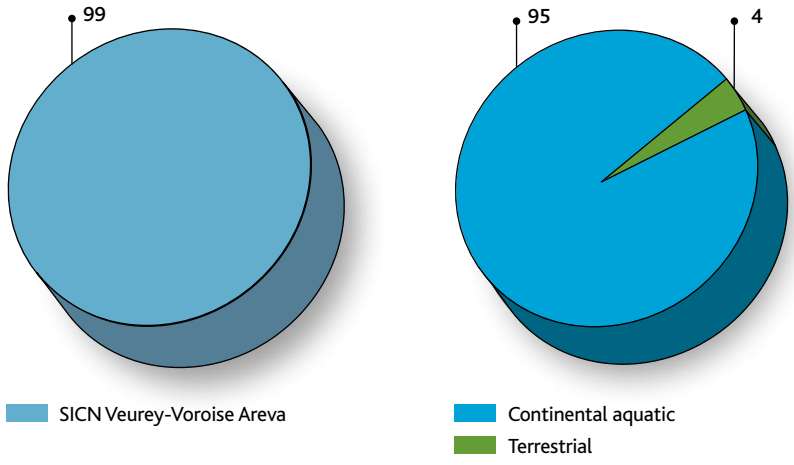

Figure V.34 - SICN Veurey-Voroize: breakdown of the number of samples by data provider and by compartment.

Surface water and ground water

Water samples are taken from the Isère downstream, opposite and upsteam of the discharge pipe of two basic nuclear installations (INB) no. 65 and no. 90. The measured uranium concentration, of approximately 2 µg/L, is equivalent to the background of the Isère.

Many piezometers at various locations on the site are used for radiological monitoring of the ground water. The uranium content in these piezometers varies between 10 and 239 µg/L. Dry wells installed during the rehabilitation of the site for rainwater drainage facilitate infiltration into the ground water.

The ground water is closely connected to the Isère, which is its outlet. The operator has identified, around an area named S6 at the southern boundary of the site, a localized zone of uranium contamination (about 2 g/kg) between the ground level and the ground water (23 m). At piezometer Pz6, the uranium content of the ground water increased steadily from 94 µg/L in January 2010 to 239 µg/L in January 2011, then started to decrease in April 2011 to 222 µg/L (*Figure V.35*).

The measurements made by the operator have confirmed this decrease, to 209 µg/L in the third quarter of 2011 and then 194 µg/L in the fourth quarter. This sampling point is located in the immediate vicinity of dry well PP2, which has a history of additional uranium concentrations from runoff water from tarred surfaces, themselves marked by the passage of handling equipment. As part of the Veurey site INB cleanup project, between September and December 2011 these tarred surfaces in the vicinity of PP2 were removed and PP2 was cleaned. This cleaning operation, by removal of the drain, involved work likely to modify the soil structure and consequently temporarily increase the diffusion of uranium concentrations in the ground water in the vicinity of point Pz6.

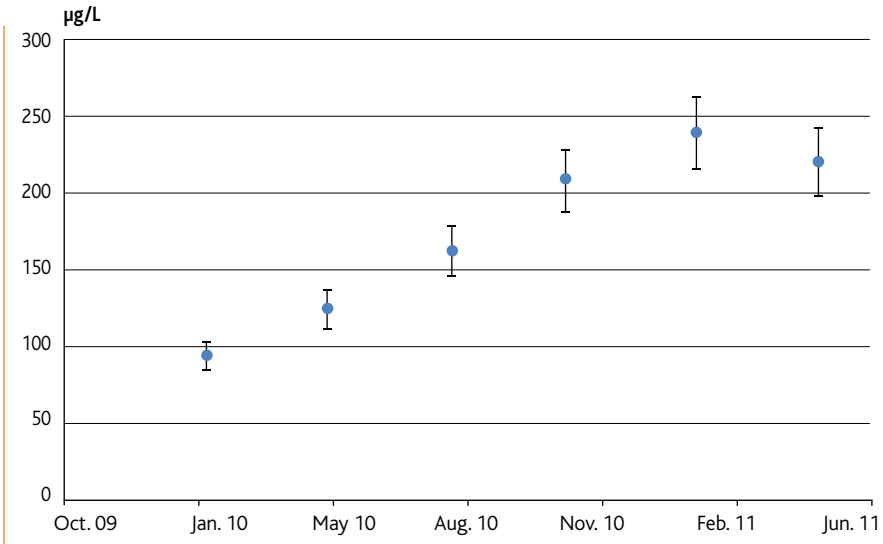

Figure V.35 - Uranium concentrations in ground water samples collected at point Pz6 on the SICN Veurey-Voroize site (µg/L)

Sediments

No significant difference was observed between upstream and downstream sediments of the SICN nuclear site (*Table V.20*). The uranium content was slightly higher opposite the discharge pipe, 2.6 ± 0.26 mg/kg dry compared with 1.4 ± 0.14 mg/kg dry upstream of the site.

Aquatic flora

In 2010, as part of the annual sampling program, four aquatic phanerogam samples were collected upstream and downstream of the SICN Veurey-Voroize site: three from the Isère (reeds on the bank closest to the outfall) and one from the Ruisset (mixture of reeds from the bank and aquatic phanerogams immersed on the river bed). The uranium concentration measured in the Isère downstream of the site was lower than the concentration upstream (*Table V.20*). The impact of discharge from the SICN Veurey-Voroize nuclear facility on the aquatic flora is not detectable.

Table V.20 - Mean uranium concentrations measured in the vicinity of the SICN Veurey-Voroize site (mg/kg dry)

	Isère			Ruisset
	Upstream of the discharge pipe	Opposite the discharge pipe	Downstream of the discharge pipe	Downstream of the site
Immersed and non-immersed aquatic phanerogams	8.8 ± 0.9	6.1 ± 0.6	3.6 ± 0.36	11 ± 1.1
Sediments	1.4 ± 0.14	2.6 ± 0.26	1.8 ± 0.18	1 ± 0.1

V.4 ENVIRONMENTAL MONITORING OF NUCLEAR POWER PLANTS

The French nuclear power plant fleet consists of 58 pressurized water reactors (PWR) in operation, located at 19 nuclear power plants (NPP) operated by EDF. They are all located close to a watercourse or on the coast , because water is essential as a coolant for the satisfactory operation of PWRs. In addition to these operating reactors, nine reactors (GCR, FNR and PWR) are being dismantled and one reactor (EPR) is under construction (*Figure V.36*).

An example of the regulatory obligations applicable to the operator of a nuclear power plant with regard to environmental monitoring is given in Chapter I (*Table I.6*).

To facilitate the presentation of the sites and the analysis of the results, the NPPs are grouped by drainage basin (e.g. Rhône, Loire) or by geographical region (NPPs of northeastern France).

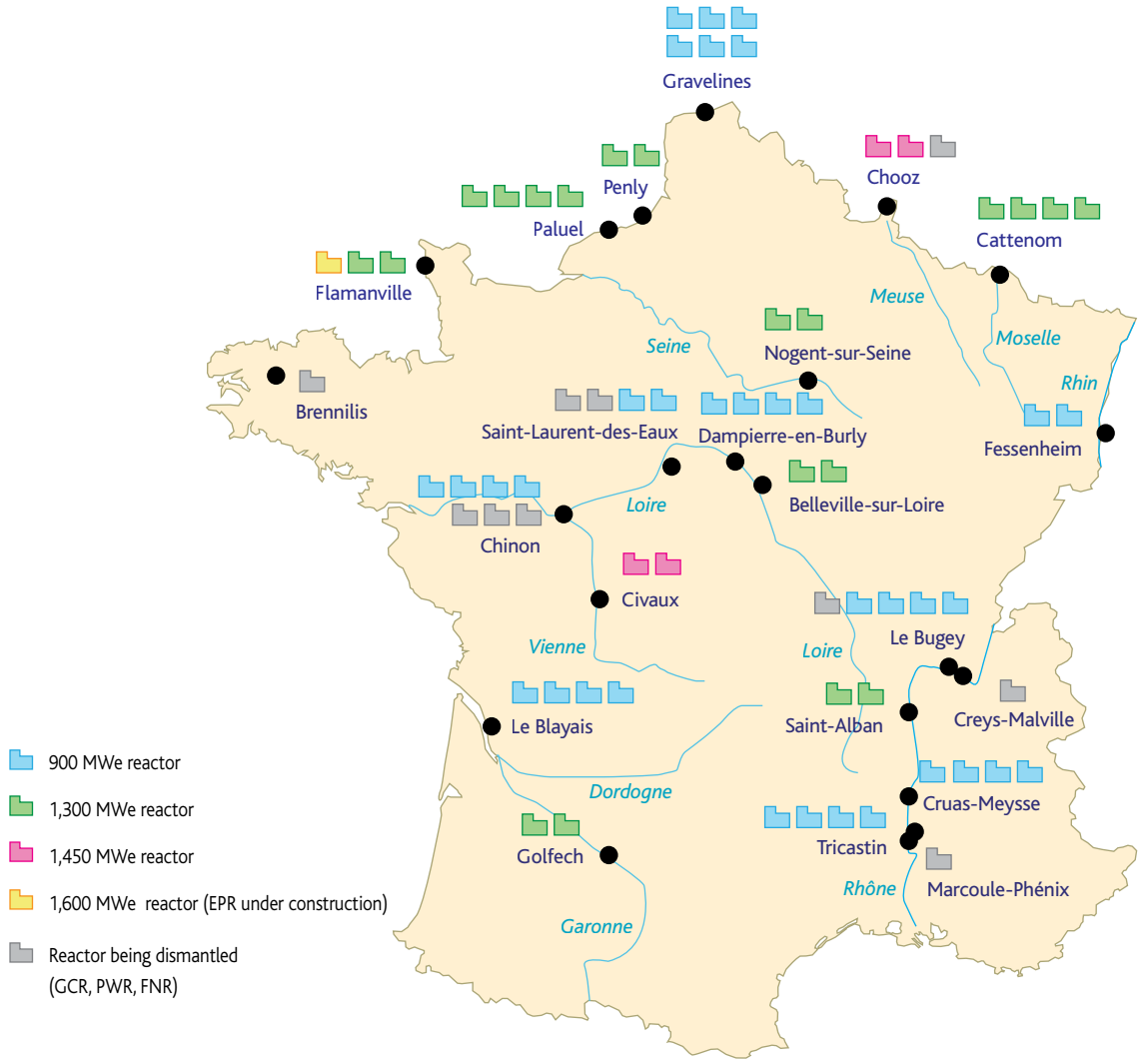

Figure V.36 - Location and type of French NPPs

Monitoring of nuclear power plants of the Loire drainage basin

There are five nuclear power plants in the Loire drainage basin (*Figure V.37*): four on the banks of the Loire (Belleville-sur-Loire, Dampierre-en-Burly, Saint-Laurent-des-Eaux and Chinon) and one on the Vienne (Civaux).

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Figure V.38 - Saint-Laurent-des-Eaux NPP

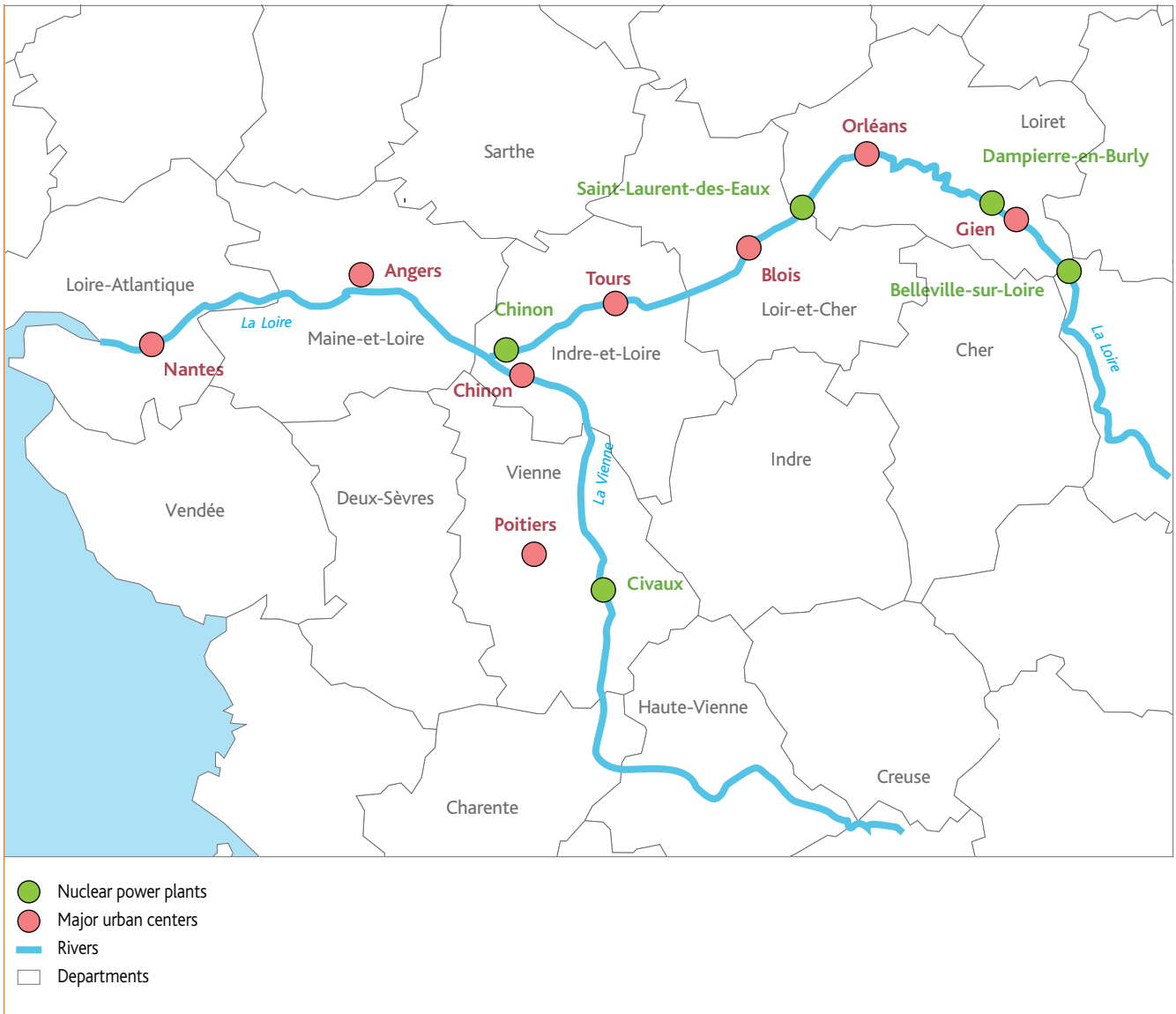

Figure V.37 - NPP locations in the Loire drainage basin

Civaux NPP

Located south of Poitiers on the left bank of the river Vienne in western France, the Civaux power plant has two 1450 MW pressurized water reactors put into service in 1997 and 1999.

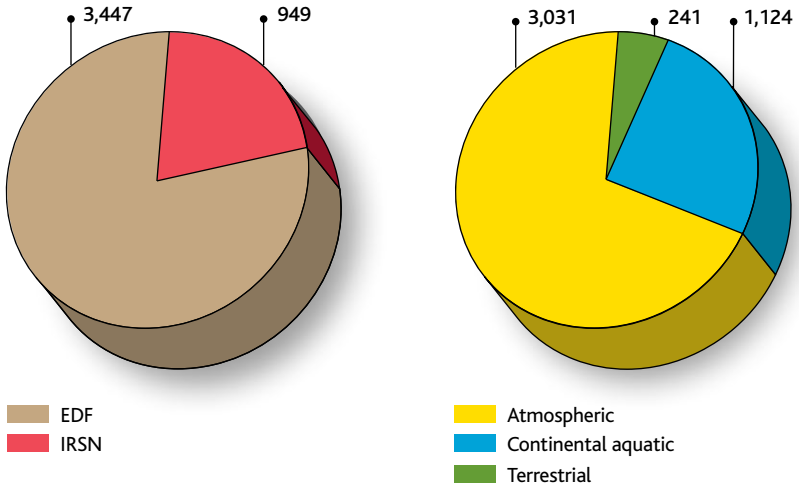

Figure V.39 - Breakdown of the number of samples by data provider and by environment for the Civaux NPP

Belleville-sur-Loire NPP

The Belleville nuclear power plant is located on the left bank of the Loire, about 100 km upstream of Orléans in north-central France. It has two 1300 MW pressurized water reactors, put into service in 1987 and 1988.

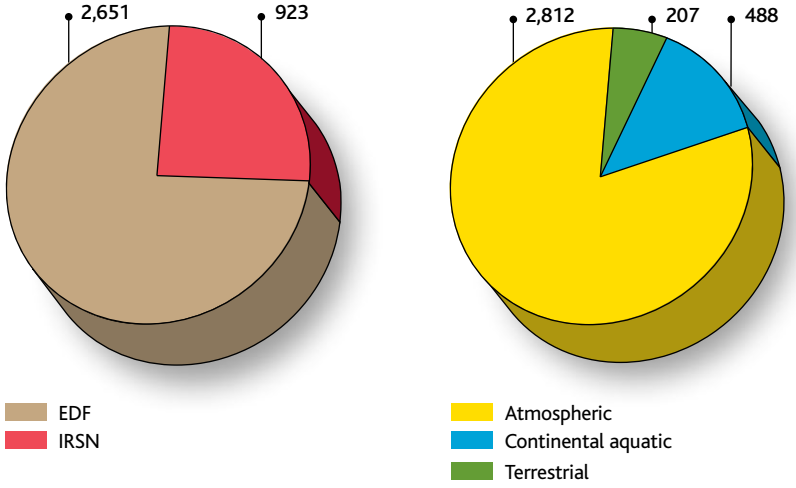

Figure V.40 - Breakdown of the number of samples by data provider and by environment for the Belleville-sur-Loire NPP

Dampierre-en-Burly NPP

The Dampierre-en-Burly nuclear power plant is located on the Loire downstream from Belleville, 45 km upstream of Orléans. It has four 900 MW reactors, all put into service in 1980 and 1981.

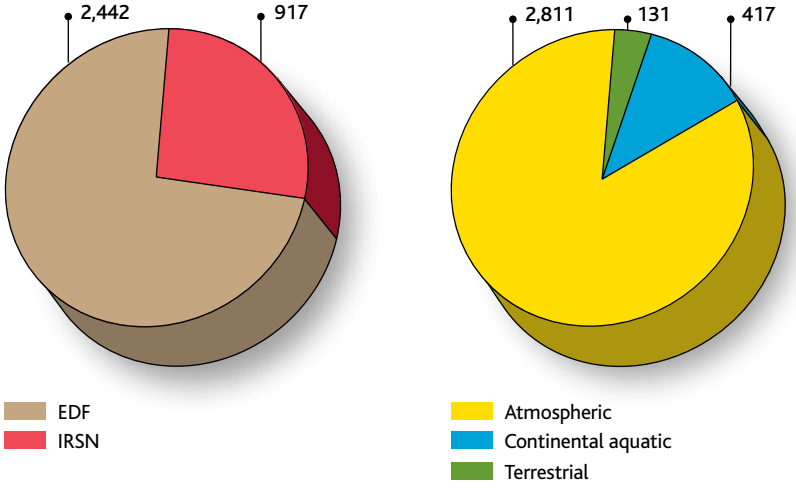

Figure V.41 - Breakdown of the number of samples by data provider and by environment for the Dampierre-en-Burly NPP

Saint-Laurent-des-Eaux NPP

The Saint-Laurent-des-Eaux nuclear power plant (*Figure V.38*) is located on the left bank of the Loire between Blois (30 km) and Orléans (24 km). It has two 900 MW pressurized water reactors (B1 and B2), put into service in 1981. Two other reactors, (GCR A1 and A2), put into service in 1969 and 1971, were shut down permanently in 1990 and 1992.

Chinon NPP

The Chinon nuclear power plant is located in west-central France. It has four 900 MW pressurized water reactors, put into service in 1982, 1983, 1986 and 1987. It also has three GCR reactors being dismantled (Chinon A, built from 1956 to 1966), an irradiated materials workshop and a storage facility for new fuel intended for French nuclear power plants.

Atmospheric compartment

Atmospheric aerosols

Apart from the observations recorded during the period of the Fukushima accident, monitoring of the gross beta activity did not reveal any abnormal value (*Figure V.44*). The gamma spectrometry measurements showed that, apart from naturally occurring radionuclides (^{7}Be, ^{210}Pb), no artificial gamma-emitting radionuclide could be measured above the decision thresholds of the instruments used.

Significant levels of cesium-134, cesium-137 and iodine-131 were observed by gamma spectrometry between the end of March 2011 and the beginning of May 2011 (*Table V.21*). These observations can be attributed to radioactive fallout on French territory from the accident at the Fukushima nuclear plant in Japan. During this same period, an increase in the beta activity index was also recorded (*Table V.22*). This short-term rise was related essentially to the presence of artificial radionuclides in the air after the Fukushima accident.

For more information
Chapter III – Fukushima accident

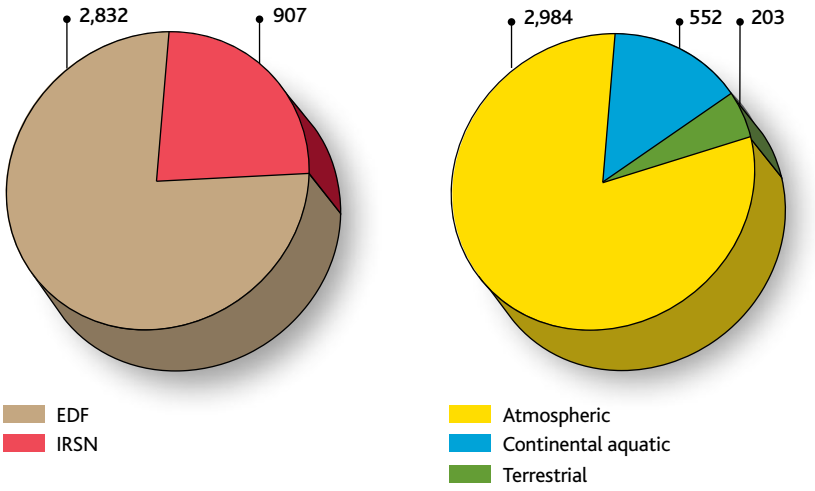

Figure V.42 - Breakdown of the number of samples by data provider and by environment for the Saint-Laurent-des-Eaux NPP

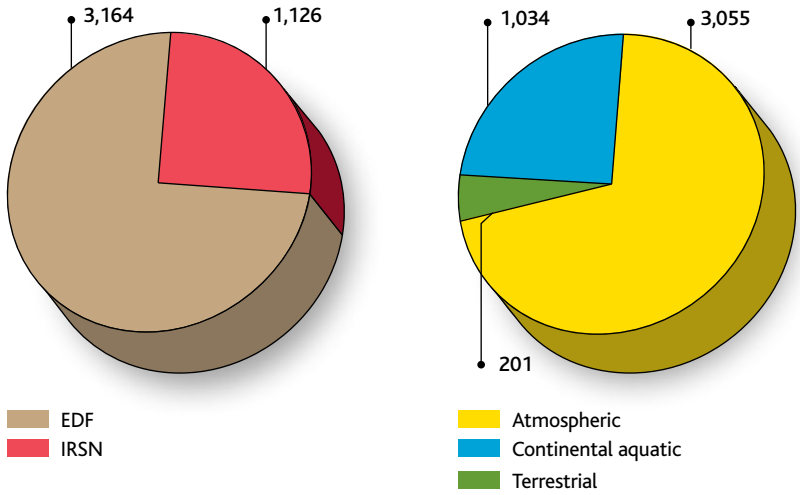

Figure V.43 - Breakdown of the number of samples by data provider and by environment for the Chinon NPP

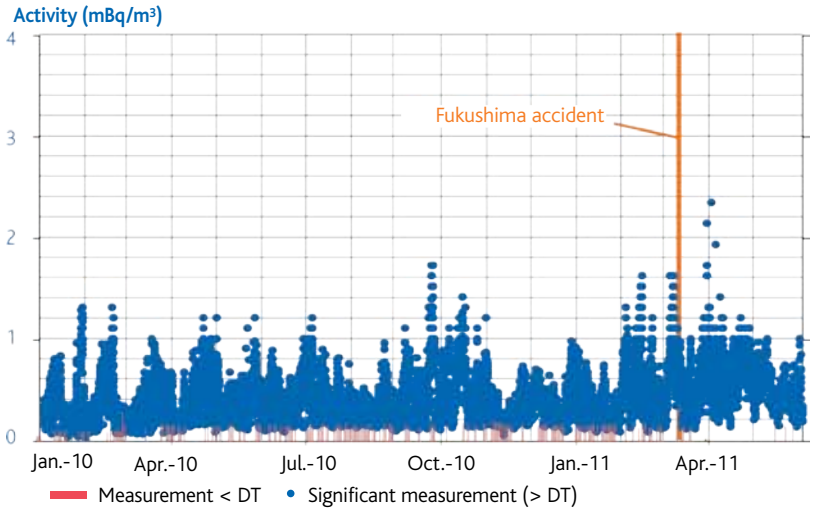

Figure V.44 - Time plot of the gross beta activity in atmospheric aerosol samples collected in the environment of the Loire drainage basin NPPs (mBq/m³)

Table V.21 - Radionuclides measured in aerosols from the environment of the Loire drainage basin NPPs during the period of the accident at the Fukushima nuclear plant (March 22 to May 6, 2011) (mBq/m³)

Plant	Radionuclide	Mean activity (mBq/m³)
Belleville-sur-Loire, Chinon, Civaux, Dampierre-en-Burly, and Saint-Laurent-des-Eaux NPPs	Cesium-134	0.034 ± 0.008
	Cesium-137	0.050 ± 0.008
	Iodine-131	0.42 ± 0.05

Rainwater

In rainwater collected near the NPPs of the Loire drainage basin, two significant tritium measurements were recorded at Civaux and Chinon (*Figure V.45*), at levels very close to the decision thresholds for this radionuclide. These activity levels can be related to gaseous discharge from the NPPs concerned.

Gases sampled by bubblers

Tritium and carbon-14 measurements in atmospheric samples from the environment in the immediate vicinity of nuclear sites did not show values higher than the decision levels at any of the NPPs in the Loire drainage basin.

Table V.22 - Gross beta activity in atmospheric aerosol samples collected in the environment of the Loire drainage basin NPPs (mBq/m³).

Plant	Radionuclide	Mean activity (mBq/m³)
Belleville-sur-Loire NPP	Gross beta activity	0.29 ± 0.01 0.53 ± 0.02*
Chinon NPP		0.26 ± 0.01 0.64 ± 0.02*
Civaux NPP		0.35 ± 0.01 0.65 ± 0.02*
Dampierre NPP		0.28 ± 0.01 0.52 ± 0.02*
Saint-Laurent-des-Eaux NPP		0.34 ± 0.01 0.75 ± 0.02*

** Measurements made from March 22 to May 6, 2011 during the period of the accident at the Fukushima nuclear plant*

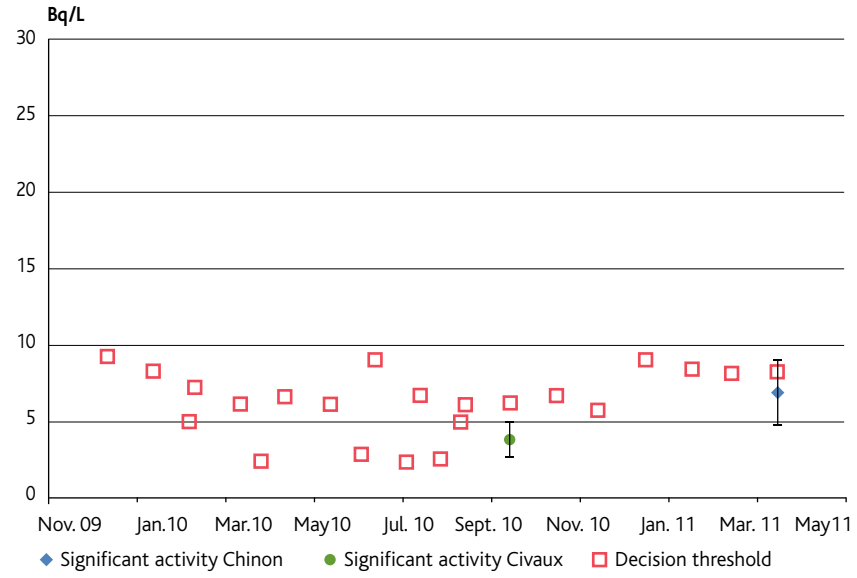

Figure V.45 - Tritium activity in rainwater collected in the vicinity of the Loire drainage basin NPPs (the decision thresholds are averaged for all the NPPs – IRSN and EDF data) (Bq/L)

Terrestrial compartment

Terrestrial flora

Grass samples were collected monthly in two municipalities located near the nuclear power plants. Under normal circumstances, gamma spectrometry analysis results for most samples did not reveal traces of artificial radioactivity attributable to discharge from the power plants. Only one grass sample, collected in the vicinity of the Civaux plant, showed significant cesium-137 activity (1.7 ± 0.47 Bq/kg dry on January 8, 2010) out of the 34 samples collected around this site between January 2010 and June 2011.

At the beginning of April 2011, traces of iodine-131 and cesium-134 and -137 were detected near the Civaux NPP. Traces of iodine-131 were also measured near the Chinon nuclear plant. These activity levels were a consequence of releases following the accident at the Fukushima plant in Japan on March 11, 2011.

For more information
Chapter III – Fukushima accident

Soil

Cesium-137 was measured in all the soil samples collected near the Civaux, Belleville, Saint-Laurent-des-Eaux and Chinon NPPs, at activity levels between 2 ± 0.15 Bq/kg dry and 9.1 ± 0.12 Bq/kg dry.

These activity levels (*Table V.23*) were due mainly to past atmospheric fallout (the Chernobyl accident in particular).

Table V.23 - Cesium-137 activity levels measured in soil in the vicinity of the Civaux NPP (Bq/kg dry)

Sampling locality	Leignes-sur-Fontaine	Lhommaize	Sillars
Distance from the Civaux NPP	8.5 km under the primary prevailing winds	5.5 km under the secondary prevailing winds	12 km, outside the area of influence
^{137}Cs activity (Bq/kg dry)	9.1 ± 1.1	5.3 ± 0.49	3.7 ± 0.6

Farm produce and foodstuffs

Milk

All the results showed that the radioactivity measured in milk was mainly due to naturally occurring potassium-40, with mean activity concentrations between 46.8 ± 1.5 Bq/L and 54.7 ± 1.9 Bq/L. No artificial gamma-emitting radionuclide was detected above the decision thresholds of the instruments used. The free tritium measurements were also below the decision thresholds.

In the 32 analyses performed, only one significant strontium-90 measurement was observed in milk collected in the vicinity of the Belleville NPP. The measured activity of this radionuclide (0.4 ± 0.35 Bq/L) is low and can be attributed to past fallout from atmospheric nuclear weapons testing.

Cereals

Gamma-emitting radionuclides discharged or likely to be discharged by the NPPs were not detected in the wheat samples collected near the sites.

Leafy vegetables

In 2010, lettuce samples were collected near Belleville, Chinon and Civaux NPPs. The radioactivity in these samples was due mainly to naturally occurring potassium-40, which showed activity levels varying between 80 ± 8 Bq/kg and 190 ± 20 Bq/kg wet according to the geographical sector.

The specific activity of carbon-14 measured near the Civaux plant was 232 ± 1.3 Bq/kg of carbon. This activity is similar to the measurements taken in areas not affected by discharge from the NPPs.

Traces of cesium-137 close to the decision thresholds were detected in nearly all samples (activity levels between 0.02 and 0.04 Bq/kg wet). These activities can be attributed to fallout from the Chernobyl accident in 1986.

The specific activity levels of the other artificial radionuclides (^{110m}Ag, ^{60}Co, HTO, etc.) likely to be discharged by these NPPs remained below the decision thresholds (*Table V.24*).

Table V.24 - Activity levels measured in lettuce collected near the Loire drainage basin NPPs (Bq/kg wet).*

Radionuclide	Civaux NPP	Belleville-sur-Loire NPP	Chinon NPP
^{40}K	91 ± 7	101 ± 17	134 ± 9
^{137}Cs	0.023 ± 0.004	0.04 ± 0.007	0.023 ± 0.005
Other gamma-emitting RNs (^{54}Mn, ^{58}Co, ^{60}Co, ^{110m}Ag, ^{134}Cs)	< 0.024	< 0.029	nm
^{14}C (Bq/kg carbon)	232 ± 1.3	nm	nm
HTO	< 9	nm	nm

** Unless otherwise indicated*

Wine

The analyses performed on red wine produced in the vicinity of the Chinon plant did not detect artificial gamma-emitting radionuclides above the decision thresholds of the instruments used. Only naturally occurring potassium-40 was measured, at a mean activity concentration of 36 ± 2.7 Bq/L.

Continental aquatic compartment

The nuclear plants in the Loire drainage basin are located on two rivers: the Loire and its tributary, the Vienne. The first NPP on the banks of the Loire is located about 500 km downstream of its source, at a point where the river curves to the west, its bed broadening considerably across the plain to reach an average width of 300 meters; shifting shoals of sand and pebbles appear. The large area of the drainage basin, the influence of the oceanic climate in its western and northern part, and the flat relief result in high variations of the flow rates, with sudden floods. A dam was built at Villerest, 235 km upstream of Belleville-sur-Loire, to limit the major floods to 8,500 m³/s and to maintain a minimum flow rate in low water periods. The average annual flow rate of the Loire is 350 m³/s at Orléans and 900 m³/s at its mouth (*Figure V.46*).

The river Vienne, which has its source in the Massif Central, flows for 400 kilometers to join the Loire. Its average width is 100 meters in the last part of its course. Notably, it is joined by a very large number of streams and small rivers, and its main tributaries are the Creuse and the Clain. Some of these many tributaries are affected by former mining sites.

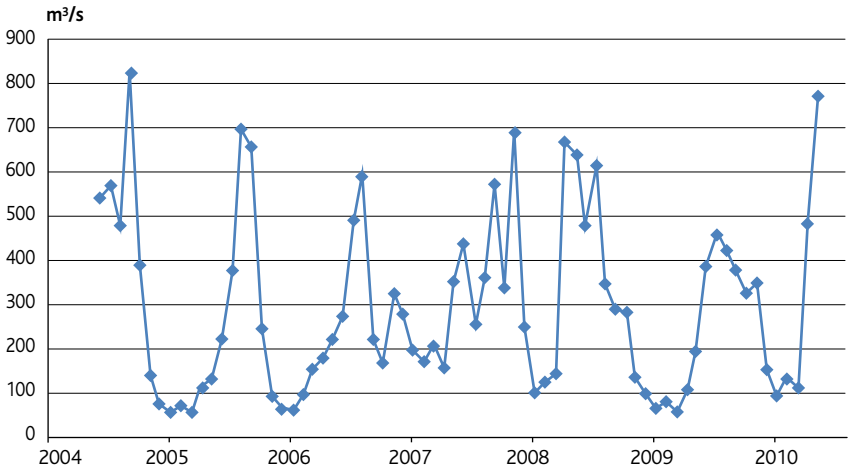

Figure V.46 - Flow rate of the Loire at Orléans – source: Banque Hydro (m³/s)

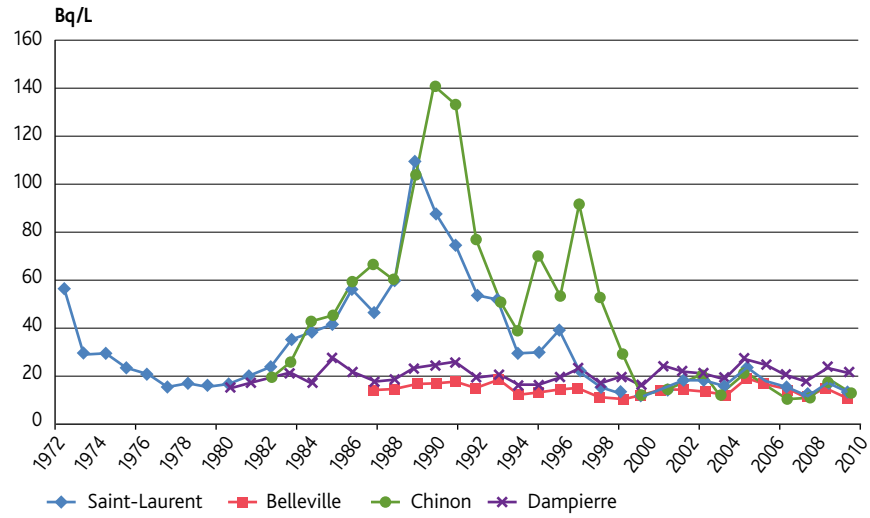

Figure V.47 - Tritium activity downstream of the Loire NPPs (Bq/L)

Surface water

The Loire

The tritium discharged into the Loire by the four NPPs can be detected almost constantly. They discharge total tritium activity of 160 TBq/year in liquid form, 17% of the liquid discharge of tritium by the EDF fleet. The Saint-Laurent-des-Eaux NPP coordinates the discharge of all the NPPs discharging into the river. Unless a waiver is agreed, two tank discharges cannot be carried out at the same time.

The time plot of the tritium activity measured by IRSN since the 1970s shows the decrease in tritium activity discharged by nuclear plants into the environment in the Loire, but with a marked accumulation effect at Chinon up to 2000 (*Figure V.47*). This can be explained by the consultation on discharge and renewal of the water intake and discharge permits, which resulted in smoothing of the activity levels measured in the Loire from 1999.

Seasonal effects can be observed, with higher activity levels at low water and lower activity levels during winter flood periods (*Figure V.48*). However, this natural effect is smoothed by the procedure for liquid waste discharge from the NPPs, which determines the maximum activity flow rate at the main discharge points for a 24-hour average flow rate Q (in L/s) of the Loire. Thus, for tritium, this value is 80 x Q for the Dampierre-en-Burly NPP.

The severe climatic conditions in May-June 2011, with a substantial rainfall deficit, led to increased tritium activity in the river to a level that had not been observed since 1996. However, these activity levels remained compliant with the discharge permits applicable to nuclear power plant operators.

Other than tritium, strontium-90 was the only radionuclide detected in the vicinity of the Chinon and Saint-Laurent-des-Eaux NPPs, with activity levels close to the decision thresholds (*Figure V.49*). These measurements were made in the past because of the use of the GCR system at Saint-Laurent-des-Eaux and Chinon A. There are also spent graphite storage silos on the Saint-Laurent-des-Eaux site. However, the strontium-90 activity levels measured here can be linked to atmospheric fallout from nuclear weapons testing.

The Vienne

Discharge from the Civaux NPP are monitored by means of automated sampling of the Vienne river. Since 2001, an increase in tritium activity has been observed in water samples collected downstream of the NPP, with the annual mean rising from about 9 Bq/L in 2000 to 27 Bq/L in 2010 (*Figure V.50*).

Ground water

The ground water samples collected in the vicinity of the NPPs located on the banks of the Loire had additional concentrations of tritium at an activity of about 10 Bq/L, with a maximum value of 49 Bq/L measured at Dampierre-en-Burly in July 2010. There did not appear to be any variability or changing trend over time (*Figure V.51*).

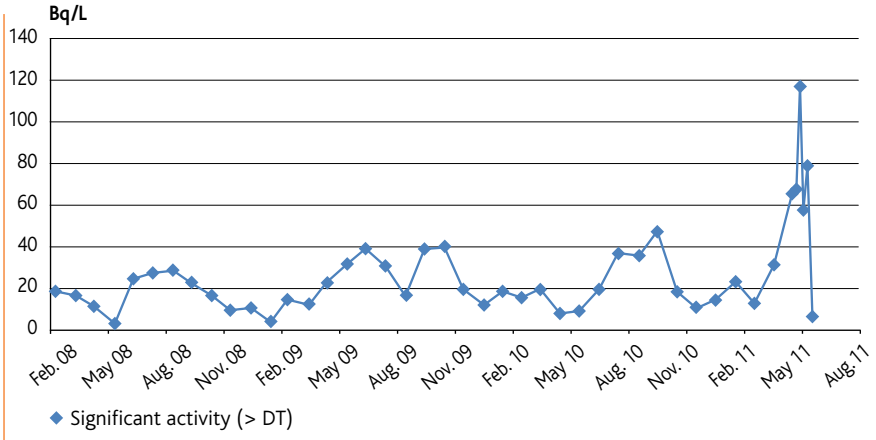

Figure V.48 - Tritium activity downstream of the Dampierre NPP, illustrating the cyclic nature of the measured activity levels

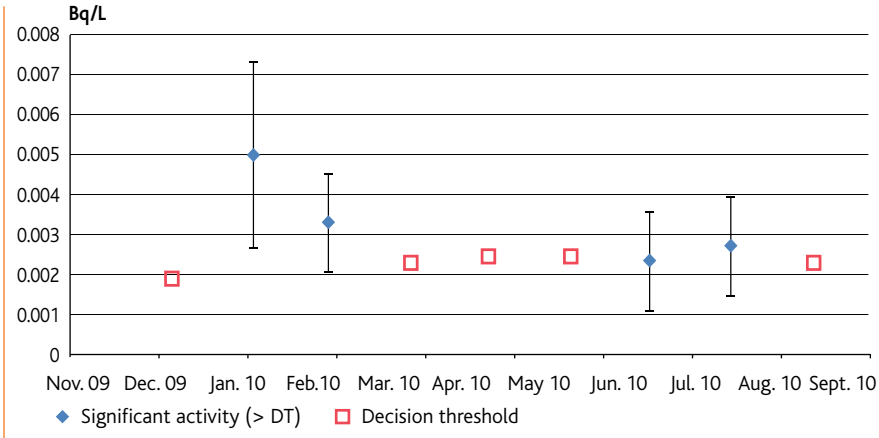

Figure V.49 - Strontium activity in water samples collected from the Loire (Bq/L)

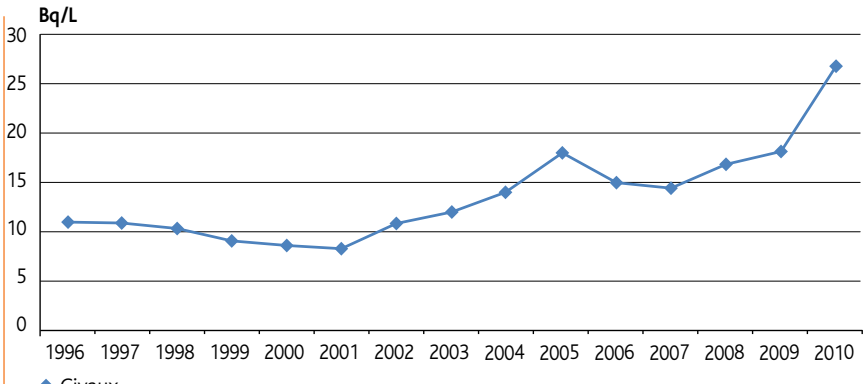

Figure V.50 - Mean annual tritium activity in the Vienne river downstream of the Civaux NPP (Bq/L)

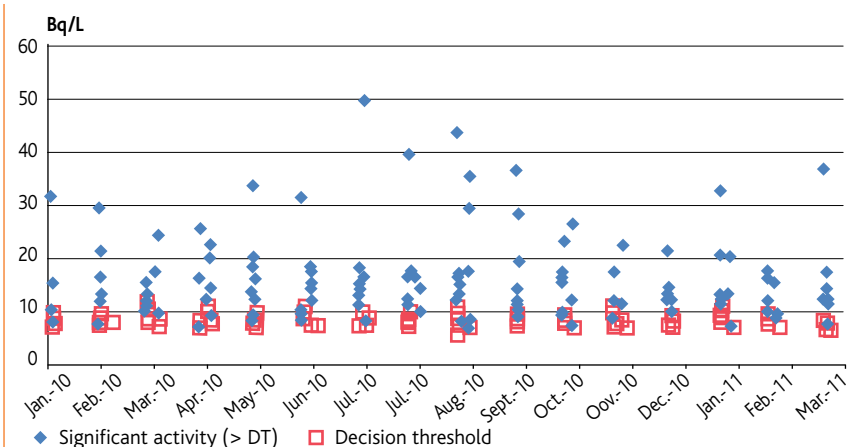

Figure V.51 - Tritium activity in ground water under or near the Loire NPPs (Bq/L)

Sediments

Analysis results for sediments sampled upstream and downstream of the Belleville-sur-Loire, Chinon and Civaux NPPs did not show significant differences between the upstream and downstream stations (*Table V.25*). An increase in cesium-137 activity levels was observed along the course of the Loire: 5.6 ± 0.8 Bq/kg dry upstream of the Belleville-sur-Loire plant and 9.6 ± 1.2 Bq/kg dry downstream of Chinon. However, these results do not allow a distinction to be made between the activity attributable to NPP discharge and the activity related to persistent traces of fallout from the Chernobyl accident.

In 2010, cobalt-60 was detected in one of the two samples collected downstream of the Civaux plant at a specific activity of 0.68 ± 0.35 Bq/kg dry. This low level of radioactivity can be attributed to the permitted routine discharge from the NPP.

Other gamma-emitting artificial radionuclides likely to be discharged by the NPPs were not detected by the measuring instruments used.

Continental aquatic fauna

In 2010, analyses were performed on fish caught upstream and/or downstream of the following four NPPs: Belleville-sur-Loire, Saint-Laurent-des-Eaux, Chinon and Civaux.

Among the gamma-emitting artificial radionuclides discharged or likely to be discharged by the NPPs, only cesium-137 was measured in all samples, at mean specific activity levels of between 0.033 ± 0.018 and 0.283 ± 0.037 Bq/kg wet (*Table V.26*). No significant difference in activity was observed between areas upstream and downstream of the plants. This observation may be related to the seasonal movements or migration of fish during their lives. In contrast, analyses performed on fish caught downstream of the Saint-Laurent-des-Eaux NPP detected small quantities of tritium (activity close to the decision threshold), attributable to the routine discharge from this plant, and carbon-14 at an activity of 350 ± 1.7 Bq/kg carbon, higher than the background (235 Bq/kg carbon).

Table V.25 - Mean activity levels measured in sediment samples from the freshwater environment of the Loire drainage basin NPPs (Bq/kg dry)

Radionuclide	Belleville-sur-Loire NPP		Chinon NPP			Civaux NPP	
	2.5 km upstream La-Celle-sur-Loire	5.5 km downstream Beaulieu-sur-Loire	15 km upstream Bréhémont	5 km downstream Savigny-en-Véron	10 km downstream Varennes-sur-Loire	2.5 km upstream Civaux	6 km downstream Valdivienne
^{137}Cs	5.6 ± 0.8	5.4 ± 0.9	6.7 ± 1.5	6.1 ± 0.7	9.6 ± 1.2	10 ± 0.8	9 ± 1.1
^{60}Co	< 0.12	< 0.13	nm	nm	nm	< 0.14	0.23 ± 0.08
^{40}K	980 ± 140	1,000 ± 100	620 ± 90	660 ± 90	770 ± 110	710 ± 70	660 ± 70
Other gamma-emitting RNs (^{54}Mn, ^{58}Co, ^{110m}Ag, ^{134}Cs)	< 0.68	< 0.65	nm	nm	nm	< 0.81	< 0.6

nm: not measured

Table V.26 - Mean activity levels measured in fish caught in the Loire drainage basin NPPs (Bq/kg wet).*

Radionuclide	Belleville-sur-Loire NPP		Saint-Laurent-des-Eaux NPP	Chinon NPP		Civaux NPP	
	Common carp		Fish	Common carp		Common carp	
	1 km upstream Sury-près-Léré	12.5 km downstream Châtillon-sur-Loire	16 km downstream Fontaines-en-Sologne	8 km upstream Rigny Usse	4 km downstream Chouze-sur-Loire	7 km upstream Lussac-les-Châteaux	4 km downstream Valdivienne
^{137}Cs	0.033 ± 0.018	0.039 ± 0.028	0.062 ± 0.015	0.045 ± 0.021	0.065 ± 0.021	0.283 ± 0.037	0.236 ± 0.026
^{40}K	150 ± 20	140 ± 20	90 ± 11	140 ± 20	150 ± 20	165 ± 14	118 ± 9
Other gamma-emitting RNs (^{54}Mn, ^{58}Co, ^{60}Co, ^{110m}Ag, ^{134}Cs)	< 0.31	< 0.21	< 0.23	nm	nm	< 0.13	< 0.1
HTO	nm	nm	5.4 ± 1.5	nm	nm	nm	nm
^{14}C (Bq/kg carbon)	nm	nm	350.3 ± 1.7	nm	nm	nm	nm

** Unless otherwise indicated*
nm: not measured

Continental aquatic flora

In 2010, gamma spectrometry analyses were performed on aquatic phanerogam samples collected upstream and downstream of the Belleville-sur-Loire, Chinon and Civaux NPPs.

Artificial radionuclides (^{110m}Ag, ^{58}Co, ^{60}Co) were measured at levels close to the decision thresholds downstream of the Civaux NPP (*Table V.27*). They were not detected upstream of the site, and indicate slight added concentrations in the aquatic environment due to the liquid waste discharge from this plant. Cesium-137 was measured upstream and downstream of the site at specific activity levels of 0.445 ± 0.038 Bq/kg wet and 0.328 ± 0.045 Bq/kg wet, respectively.

The cesium-137 activity levels at the NPPs located on the banks of the Loire varied considerably, although overall the values measured downstream of the plants were slightly higher than the values obtained in the upstream samples. However, the possible contribution by the NPPs to the radioactive cesium in the aquatic environment cannot be distinguished from the main sources of added environmental concentration in France (fallout from Chernobyl and from atmospheric nuclear weapons testing).

Table V.27 - Mean activity levels measured in aquatic phanerogam samples at the Belleville-sur-Loire, Chinon and Civaux NPPs (Bq/kg dry)

Radionuclide	Belleville-sur-Loire NPP			Chinon NPP			Civaux NPP	
	Pondweed 15 km upstream Cosne Cours-sur-Loire	Reed canary grass 2.5 km upstream La Celle-sur-Loire	Pondweed 11 km downstream Ousson-sur-Loire	Reed canary grass 15 km upstream Bréhémont	Reed canary grass 11 km downstream Varennes-sur-Loire	Reed canary grass 13 km downstream Parnay	Aquatic ranunculus 2.5 km upstream Civaux	Aquatic ranunculus 6.5 km downstream Valdivienne
^{110m}Ag	< 0.037	< 0.061	< 0.04	nm	nm	nm	< 0.035	0.067 ± 0.017
^{134}Cs	< 0.032	< 0.046	< 0.043	nm	nm	nm	< 0.032	< 0.031
^{137}Cs	0.232 ± 0.037	0.11 ± 0.06	0.5 ± 0.06	0.56 ± 0.07	0.53 ± 0.07	1.01 ± 0.13	0.445 ± 0.038	0.328 ± 0.045
^{58}Co	< 0.048	< 0.23	< 0.048	nm	nm	nm	< 0.046	0.047 ± 0.016
^{60}Co	< 0.046	< 0.058	< 0.055	nm	nm	nm	< 0.042	0.095 ± 0.042
^{54}Mn	< 0.056	< 0.064	< 0.063	nm	nm	nm	< 0.05	< 0.05
^{40}K	920 ± 130	1,210 ± 200	1,220 ± 240	620 ± 70	940 ± 130	870 ± 130	900 ± 90	804 ± 47

nm: not measured

Monitoring of nuclear power plants in northeast France

There are three nuclear power plants in northeast France (*Figure V.52*), located on the banks of the Meuse (Chooz NPP), the Moselle (Cattenom NPP) and on the Grand canal d'Alsace alongside the Upper Rhine (Fessenheim NPP).

Figure V.52 - NPP locations in northeast France

Figure V.53 - Chooz NPP

Chooz NPP

The Chooz nuclear power plant (*Figure V.53*) is located beside the Meuse in a small enclave of French territory in the Ardennes, close to the Belgian border. The Chooz B site has two 1450 MW pressurized water nuclear reactors, put into service in 1996. The Chooz A plant, in operation between 1967 and 1991, has one pressurized water reactor (PWR), currently being dismantled.

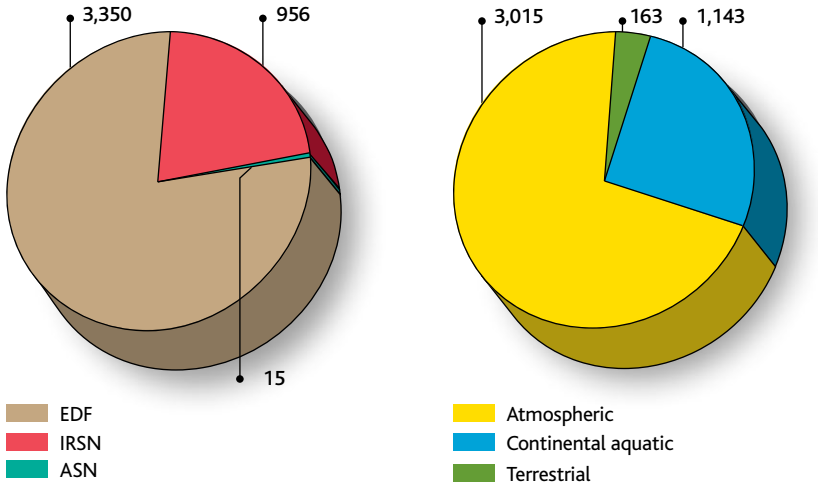

Figure V.54 - Breakdown of the number of samples by data provider and by environment for the Chooz NPP

Fessenheim NPP

The Fessenheim nuclear power plant is located beside the Grand Canal d'Alsace, some thirty kilometers northeast of Mulhouse, near the Swiss and German borders. It has two 900 MW reactors put into service in 1977.

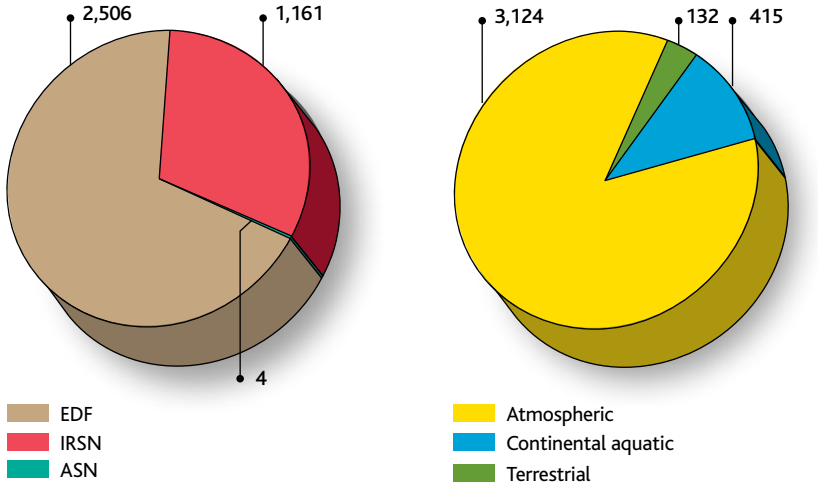

Figure V.55 - Breakdown of the number of samples by data provider and by environment for the Fessenheim NPP

Cattenom NPP

The Cattenom nuclear power plant is located between the Moselle and the Garche national forest, not far from the German and Luxembourg borders. The plant has four 1300 MW pressurized water reactors, put into service in 1986, 1987, 1990 and 1991.

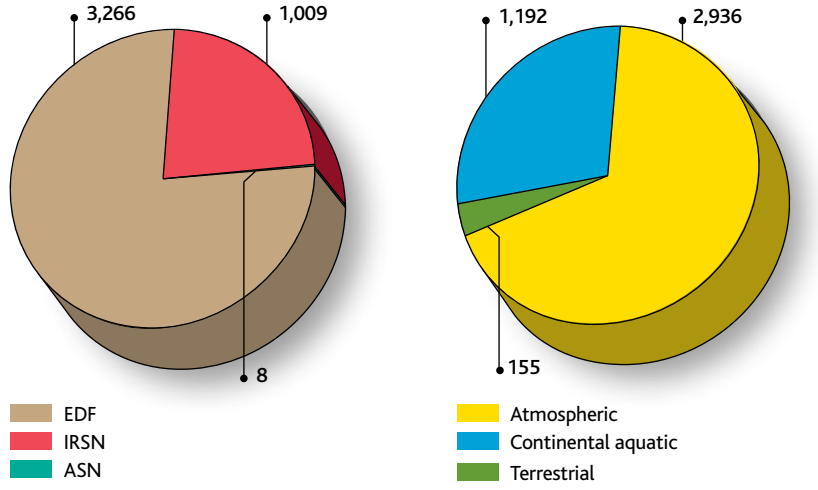

Figure V.56 - Breakdown of the number of samples by data provider and by environment for the Cattenom NPP

Atmospheric compartment

Atmospheric aerosols

Apart from the observations recorded during the period of the Fukushima accident, monitoring of the beta activity index did not reveal any abnormal value (*Figure V.57*). The gamma spectrometry measurements showed that, apart from naturally occurring radionuclides (^{7}Be, ^{210}Pb), no artificial gamma-emitting radionuclide could be measured above the decision thresholds of the instruments used.

Significant levels of cesium-134, cesium-137 and iodine-131 were observed by gamma spectrometry between the end of March 2011 and the beginning of May 2011 (*Table V.28*). These were due to the radioactive fallout on French territory from the Fukushima accident. During this same period, an increase in the gross beta activity was also recorded (*Table V.29*). This short-term rise was also related to the presence of artificial radionuclides in the air after the Fukushima accident.

For more information
Chapter III – Fukushima accident

Rainwater

IRSN measured significant tritium activity levels in rainwater collected in the immediate vicinity of the Cattenom NPP, of approximately 5 Bq/L (*Figure V.58*). No other significant activity of anthropogenic origin was measured in the rainwater collected in the immediate vicinity of the Fessenheim, Chooz and Cattenom NPPs, nor in the ambient air.

Gases sampled by bubblers

No significant activity of gaseous tritium was detected near the NPPs in northeast France over the period January 2010 - June 2011.

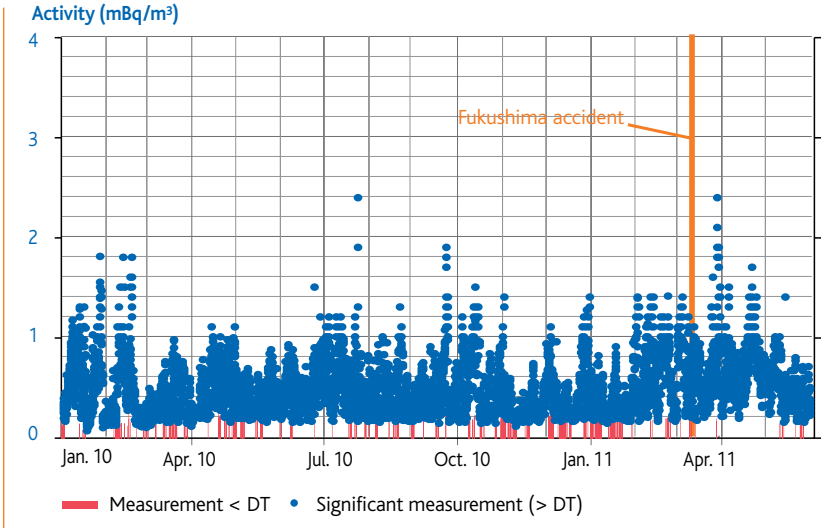

Figure V.57 - Time plot of the beta activity index in atmospheric aerosol samples collected in the environment of the NPPs in northeast France (mBq/m³)

Table V.28 - Radionuclides measured in atmospheric aerosol samples collected in the environment of the NPPs of northeast France during the period of the Fukushima accident (March 22 to May 6, 2011) (mBq/m³)

Plants	Radionuclide	Activity (mBq/m³)
Cattenom, Chooz, and Fessenheim NPPs	Cesium-134	0.030 ± 0.004
	Cesium-137	0.034 ± 0.004
	Iodine-131	0.11 ± 0.02

Table V.29 - Gross beta activity in atmospheric aerosol samples collected in the environment of the NPPs in northeast France (mBq/m³)

Plant	Radionuclide	Mean activity (mBq/m³)
Cattenom NPP	Gross beta activity	0.38 ± 0.01 0.73 ± 0.02*
Chooz NPP		0.26 ± 0.01 0.49 ± 0.02*
Fessenheim NPP		0.38 ± 0.01 0.60 ± 0.02*

** Measurements made from March 22 to May 6, 2011 during the period of the nuclear accident at the Fukushima nuclear plant*

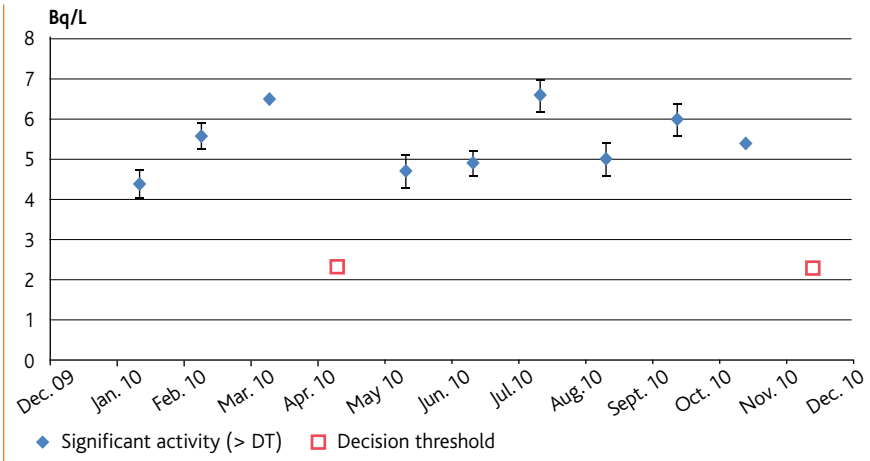

Figure V.58 - Tritium activity in rainwater collected in the vicinity of the Cattenom NPP (IRSN measurements) (Bq/L)

Terrestrial compartment

Terrestrial flora

Two grass samples were collected monthly around each NPP. Their analysis did not detect any gamma-emitting radionuclides potentially emitted by these plants. A single significant value of cesium-137 (2.8 ± 1.6 Bq/kg dry on January 4, 2011) was measured near the Chooz NPP out of the 34 analyses performed around the plant.

Occasional traces of iodine-131, which can be attributed to the accident at the Fukushima nuclear plant, were observed at the beginning of April 2011 in grass collected around the Cattenom and Fessenheim plants.

For more information
Chapter III – Fukushima accident

Farm produce and foodstuffs

Cereals
Gamma-emitting radionuclides discharged or likely to be discharged by NPPs were not detected in wheat samples collected in the vicinity of the sites. Only naturally occurring potassium-40 was measured, at a mean activity of 132 ± 12 Bq/kg dry.

Milk
The naturally occurring radioactivity measured in cow's milk collected around the Chooz, Fessenheim and Cattenom NPPs was mainly due to potassium-40, giving a mean activity concentration of 50.7 ± 1.4 Bq/L.

No trace of artificial radioactivity was observed. All the measurement results (^{131}I, ^{134}Cs, ^{137}Cs, ^{90}Sr, HTO) were below the decision thresholds of the measuring instruments used.

Leafy vegetables
The only significant activity measured in lettuce samples collected in the vicinity of the Fessenheim NPP was of naturally occurring potassium-40, at a specific activity of 131 ± 17 Bq/kg wet. The activity levels of artificial radionuclides (gamma emitters, tritium) were all below the decision thresholds of the measuring instruments used.

Continental aquatic compartment

Surface water

Chooz NPP
The Meuse river is 950 km long, with a drainage basin of 36,000 sq km oriented south to north. Its source is close to the Langres plateau in eastern France, where the Seine also rises.

The Meuse shows seasonal flow fluctuations, with high water in winter (mean monthly flow rates of 250 m³/s from December to March) and low water in August-September (mean monthly flow rates of 50.5 m³/s).

The tritium activity measured downstream of the NPP (*Figure V.59*) was related to the liquid discharge from the NPP. The mean activity measured in the Meuse downstream in 2010 was 22 Bq/L, with a minimum of 8.4 Bq/L and a maximum of 36 Bq/L measured by IRSN. The final shutdown of Chooz A in 1991 led to a substantial reduction of the tritium activity in the Meuse in the early 1990s, then a slight increase, but on average lower than or close to 20 Bq/L.

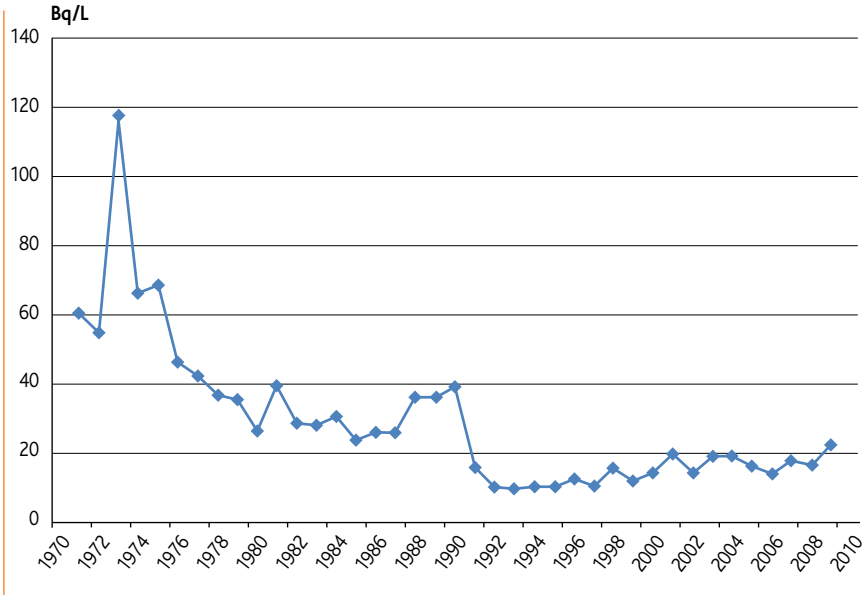

Figure V.59 - Annual tritium activity in the Meuse river downstream of the Chooz NPP (Bq/L)

Cattenom NPP

The Moselle, a tributary of the Rhine, has its source in the Vosges mountains. Its drainage basin in France covers about 11,500 sq km. At Bertrange-Imeldange, 20 km upstream of the NPP, the mean monthly flow rate of the Moselle is about 250 m³/s from December to March, decreasing to 50 m³/s in the summer.

No abnormal gross alpha or gross beta activity was detected in the surface water samples collected upstream and downstream of the NPP, and no artificial radionuclide other than tritium was detected.

The tritium concentrations measured downstream of the NPP can be related to the routine liquid discharge by the plant. The mean activity measured in the Moselle downstream of the NPP in 2010 was 36 Bq/L, with a minimum of 14.4 Bq/L and a maximum of 51 Bq/L. The activity measured downstream of the NPP shows an upward trend (*Figure V.60*), increasing from 15 Bq/L in 1985 to 35 Bq/L en 2010.

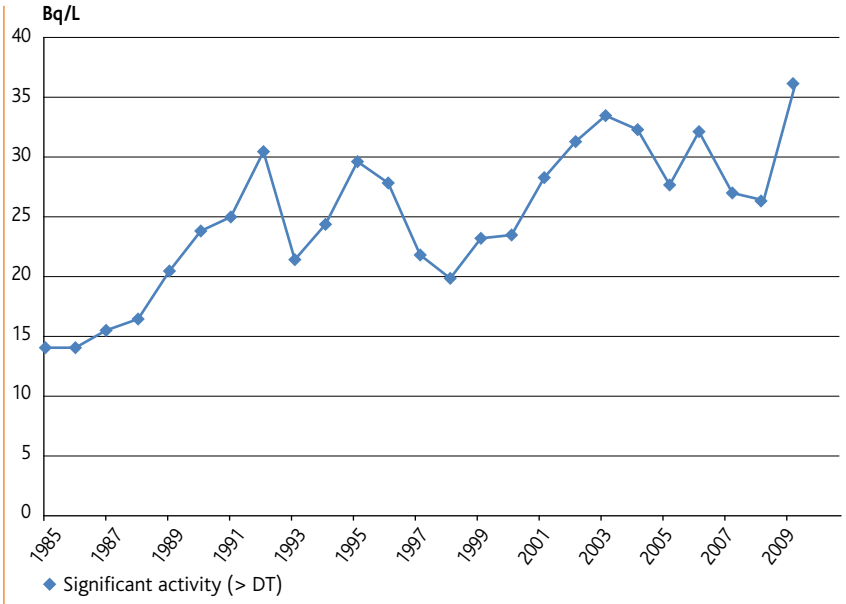

Figure V.60 - Annual tritium activity in the Moselle downstream of the Cattenom NPP (Bq/L)

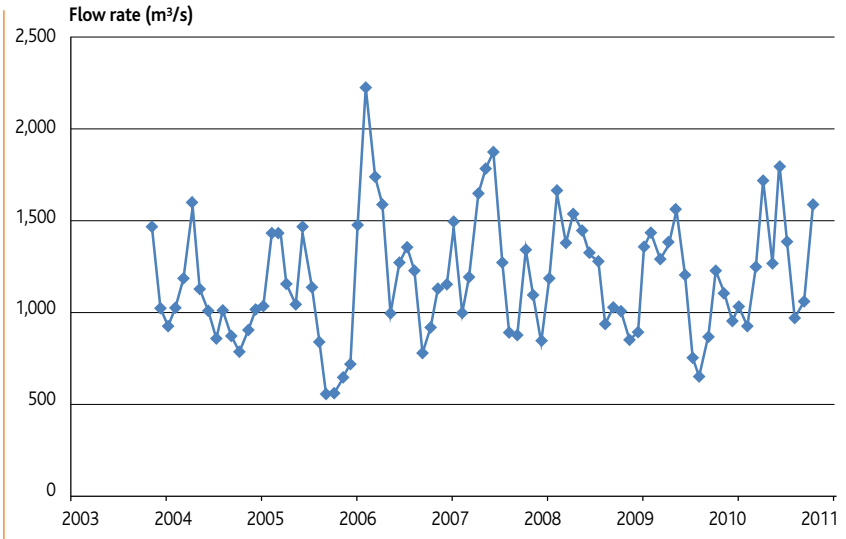

Figure V.61 - Mean monthly flow rate of the Rhine at Lauterbourg (Banque Hydro data) (m³/s)

Fessenheim NPP

The source of the Rhine is on the flank of the Saint-Gotthard massif, in the east of Switzerland. Its hydrological regime is regular. At Lauterbourg, 150 km downstream from Fessenheim, the amplitude of the annual variation of monthly flow rates is about 1000 m³ (*Figure V.61*). The Fessenheim NPP is located beside the Grand Canal d'Alsace, which runs parallel to the Rhine, separated from it by a few hundred meters, over a distance of 50 km.

The tritium activity measured downstream of the Fessenheim NPP was not significantly different from that measured upstream (*Figure V.62*). Tritium activity has decreased steadily since 1976. Since 2008, improved metrological performance has enabled IRSN to again measure tritium in the water of the Rhine, at levels close to 5 Bq/L.

The activity levels of this radionuclide can be related to the routine liquid discharge by the plant. Another source of tritium in the Rhine is the Swiss watchmaking industry, which has discharged tritium in organic form bound to sediments at activity levels of approximately 3000 to 8000 Bq/L into the Rhine and the Rhône, where the slow, persistent breakdown of the organic materials results in transfer of tritium from the solid phase to the aqueous phase.

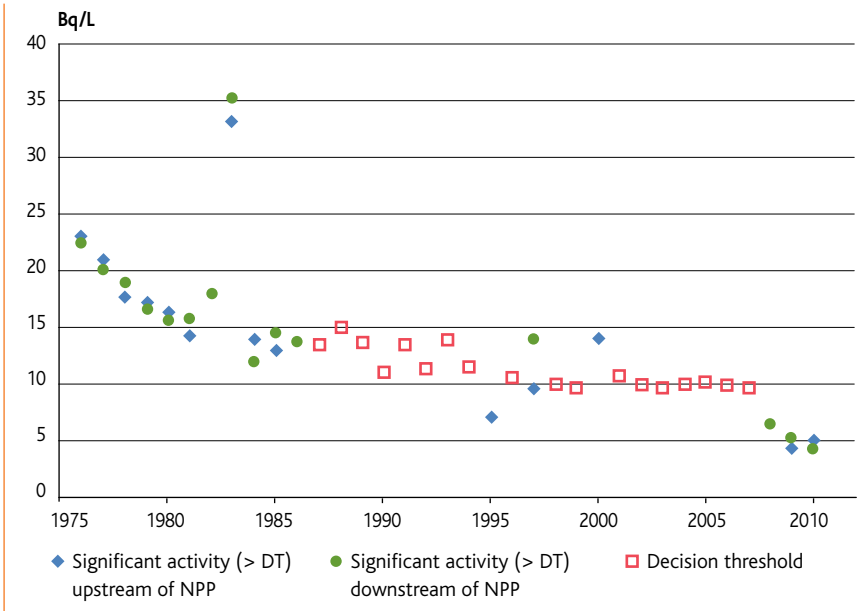

Figure V.62 - Annual tritium activity in the Grand Canal d'Alsace upstream and downstream of the Fessenheim NPP (Bq/L)

Ground water

Ground water monitoring by the operator of the Chooz NPP demonstrated the absence of detectable quantities of anthropogenic radionuclides.

The operator of the Fessenheim NPP analyses the ground water around the plant at several monitoring points (piezometers). The gross alpha and beta activity levels are similar to the background, and fission products such as cesium-134 and -137 are not detected in the piezometers. Exceptionally high tritium activity of 460 Bq/L was measured at point BTN EST in April 2011 (*Figure V.63*), which subsequently decreased rapidly when pumping was implemented (at well N08) to recover the tritiated water. Investigations of the facilities by EDF have identified the causes of these tritium activity increases: the first involved a recovery area for liquid waste from the water tank used to fill the reactor pools of unit 2; the second was related to the overflow of a liquid waste tank on March 6, 2011. On March 30, 2011, the Fessenheim NPP declared a significant environmental excursion to ASN following this increase in tritium activity.

At the Cattenom NPP, operators monitor ground water quality by means of eight piezometers. Three sampling points showed slight tritium concentrations, including piezometer NAPPE N2 located at the site (*Figure V.64*).

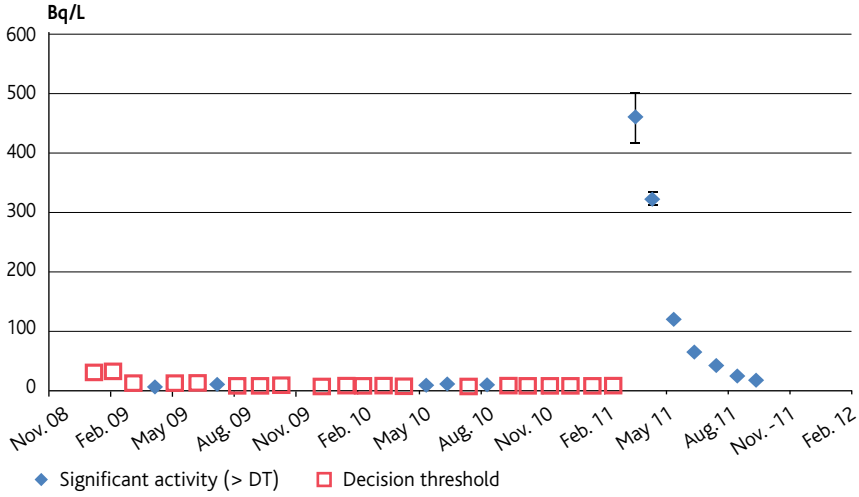

Figure V.63 - Tritium activity in ground water samples collected at point BTN EST of the Fessenheim NPP (Bq/L)

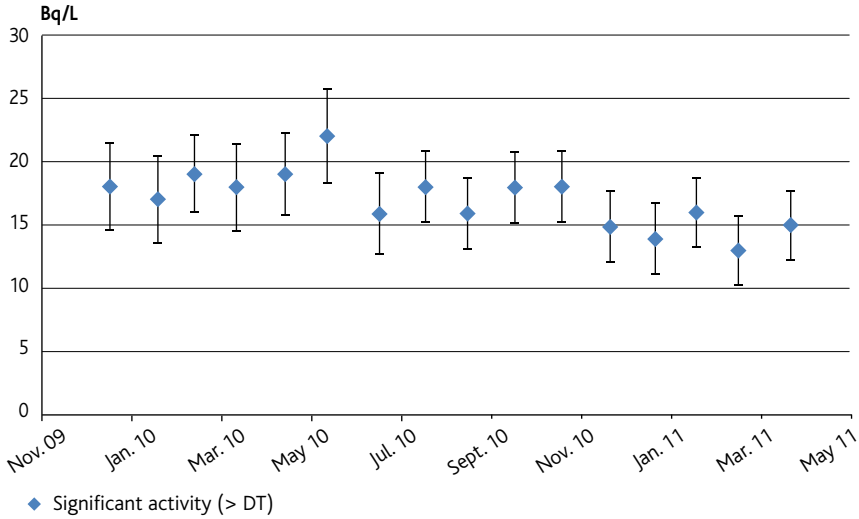

Figure V.64 - Tritium activity in water samples collected at point NAPPE N2 of the Cattenom NPP (Bq/L)

Monitoring of nuclear power plants of the Garonne drainage basin

There are two nuclear power plants in the Garonne drainage basin (*Figure V.65*), located on the bank of the Garonne river (Golfech NPP) and on the Gironde estuary (Le Blayais NPP).

Figure V.65 - NPP locations in the Garonne drainage basin

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Figure V.66 - Le Blayais NPP

Le Blayais NPP

Located on the right bank of the Gironde estuary, the Le Blayais NPP (*Figure V.66*) is half-way between Bordeaux and Royan, in the middle of 6,000 hectares of marshland. It has four 900 MW pressurized water reactors put into service in 1981, 1982, and 1983.

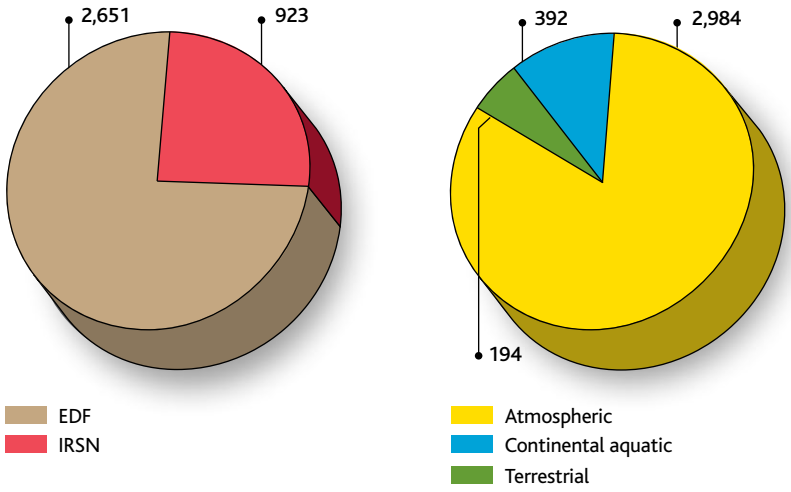

Figure V.67 - Breakdown of the number of samples by data provider and by environment for Le Blayais NPP

Golfech NPP

The Golfech nuclear plant is located downstream of the confluence of the Tarn and Garonne rivers, 80 km from Toulouse, in southwestern France. It has two 1300 MW pressurized water reactors, put into service in 1990 and 1994.

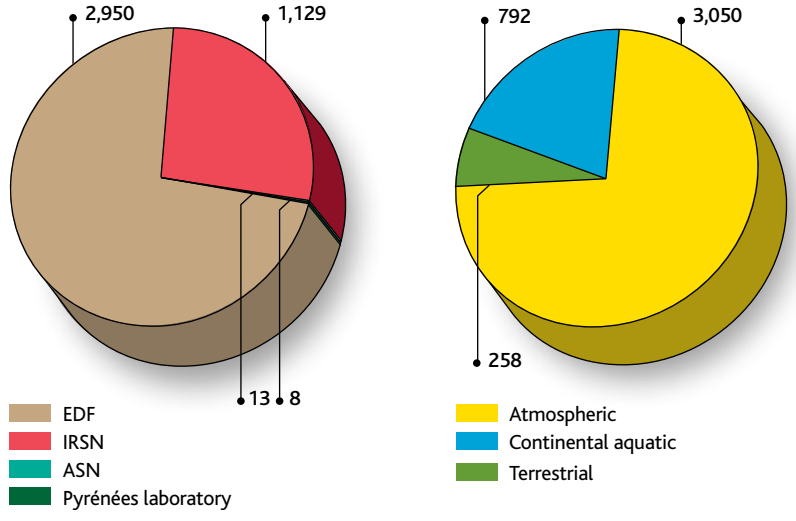

Figure V.68 - Breakdown of the number of samples by data provider and by environment for Golfech NPP

Atmospheric compartment

Atmospheric aerosols

Apart from the observations recorded during the period of the Fukushima accident, monitoring of the gross beta activity did not reveal any abnormal value (*Figure V.69*). The gamma spectrometry measurements showed that, apart from naturally occurring radionuclides (^{7}Be, ^{210}Pb), no artificial gamma-emitting radionuclide could be measured above the decision thresholds of the instruments used.

Significant levels of cesium-134, cesium-137 and iodine-131 were observed by gamma spectrometry between the end of March 2011 and the beginning of May 2011 (*Table V.30*). During this same period, an increase in the beta activity index was also recorded (*Table V.31*). This short-term rise was related essentially to the presence of artificial radionuclides in the air after the Fukushima accident.

For more information

Chapter III – Fukushima accident

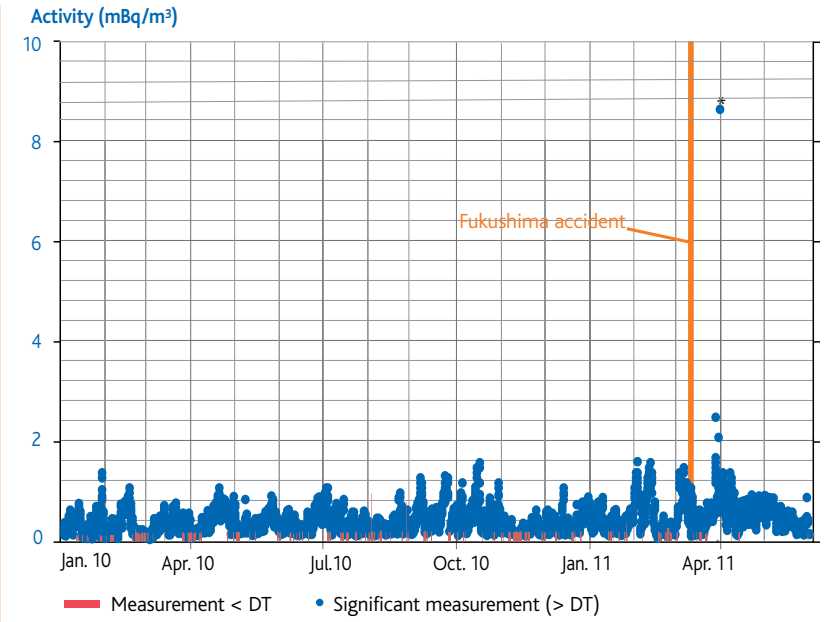

Figure V.69 - Time plot of the gross beta activity in atmospheric aerosol samples collected in the environment of the Garonne drainage basin NPPs (mBq/m³)

** Abnormal value (8.6 ± 2.1 mBq/m³ on March 31, 2011) entailing additional measurements leading IRSN to exclude this result from its study on the impact in France of fallout from the Fukushima accident.*

Table V.30 - Radionuclides measured by gamma spectrometry in atmospheric aerosol samples collected in the environment of the Garonne drainage basin NPPs during the period of the Fukushima accident (March 22 to May 6, 2011) (mBq/m³)

Plant	Radionuclide	Mean activity (mBq/m³)
Le Blayais and Golfech NPPs	Cesium-134	0.033 ± 0.007
	Cesium-137	0.043 ± 0.007
	Iodine-131	0.83 ± 0.07

Table V.31 - Gross beta activity in atmospheric aerosol samples collected in the environment of the Garonne drainage basin NPPs (mBq/m³)

Plant	Radionuclide	Mean activity (mBq/m³)
Le Blayais NPP	Gross beta activity	0.31 ± 0.01 0.53 ± 0.02*
Golfech NPP		0.33 ± 0.01 0.59 ± 0.02*

** Measurements made from March 22 to May 6, 2011 during the period of the nuclear accident at the Fukushima nuclear plant*

© EDF Médiathèque/Eranian Philippe

Figure V.70 - Recovery by an EDF technician of an atmospheric aerosol sample collected on a filter in the environment near the Le Blayais NPP

Rainwater and gases collected by bubblers

No artificial radionuclide other than tritium (5 Bq/L) was measured in rainwater or gases collected in the immediate vicinity of the Le Blayais and Golfech NPPs.

Terrestrial compartment

Terrestrial flora

Most of the results of gamma spectrometry analyses on grass samples collected near the Golfech and Le Blayais NPPs were below the decision thresholds of the measuring instruments used.

However, cesium-137 was occasionally detected in two samples (out of a total of 66 samples analyzed between January 2010 and May 2011). The specific activity levels measured near the Golfech and Le Blayais NPPs were 2 ± 0.9 Bq/kg dry and 0.13 ± 0.04 Bq/kg dry, respectively.

Following the accident on March 11, 2011 at the Fukushima nuclear plant, traces of iodine-131 and cesium-134 and -137 were detected in the grass samples collected in April 2011 at the two NPPs.

For more information
Chapter III – Fukushima accident

Soil

Cesium-137 was detected in all the soil samples collected near the Golfech and Le Blayais NPPs at specific activity levels of 4.3 ± 0.6 and 0.59 ± 0.1 Bq/kg dry, respectively. These activity levels can be attributed mainly to fallout from the Chernobyl accident. Other artificial radionuclides discharged or potentially discharged by the NPPs were not detected by gamma spectrometry analysis.

Farm produce and foodstuffs

Cereals
No gamma-emitting artificial radionuclide was detected in the wheat sample collected near the Golfech plant.

Milk
A cow's milk sample is collected and analyzed every month from two farms near the Golfech and Le Blayais NPPs. No trace of artificial radioactivity attributable to atmospheric discharge from these nuclear plants (^{131}I, ^{134}Cs, ^{137}Cs, ^{14}C, ^{3}H) was detected in these milk samples. Only naturally occurring potassium-40 was detected, at a mean concentration of 52.2 ± 1.2 Bq/L.

Root vegetables

Radishes collected near the Le Blayais plant did not show any trace of artificial radionuclides (gamma emitters, HTO) attributable to discharge from the plant.

Wine

In 2010, a red wine produced on the côteaux du Blayais near the Le Blayais plant was analyzed by gamma spectrometry. Most of the measured radioactivity was due to naturally occurring potassium-40 (36.4 ± 3.8 Bq/L). No artificial radionuclide was detected. Analyses carried out on grape juice obtained by crushing the pulp, produced at Saint-Estèphe, led to the same conclusions (activity concentration of potassium-40 of 50.5 ± 4.8 Bq/L).

Radioactivity measurements made on apple juice produced at Donzac, near the Golfech NPP, were below the decision thresholds for artificial radionuclides. Potassium-40 was measured at an activity concentration of 55 ± 5 Bq/L.

Continental aquatic compartment

The headwaters of the Garonne are in the Aran valley in the Spanish Pyrenees, and the river is 647 km long. Its drainage basin covers about 55,000 sq km.

The flow rate of the Garonne, observed since 2004 immediately downstream of the Golfech NPP located on the right bank, is around 320 m³/s (*Figure V.71*). The mean monthly low water flow rate is about 60 m³/s, while the winter flood flow rate is about 700 m³/s, with instantaneous flow rates of up to 1,500 m³/s in 2010. The Garonne thus shows marked seasonal flow rate fluctuations.

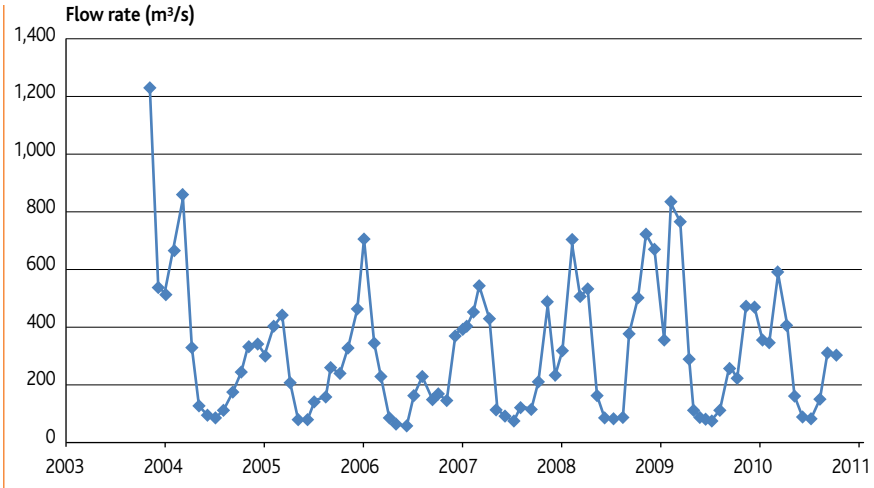

Figure V.71 - Mean monthly flow rate of the Garonne at Lamagistère (source: Banque Hydro) (m³/s)

Surface water

The tritium activity measured in the water of the Garonne downstream of Golfech has been about 10 Bq/L, varying between 8 and 14 Bq/L, since 1990 (*Figure V.72*).

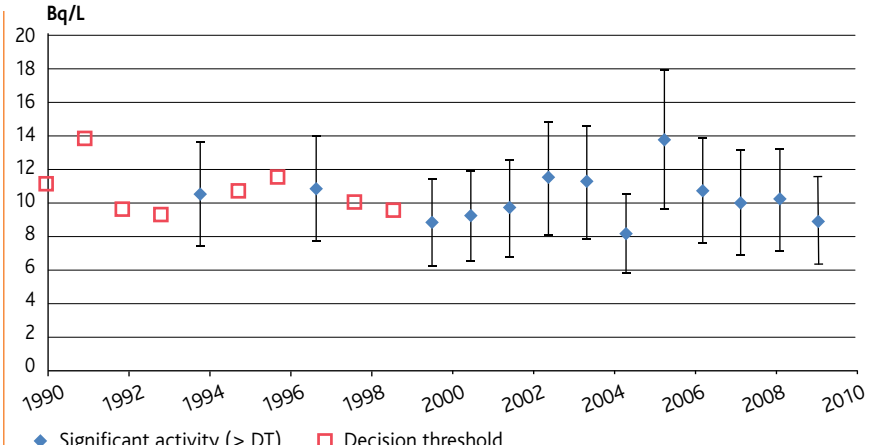

Figure V.72 - Mean annual tritium activity measured in water from the Garonne at Laspeyres, downstream of the Golfech NPP (Bq/L)

The Le Blayais NPP draws water from the Gironde estuary for cooling its condensers. The meeting of the alluvium-rich fresh water (the Garonne and the Dordogne supply 900 m³/s of fresh water) with salt water (the flood tide comprises 20,000 m³ of sea water) flocculates the clayey particles and forms a silt plug characteristic of estuary water.

Samples taken directly from the discharge channel of the NPP show tritium activity levels of 5 to 40 Bq/L which, after dilution in the estuary, are in general no longer detectable at Vitrezay or at Pauillac (*Figure V.73*).

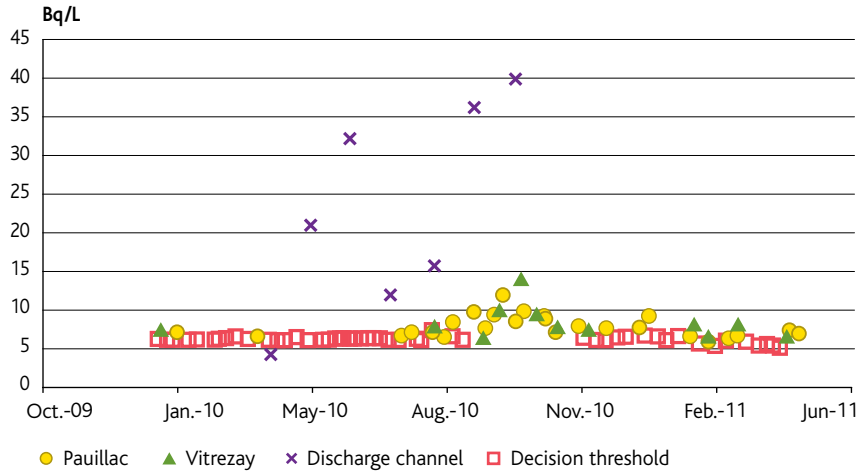

Figure V.73 - Tritium activity measured in the water of the Gironde estuary and in the overflow of Le Blayais NPP (Bq/L)

Ground water

Analysis of the results at five piezometers of the Le Blayais NPP showed that the ground water at point N01 had additional concentrations of tritium (*Figure V.74*), and that its activity had increased since 2009, from 10 Bq/L to 25 Bq/L. The gross beta activity, of approximately 0.8 to 1 Bq/L, can be attributed to potassium-40 from sea water present in the ground water.

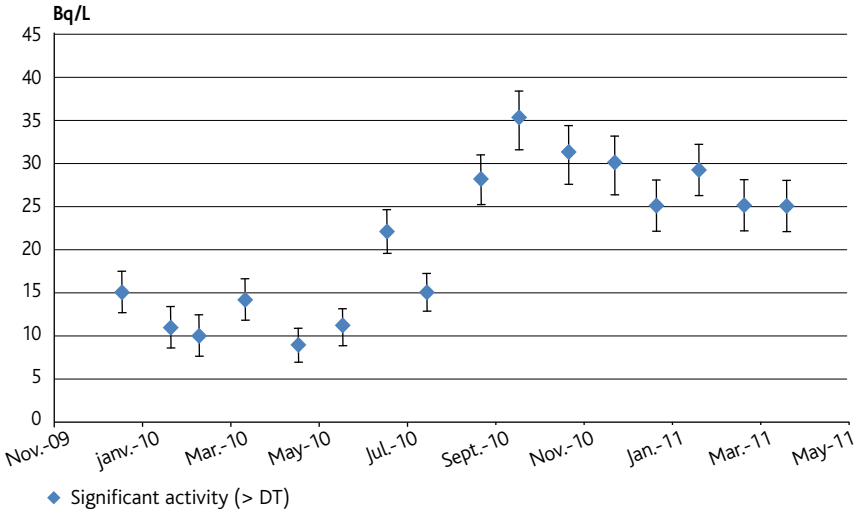

Figure V.74 - Tritium activity in ground water at point N01 on the site of Le Blayais NPP (Bq/L)

Sediments

In 2010, sediment samples were collected upstream and downstream of the Le Blayais NPP (*Table V.32*). The analysis results indicated that cesium-137 was present at similar levels at the two sampling points. There is consequently no quantifiable impact of liquid discharge, the measured cesium-137 being mainly the result of fallout from atmospheric nuclear weapons testing in the 1960s and from the Chernobyl accident. It should be noted that the other gamma-emitting artificial radionuclides likely to be discharged by the NPP (^{58}Co, ^{60}Co, ^{110m}Ag, ^{54}Mn, etc.) were not detected by the measuring instruments used.

Table V.32 - Activity levels measured in sediment samples from the aquatic environment upstream and downstream of Le Blayais NPP (Bq/kg dry)

Radionuclide	7.5 km - South Saint-Androny	8 km - North Saint-Sorlin-de-Conac
^{137}Cs	6.1 ± 0.9	5.4 ± 0.7
^{40}K	840 ± 120	830 ± 120

Continental aquatic fauna

Low levels of cesium-137 were measured in fish caught upstream and downstream of the Le Blayais plant (*Table V.33*). Other artificial radionuclides likely to be discharged in liquid effluent from PWR plants (^{58}Co, ^{60}Co, ^{110m}Ag, ^{54}Mn, ^{14}C, ^{3}H, etc.) were not quantified.

Table V.33 - Activity measured in fish caught upstream and downstream of Le Blayais NPP (Bq/kg wet)

Radionuclide	Fish	Fish
	7.5 km - South Saint-Androny	3 km - North Saint-Ciers-sur-Gironde
^{137}Cs	0.081 ± 0.36	0.066 ± 0.029
^{40}K	180 ± 0.20	140 ± 10

Monitoring of nuclear power plants of the Rhône drainage basin

There are five nuclear power plants in the Rhône drainage basin (*Figure V.75*) located on the banks of the Rhône upstream of Lyon (Creys-Malville and Bugey NPPs) and downstream (Saint-Alban, Cruas and Tricastin NPPs).

Figure V.75 - NPP locations in the Rhône drainage basin

© Grégoire Maisonneuve/IRSN

Figure V.76 - Cruas NPP

Creys-Malville site

The Creys-Malville nuclear site is located in east-central France 50 km east of Lyon and 60 km west of Chambéry. It is on the bank of the Rhône 30 km upstream of the Bugey nuclear power plant. The site accommodates the industrial prototype of a sodium-cooled fast neutron reactor. The 1200 MW Superphénix reactor was put into service in 1985. Following a government decision, its final shutdown was implemented in December 1998, and it is currently being dismantled.

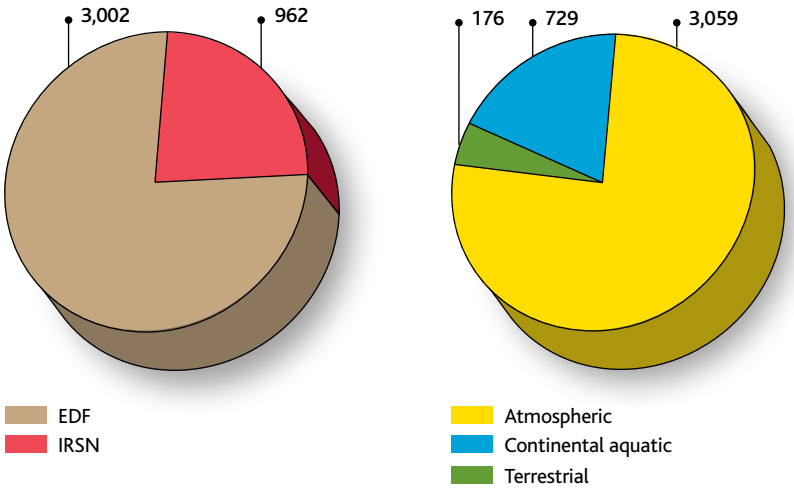

Figure V.77 - Breakdown of the number of samples by data provider and by environment for the Creys-Malville site

Bugey NPP

Located on the right bank of the Rhône, some thirty kilometers from Lyon, the Bugey NPP has four 900 MW pressurized water reactors put into service in 1978 and 1979. It also has a GCR reactor, shut down in 1994 and currently being dismantled.

Note: Following a technical incident affecting the transmission of data from the Bugey NPP to the RNM, only the measurements made by IRSN were available for use in this 2010-2011 report. The results of the monitoring measurements made by EDF are now available on the RNM website: www.mesure-radioactivite.fr.

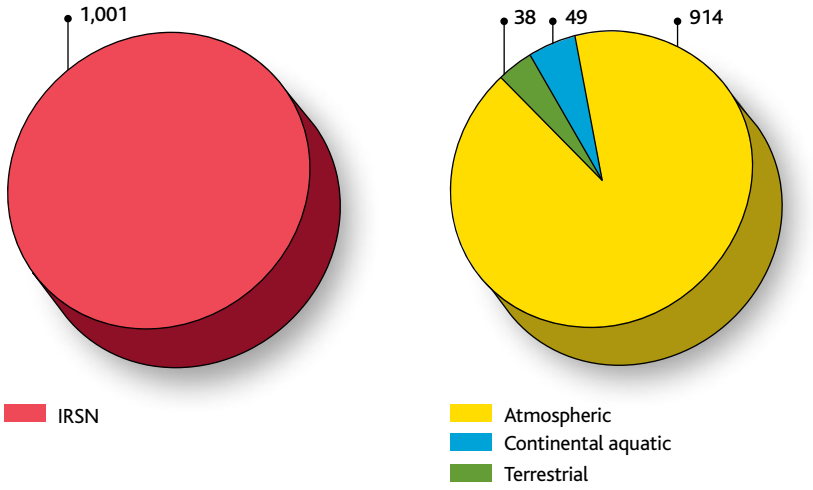

Figure V.78 - Breakdown of the number of samples by data provider and by environment for the Bugey NPP

Saint-Alban NPP

Located on the left bank of the Rhône, 50 km south of Lyon, the Saint-Alban NPP has two 1300 MW pressurized water reactors put into service in 1985 and 1986.

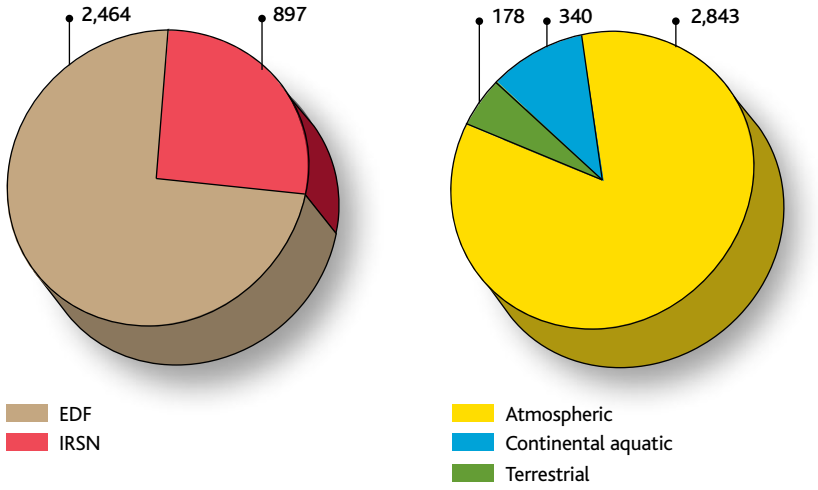

Figure V.79 - Breakdown of the number of samples by data provider and by environment for the Saint-Alban NPP

Cruas NPP

The Cruas-Meysse plant (*Figure V.76*) is located on the right bank of the Rhône, in southeastern France near Montélimar. It has four 900 MW pressurized water reactors put into service in 1983 and 1984.

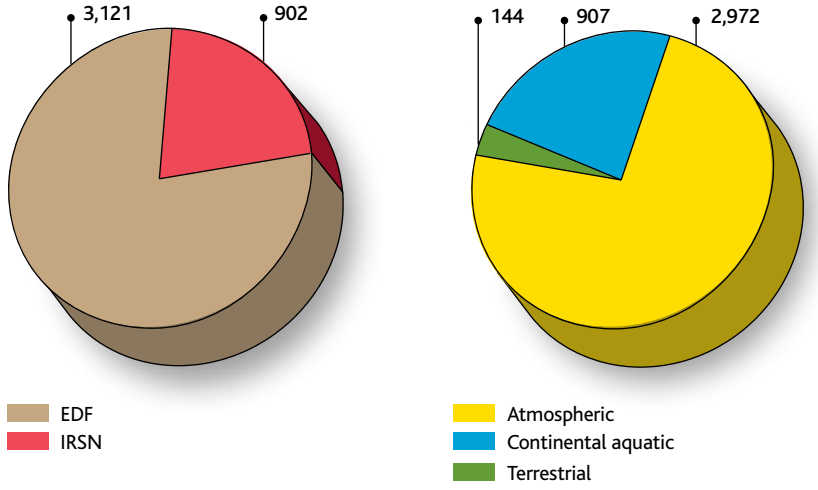

Figure V.80 - Breakdown of the number of samples by data provider and by environment for the Cruas NPP

Tricastin NPP

Located on the right bank of the Rhône diversion canal about 70 km north of Avignon, in the south of France, the Tricastin NPP has four 900 MW pressurized water reactors put into service in 1980 and 1981.

Note: Following a technical incident affecting the transmission of data from the Tricastin NPP to the RNM, the majority of the measurements used for this 2010-2011 report were made by IRSN. The results of the monitoring measurements made by EDF are now available on the RNM website: www.mesure-radioactivite.fr.

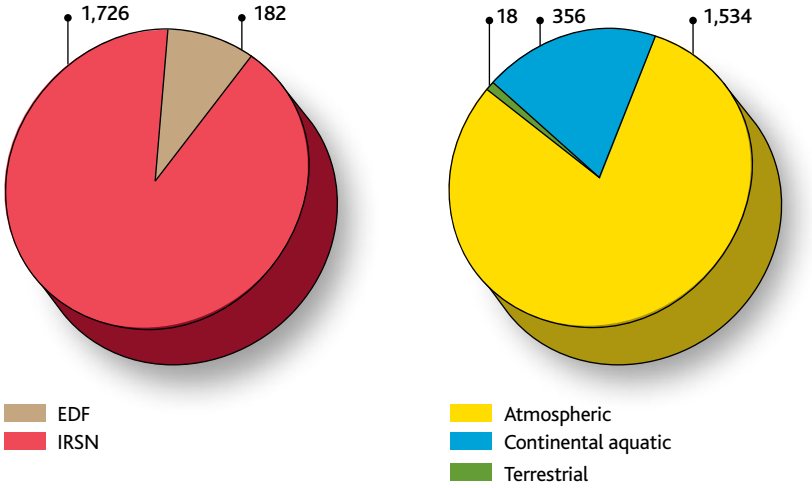

***Figure V.81** - Breakdown of the number of samples by data provider and by environment for the Tricastin NPP*

Atmospheric compartment

Atmospheric aerosols

In 2010, monitoring of atmospheric aerosols detected some abnormal values of the gross beta activity in samples collected in the environment of the Creys-Malville NPP, at Creys-Mépieu, on June 3-4, 2010: 9.2 ± 1.1 mBq/m³ and 5.0 ± 0.7 mBq/m³. Additional investigations by the operator established that these unusual activity levels were not due to artificial radionuclides.

Apart from these observations and the results obtained during the period of the Fukushima accident, monitoring of the gross beta activity did not reveal any abnormal value (*Figure V.82*). The gamma spectrometry analyses showed that, apart from naturally occurring radionuclides (^{7}Be and ^{210}Pb), no artificial radionuclide was present in the environment.

Significant levels of cesium-134, cesium-137 and iodine-131 were observed between the end of March 2011 and the beginning of May 2011 (*Table V.34*). These results were evidence of radioactive fallout on French territory from the accident at the Fukushima nuclear plant. Also during this period, a temporary increase in the gross beta activity was observed (*Table V.35*), related mainly to the presence of artificial radionuclides in the air following the Fukushima accident.

For more information

Chapter III – Fukushima accident

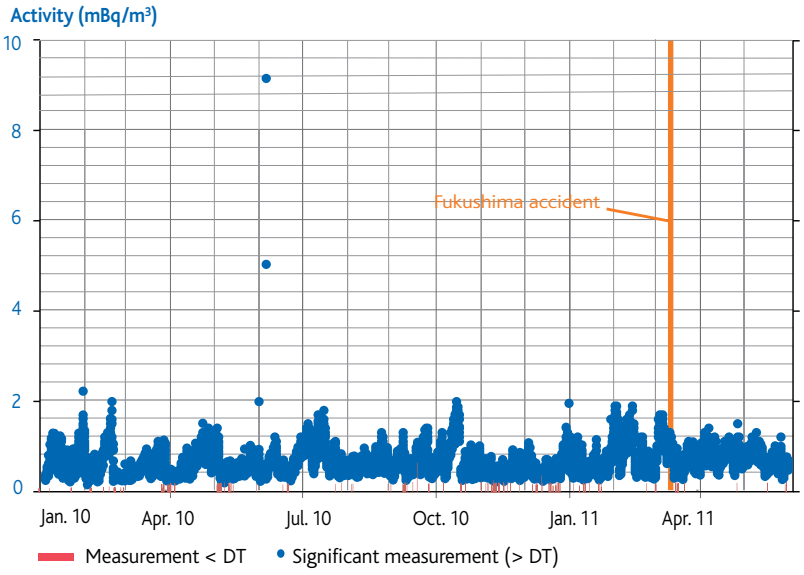

***Figure V.82** - Time plot of the gross beta activity in atmospheric aerosol samples collected in the environment of the Rhône valley NPPs (mBq/m³)*

***Table V.34** - Radionuclides measured in aerosols from the environment of the Rhône valley NPPs during the period of the accident at the Fukushima nuclear plant from March 22 to May 6, 2011 (mBq/m³)*

Plant	Radionuclide	Mean activity (mBq/m³)
Bugey, Creys-Malville, Cruas, Saint-Alban and Tricastin NPPs	Cesium-134	0.025 ± 0.005
	Cesium-137	0.028 ± 0.005
	Iodine-131	0.15 ± 0.02

***Table V.35** - Gross beta activity in atmospheric aerosol samples collected in the environment of the Rhône valley NPPs (mBq/m³)*

Plant	Radionuclide	Mean activity (mBq/m³)
Bugey NPP	Gross beta activity	0.38 ± 0.01
Creys-Malville NPP		0.32 ± 0.01 0.57 ± 0.02*
Cruas NPP		0.40 ± 0.01 0.68 ± 0.02*
Saint-Alban NPP		0.40 ± 0.01 0.62 ± 0.02*
Tricastin NPP		0.37 ± 0.01 0.50 ± 0.02*

** Measurements made from March 22 to May 6, 2011 during the period of the accident at the Fukushima nuclear plant*

Rainwater

The significant tritium activity levels observed in 2010 in the rainwater for all the NPPs ranged between the decision thresholds and 40 Bq/L (value measured at the Tricastin NPP). These results can be viewed in the context of the time plots compiled by IRSN, showing a decrease in measured activity levels over the decades, which can be related to the reduction of gaseous tritium discharge from the Marcoule site. This trend is illustrated in Figure V.83, which shows the annual means of the significant tritium activity levels for all the NPPs located in the Rhône valley.

The time plot of the annual tritium activity measured in rainwater in the vicinity of the Tricastin NPP (*Figure V.84*) shows quite high variability between the minimum and maximum values. This variability can be explained by the geographical proximity of the Marcoule and Pierrelatte sites, to which must be added influencing environmental factors such as wind speed and rainfall.

Gases sampled by bubblers

Tritium in form HTO (tritiated water vapor) could be detected at values close to the decision thresholds in the immediate vicinity of the Cruas NPP (*Figure V.85*). The available results for the other Rhône NPPs showed only decision thresholds.

The levels generally observed in the air in France are from 0.01 to 0.05 Bq/m³ away from any tritium emission source, and between 0.5 and a few Bq/m³ in the near-field environment of nuclear sites permitted to discharge tritium into the atmosphere.

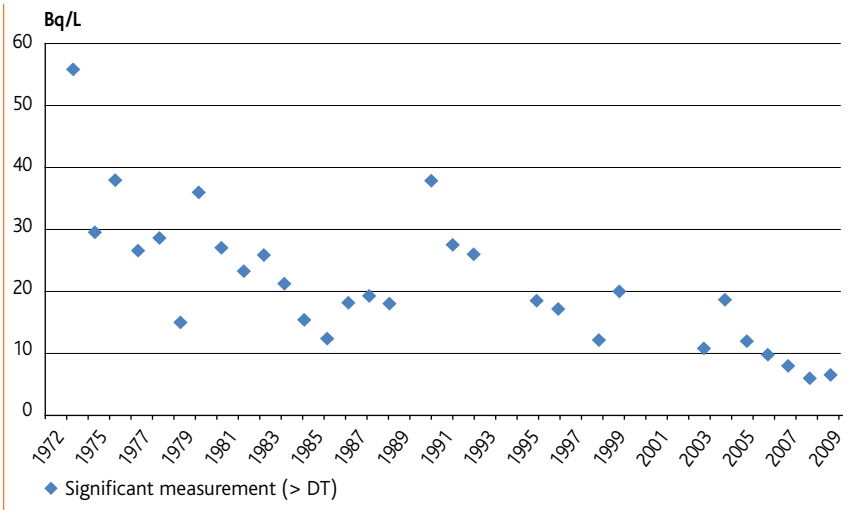

Figure V.83 - Time plot of past annual mean tritium activity measured by IRSN in rainwater collected in the vicinity of the Rhône NPPs (Bq/L)

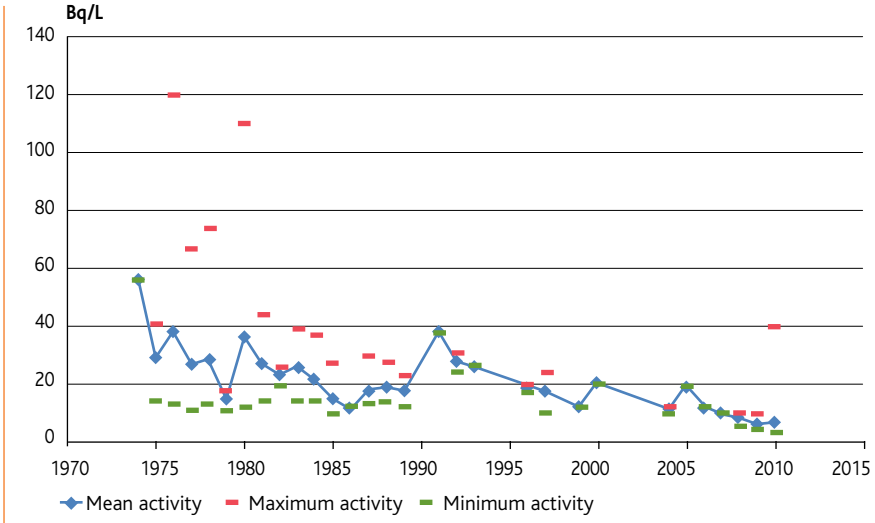

Figure V.84 - Historic variability of tritium activity in rainwater collected at the Tricastin NPP (Bq/L)

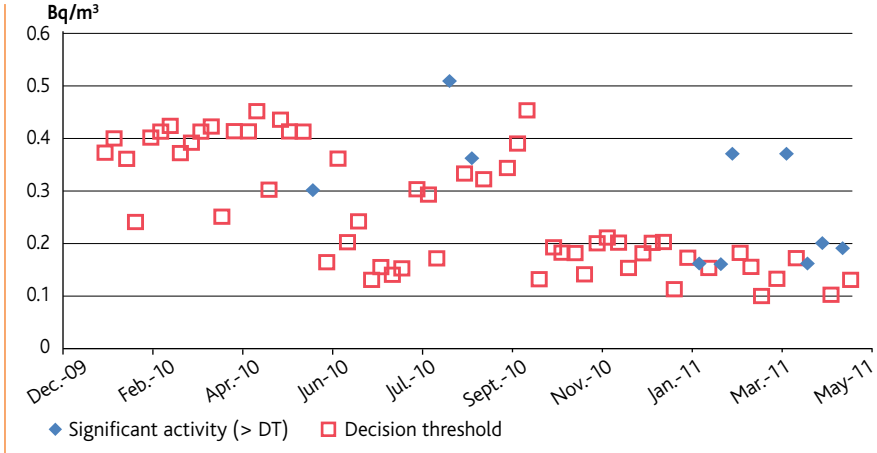

Figure V.85 - Tritium activity measured in the air in the vicinity of the Cruas NPP (Bq/m³)

Terrestrial compartment

Terrestrial flora

Cesium-137 was detected occasionally in grass samples collected monthly within 4 km of the Creys-Malville and Cruas NPPs (*Table V.36*). The mean specific activity levels of the significant measured results varied between 1.3 ± 0.5 Bq/kg dry and 4.2 ± 2 Bq/kg dry. These intervals of variation, close to the means calculated for the results below the decision thresholds (between 0.5 and 1.3 Bq/kg dry), are within the range of values characteristic of the Chernobyl accident. Any impact on the operation of these plants cannot be detected.

Traces of iodine-131 were detected at the beginning of April 2011 on grass samples collected in the vicinity of the Creys-Malville and Saint-Alban NPPs. These activity levels were related to fallout from the Fukushima plant accident in Japan on March 11, 2011.

For more information
Chapter III – Fukushima accident

Soil

In 2010, a soil sample was collected 5.5 km from the Saint-Alban NPP under the prevailing winds. Cesium-137 activity was detected in this sample at 21 ± 2 Bq/kg dry. The majority of this activity can be explained by fallout from past atmospheric nuclear weapons testing and from the Chernobyl accident. The contribution to the activity attributable to discharge from the NPP cannot be quantified.

Farm produce and foodstuffs

Cereals
Gamma-emitting radionuclides likely to be discharged by the PWR plants were not detected in wheat samples collected near the Creys-Malville, Bugey, Saint-Alban and Cruas NPPs.

Milk
The radioactivity measured in milk produced in the vicinity of the NPPs in the Rhône valley basin was due mainly to potassium-40, with mean activity levels of 48.4 ± 1.3 Bq/L in cow's milk and 57.9 ± 2.9 Bq/L in goats' milk. No trace of artificial radioactivity attributable to discharge from the NPPs (^{131}I, ^{134}Cs, ^{137}Cs, ^{3}H) could be measured by the measuring instruments used.

A significant level of strontium-90 was measured in goat's milk produced in the region of Tricastin. The activity, close to the decision thresholds (0.056 ± 0.011 Bq/L), can be attributed to past fallout from atmospheric nuclear weapons testing in the 1960s.

Table V.36 - ^{137}Cs activity measured in grass samples collected near the Rhône drainage basin NPPs (Bq/kg dry)

	Creys-Malville NPP		Saint-Alban NPP		Cruas NPP	
Sampling localities	Creys-Mépieu (1.36 km under the primary prevailing winds)	Bouvesse-Quirieu (3.7 km, slightly outside the influence of the secondary prevailing winds)	Pélussin	Saint-Pierre-de-Boeuf	Meysse (500 m under the primary prevailing wind)	Tourrettes (4 km under the secondary prevailing winds)
Number of significant measurements out of the total number of measurements	2 significant measurements out of 18	0 significant measurements out of 18	0 significant measurements out of 15	0 significant measurements out of 14	1 significant measurement out of 17	4 significant measurements out of 17
Mean ^{137}Cs activity – significant results *	1.3 ± 0.5	/	/	/	4.2 ± 2	3.9 ± 0.7
Mean ^{137}Cs activity – results below the decision thresholds	< 0.5	< 0.5	< 1.2	< 1.3	< 1.3	< 1.3

** Excluding values attributable to the Fukushima accident*

Fruit

Radionuclides discharged or likely to be discharged by the power plants (^{131}I, ^{134}Cs, ^{137}Cs, ^{60}Co, ^{3}H, etc.) were analyzed in rhubarb, strawberries, pears and peaches produced near the Bugey, Saint-Alban, Cruas and Tricastin NPPs, respectively. The analysis results showed activity levels below the decision thresholds of the instruments used. Only tritium activity was measured in peaches produced in the region of Tricastin, at 5.1 ± 1.8 Bq/kg wet. Although low, this value is characteristic of an environment affected by anthropogenic activities.

Wine

No significant anthropogenic activity was measured in red wine produced in the immediate vicinity of the Saint-Alban and Cruas NPPs. Only naturally occurring potassium-40 was measured, at a mean activity concentration of 37.7 ± 2.7 Bq/L.

Continental aquatic compartment

The Rhône rises on the southern slope of the Saint-Gotthard massif in Switzerland, feeds into Lake Geneva, exits from the lake at the city of Geneva, then marks the French-Swiss border for a few kilometers. In France, the radiological monitoring of the Rhône begins at the Injoux-Génissiat hydroelectric plant operated by the ***Compagnie Nationale du Rhône*** (CNR). Most of the radioactivity transported by the Rhône upstream of the border is bound to suspended solids. Tritium discharge by the Swiss watchmaking industry are responsible for remanent radioactivity in the Rhône.

In France, the Rhône drainage basin has a large number of nuclear facilities (4 NPPs, Creys-Malville site, Marcoule site, Pierrelatte industrial complex, etc.). Some of its tributaries also have nuclear sites, including the Isère (FBFC Romans-sur-Isère) and the Durance (CEA Cadarache). The tributaries of the Rhône are major rivers and substantially increase the volume of its water, generating a considerable dilution effect.

The Rhône is very different from the Loire in terms of hydrodynamics. Its flow rate is significantly higher and more regular. At Beaucaire, about 60 km from the mouth of the river, the mean annual flow rate of the Rhône was 1790 m³/s in 2010, with a peak instantaneous flow rate of 5950 m³/s in December. Cycles are observed in the monthly flow rates calculated from the mean daily flow rates obtained by height or flow rate measurements (*Figure V.86*). In comparison with the Loire, the low amplitude of the seasonal cycles is not reflected in the activity levels measured downstream of the NPPs. Any such influence would become harder to detect as the high flow rate of the Rhône dilutes discharge.

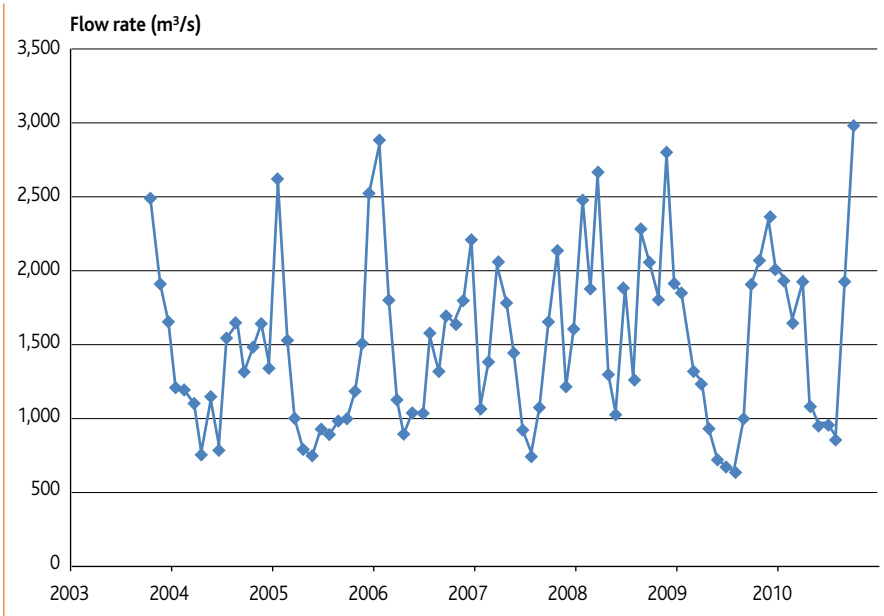

Figure V.86 - Mean monthly flow rate of the Rhône at Beaucaire (source: Banque Hydro) (m³/s)

Surface water

Routine monitoring of the Rhône NPPs by IRSN started in 1972 (Bugey I-GCR) with the installation of a river water sampler downstream of the site (*Figure V.87*). The activity measured in 1973, about 32 Bq/L, decreased rapidly to below 20 Bq/L in 1976. From the 1980s, all the NPPs have been monitored by IRSN. The activity decreased by a further factor of 2 until 1998. The metrological performance showed its limitations in the subsequent period to 2008, when the mean tritium activity in the Rhône fell below 10 Bq/L. From 2008 the decision thresholds were improved (5 Bq/L, then 1 Bq/L in 2010) and the activity in the Rhône could again be quantified.

Strontium-90 is measured periodically downstream of the Bugey NPP at activity levels of about 0.004 Bq/L, close to the decision thresholds. The measurement of strontium-90 downstream of the Bugey NPP

originated in the operation of the GCR system developed in the 1950s in France. However, the strontium-90 activity levels measured here are characteristic of atmospheric fallout from nuclear weapons testing.

Ground water

The ground water circulating under the Rhône valley NPPs and which is monitored shows additional concentrations of tritium at around 8 Bq/L, with a maximum activity of 14 Bq/L measured at the Tricastin NPP. The mean tritium activity in the vicinity of each NPP remained stable over time (*Figure V.88*).

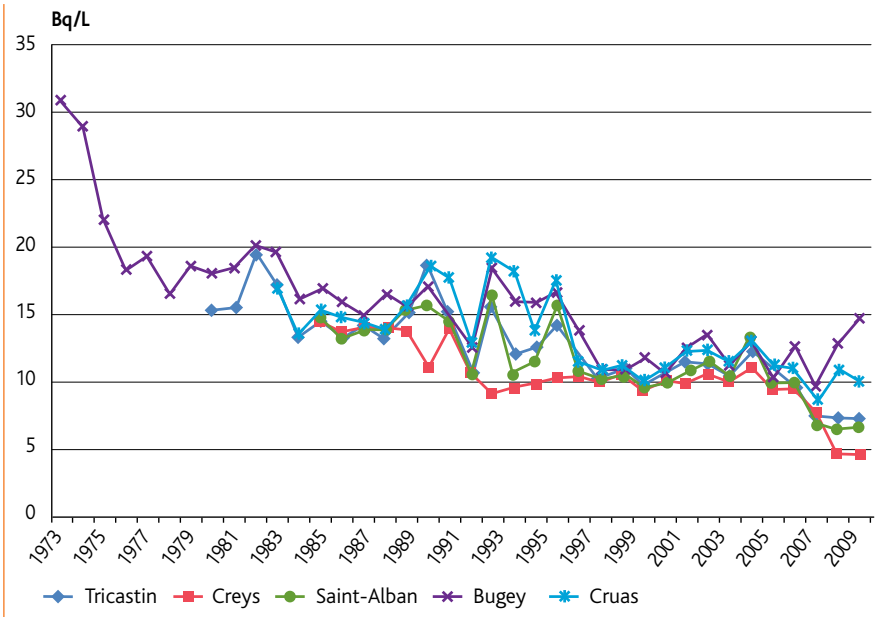

Figure V.87 - Significant (> DT) mean annual tritium activity measured in the water of the Rhône downstream of the NPPs (Bq/L)

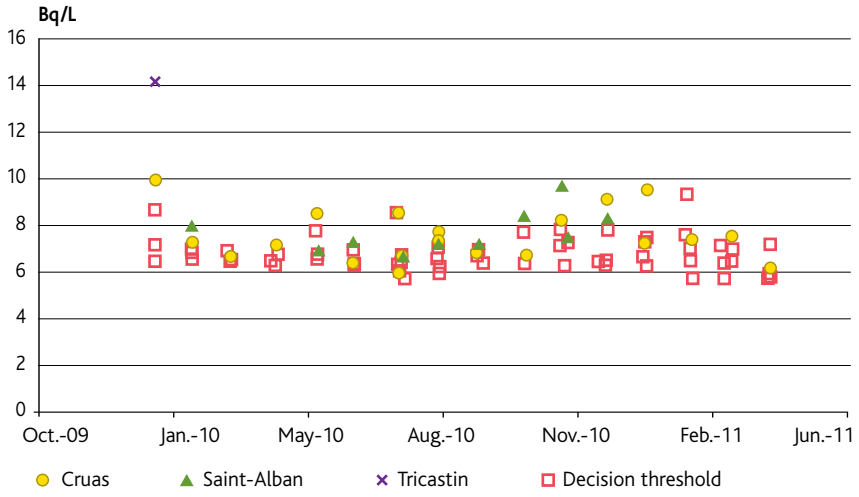

Figure V.88 - Mean tritium activity in ground water in the vicinity of the Rhône valley NPPs (Bq/L)

Monitoring of nuclear power plants on the Channel and North Sea coasts

There are four nuclear power plants along the Channel - North Sea coast (*Figure V.89*), located near Cherbourg (Flamanville NPP), in Normandy (Penly and Paluel NPPs) and between Calais and Dunkirk (Gravelines NPP).

Figure V.89 - NPP locations on the Channel - North Sea coast

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Figure V.90 - Flamanville NPP

Flamanville NPP

Located on the west coast of the Cotentin peninsular, 30 km southeast of Cherbourg, the Flamanville NPP (*Figure V.90*) has two 1300 MW pressurized water reactors put into service in 1985 and 1986, and a 1650 MW EPR unit under construction since 2006.

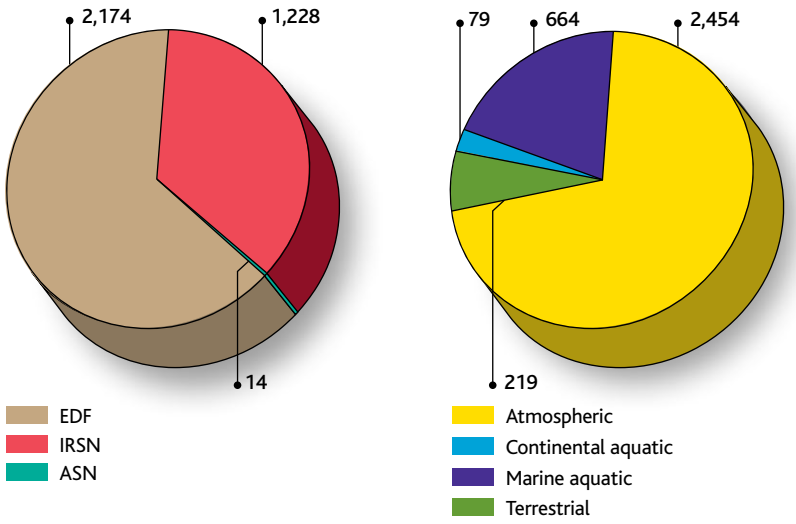

Figure V.91 - Breakdown of the number of samples by data provider and by environment for the Flamanville NPP

Paluel NPP

Located on the Channel coast 30 km west of Dieppe, the Paluel NPP has four 1300 MW pressurized water reactors put into service in 1984, 1985 and 1986.

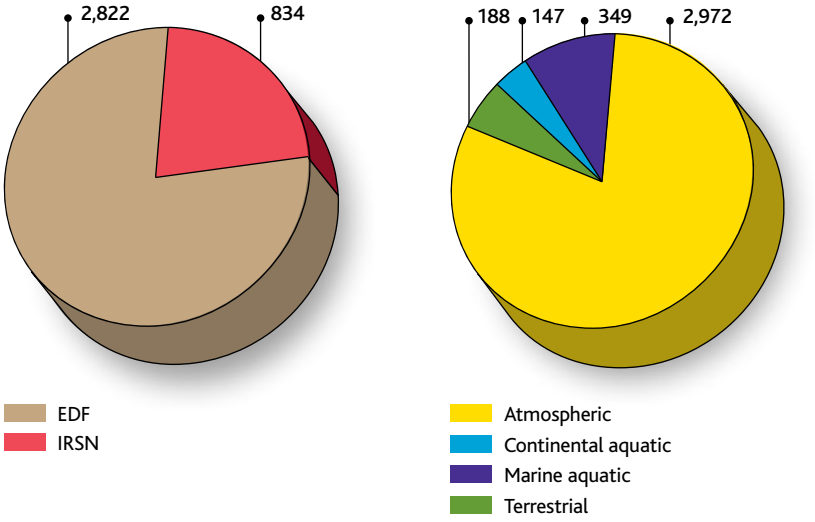

Figure V.92 - Breakdown of the number of samples by data provider and by environment for the Paluel NPP

Penly NPP

Located on the Channel coast 11 km east of Dieppe, the Penly NPP has two 1300 MW pressurized water reactors put into service in 1990 and 1992.

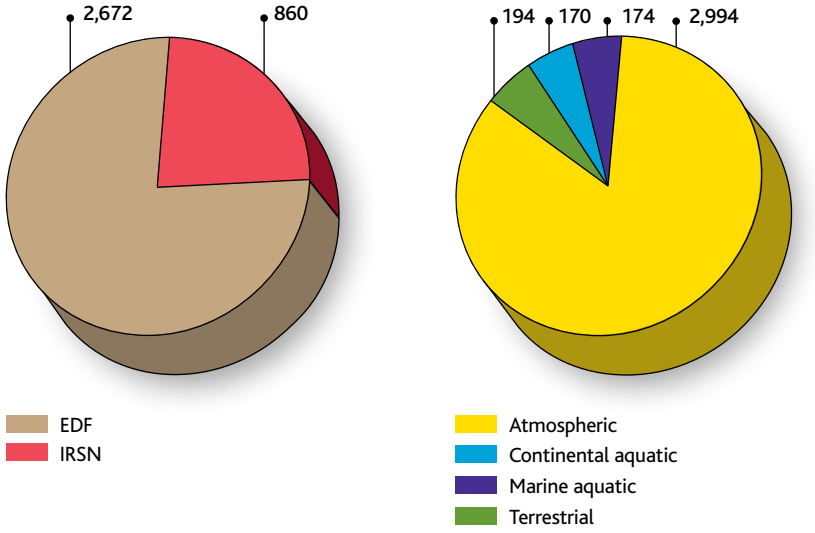

Figure V.93 - Breakdown of the number of samples by data provider and by environment for the Penly NPP

Gravelines NPP

Located on the North Sea coast between Dunkirk and Calais, the Gravelines NPP has six 900 W pressurized water reactors put into service in 1980, 1981, 1984, and 1985.

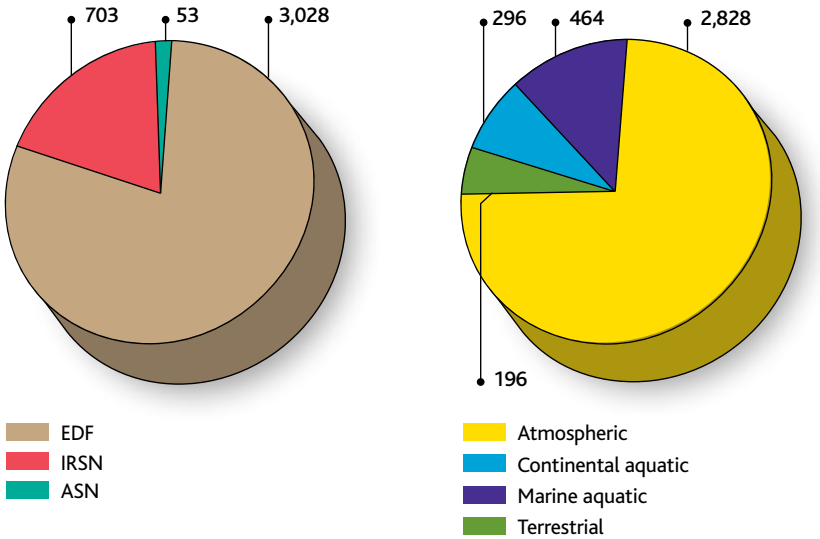

Figure V.94 - Breakdown of the number of samples by data provider and by environment for the Gravelines NPP

Atmospheric compartment

Atmospheric aerosols

Apart from the observations recorded during the period of the Fukushima accident, monitoring of the beta activity index did not reveal any abnormal value (*Figure V.95*). The gamma spectrometry measurements showed that, apart from naturally occurring radionuclides (^{7}Be and ^{210}Pb), no artificial radionuclide could be measured in the environment above the decision thresholds of the instruments used.

Significant levels of iodine-131 were observed in the aerosols between the end of March 2011 and the beginning of May 2011 (*Table V.37*). As was the case in the rest of France, these results represented detection of radioactive fallout from the accident at the Fukushima nuclear plant. The increase in the beta activity index between the end of March 2011 and the end of April 2011 (*Table V.38*) was due mainly to artificial radionuclides in fallout from the Fukushima accident.

For more information

Chapter III – Fukushima accident

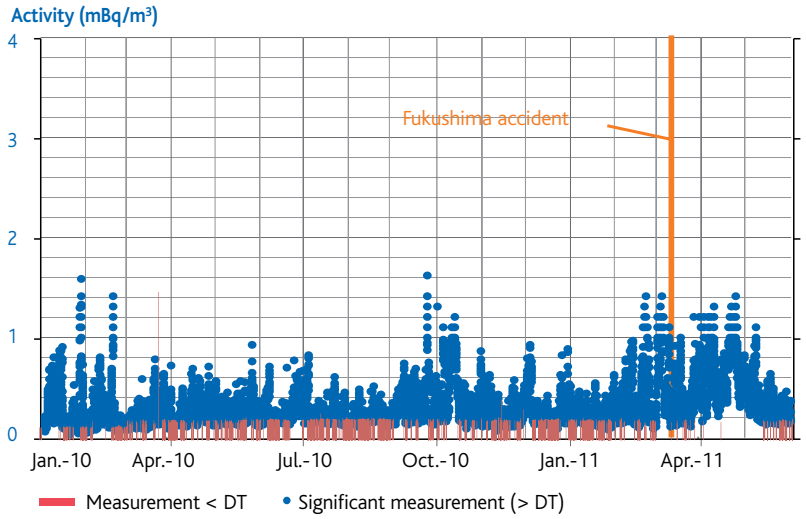

***Figure V.95** - Time plot of the gross beta activity in atmospheric aerosol samples collected in the environment of the Channel and North Sea NPPs (mBq/m³)*

***Table V.37** - Radionuclides measured in aerosols in the environments of the Channel and North Sea NPPs during the period of the accident at the Fukushima nuclear plant from March 22 to May 6, 2011 (mBq/m³)*

Plant	Radionuclide	Mean activity (mBq/m³)
Flamanville, Gravelines Paluel, and Penly NPPs	Cesium-134	< 0.037
	Cesium-137	< 0.040
	Iodine-131	0.085 ± 0.03

***Table V.38** - Gross beta activity index in atmospheric aerosol samples collected in the environment of the Channel and North Sea NPPs (mBq/m³)*

Plant	Radionuclide	Mean activity (mBq/m³)
Flamanville NPP	Gross beta activity	0.23 ± 0.01 0.56 ± 0.02*
Gravelines NPP		0.24 ± 0.01 0.47 ± 0.02*
Paluel NPP		0.24 ± 0.01 0.59 ± 0.02*
Penly NPP		0.25 ± 0.01 0.48 ± 0.02*

** Measurements made between March 22 and May 6, 2011 during the period of the nuclear accident at the Fukushima nuclear power plant*

Rainwater and gases collected by bubblers

The tritium detected in rainwater collected in the vicinity of the NPPs on the Channel and North Sea coasts was measured periodically at values close to the decision thresholds (*Figure V.96*).

No tritium activity was detected in the ambient air collected by bubblers in the environment of these NPPs.

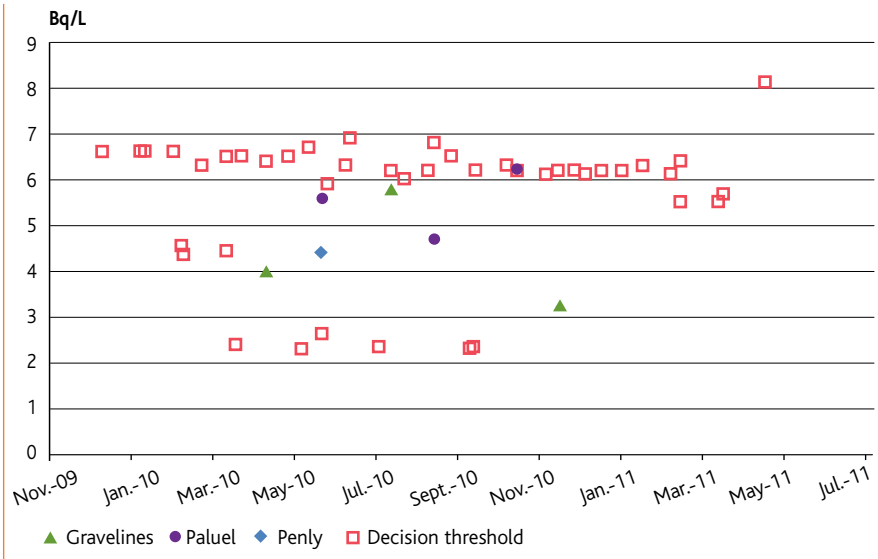

Figure V.96 - Tritium activity in rainwater collected in the vicinity of the Channel and North Sea NPPs (Bq/L)

Terrestrial compartment

Terrestrial flora

Apart from the observations recorded during the period of the Fukushima accident, the results of grass analyses by gamma spectrometry remained below the decision thresholds of the instruments used.

Following the accident at the Fukushima nuclear plant, traces of iodine-131 were detected in grass samples collected by the operators of the Flamanville, Paluel and Penly NPPs between the end of March and the beginning of April 2011. In addition, cesium-134 and -137 were measured in the vicinity of the Flamanville plant at levels close to the decision thresholds of the instruments used.

For more information
Chapter III – Fukushima accident

Soil

Cesium-137 was detected in all the soil samples collected in the vicinity of the Paluel, Penly and Gravelines NPPs (*Table V.39*). The main source of this activity was radioactive fallout from atmospheric nuclear weapons testing and the Chernobyl accident.

Table V.39 - Activity measured in soil (Bq/kg dry)

Radionuclide	Gravelines NPP	Paluel NPP	Penly NPP
^{137}Cs	3.29 ± 0.19	5.5 ± 0.5	6.8 ± 0.9

Farm produce and foodstuffs

Cereals

Gamma-emitting radionuclides likely to be discharged by the PWR plants were not detected in the wheat samples collected near NPPs.

Milk

The naturally occurring radioactivity measured in cow's milk was due mainly to potassium-40, with mean activity concentrations between 45.8 ± 1.7 and 54.3 ± 2.6 Bq/L, depending on the geographical sector. These values are consistent with those measured in milk collected in the territory as a whole. The activity concentrations of artificial radionuclides (^{131}I, ^{134}Cs, ^{137}Cs, ^{3}H) were below the decision thresholds of the instruments used. Only one significant carbon-14 measurement was obtained, in a sample of milk produced near the Penly NPP, at activity levels close to values measured outside the influence of nuclear facilities (16 ± 4.9 Bq/L).

Vegetables

In 2010, lettuce produced in the vicinity of the Paluel, Penly and Gravelines sites was analyzed for radioactivity. Leeks and potatoes were also collected in the areas affected by the Flamanville and Gravelines NPPs, respectively. No artificial radionuclides were detected in the vegetable samples collected in the vicinity of the Flamanville, Paluel and Gravelines NPPs. Traces of cesium-137, close to the decision thresholds, were measured in lettuce collected in the vicinity of Penly at activity levels of 0.035 ± 0.007 Bq/kg wet.

Aquatic compartment

Measurements made on water samples collected from the outfalls and from the Channel for these NPPs are given in Chapter IV – Marine and coastal environment.

Ground water

Flamanville NPP

Ground water at the Flamanville NPP showed spot tritium activity levels between 6 and 16 Bq/L and a median activity for all the sampling points of 6.9 Bq/L (*Figure V.97*).

Paluel NPP

Ground water circulation is linked with the particularly high level of fracturing in the coastal hanging valleys, where karst systems develop preferentially. The influence of the tides on ground water levels inland is highly variable on the scale of the site. No significant activity was measured, other than gross beta activity, which can vary with ground water salinity according to the influence of the tides (*Figure V.98*), related to ^{40}K.

Penly NPP

Tritium traces in the unconfined ground water under the Penly NPP, considered to be hydraulically confined at its base, was about 15 Bq/L at the points "nappe N1" and "nappe N2", sampled by the operator.

At piezometer N1 (*Figure V.99*), there were few traces of tritium apart from the period between November 2010 and February 2011, during which tritium activity increased to 94 Bq/L before decreasing to values below 30 Bq/L. The operator has not identified the cause of this temporary rise in activity.

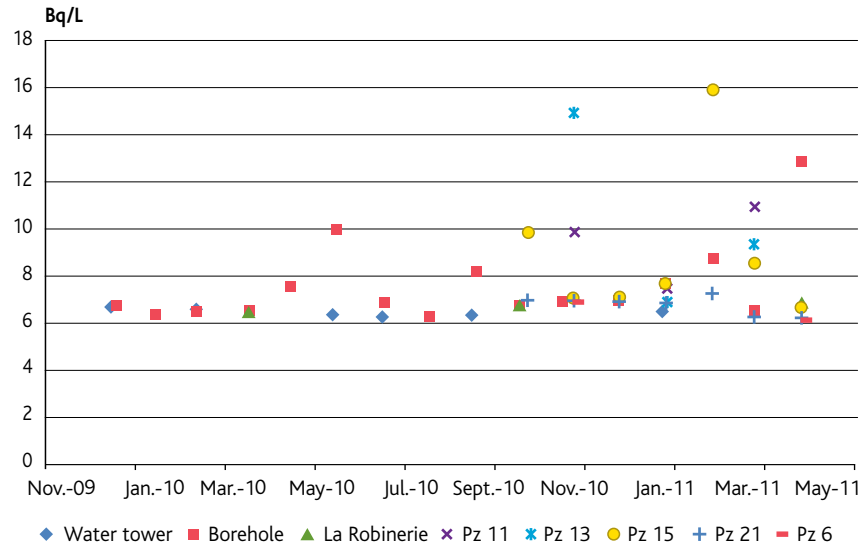

Figure V.97 - Tritium activity in ground water at and in the vicinity of the Flamanville NPP (Bq/L)

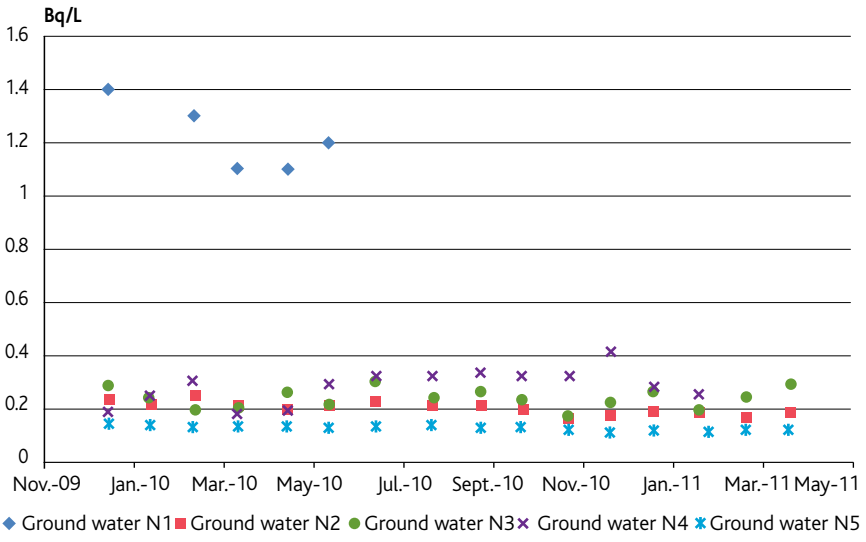

Figure V.98 - Gross beta activity in ground water on the site of the Paluel NPP (Bq/L)

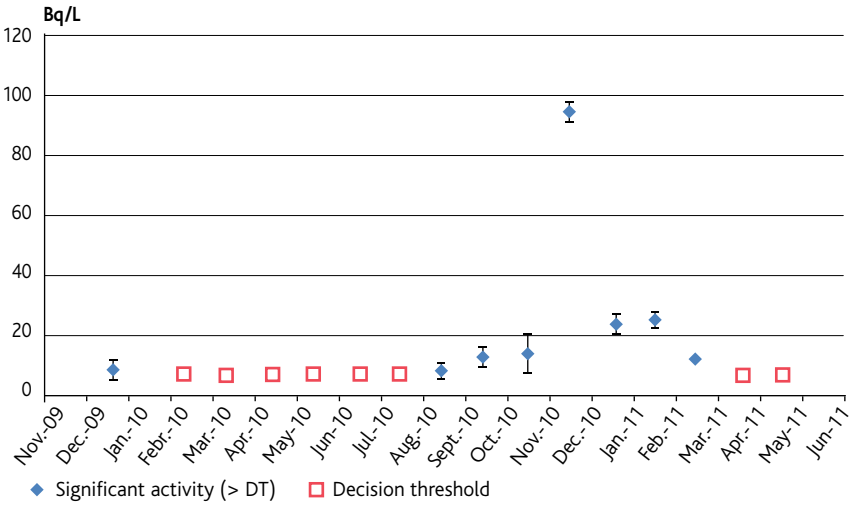

Figure V.99 - Tritium activity in ground water at point N1 on the site of the Penly NPP (Bq/L)

Piezometer N2 (*Figure V.100*) showed mean traces of tritium activity of 16 Bq/L, decreasing during the period studied.

Gravelines NPP

Two unconfined quaternary aquifers were located above a Flanders clay layer about 100 meters thick and highly impermeable. This assembly is underlain by three deep aquifers in carboniferous limestones, chalk and Ostricourt sands.

Tritium traces in the ground water were observed at seven of the eleven sampling points. The mean activity observed for all these points was 20 Bq/L. Point N5 showed a mean tritium activity level of about 20 Bq/L, disturbed between April and July 2010 by an increase in tritium activity (*Figure V.101*).

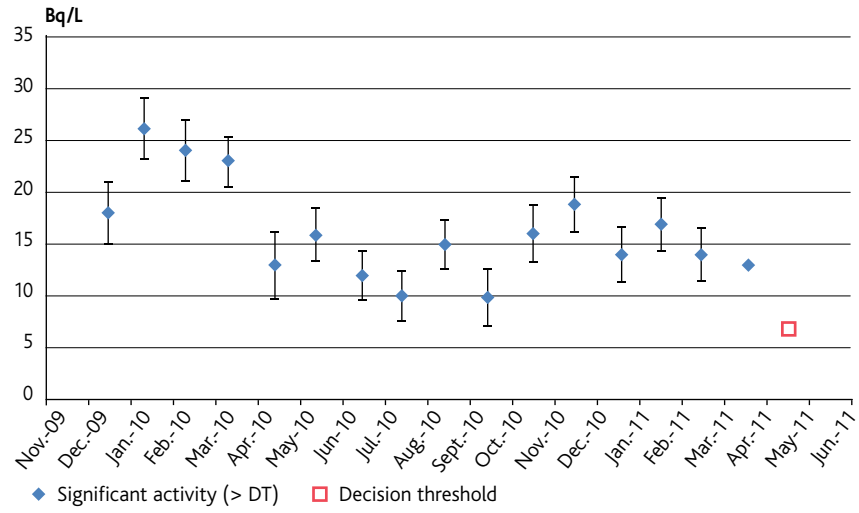

Figure V.100 - Tritium activity in ground water at point N2 on the site of the Penly NPP (Bq/L)

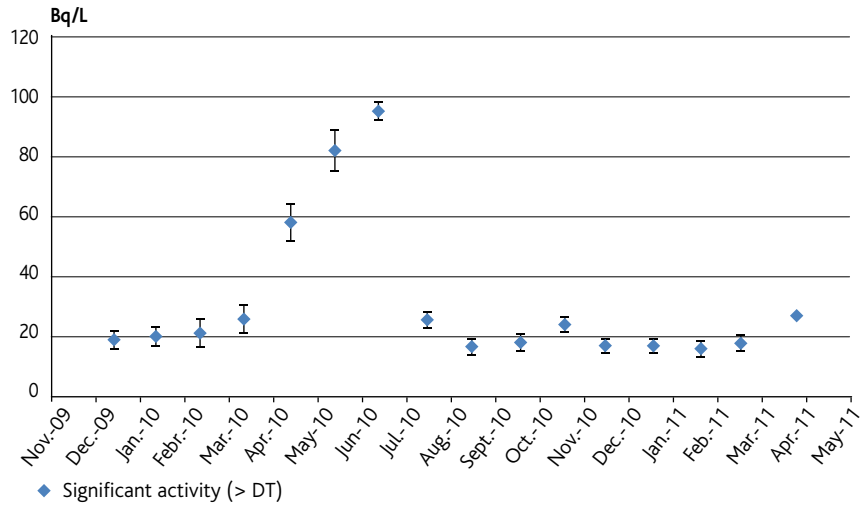

Figure V.101 - Tritium activity in ground water at point N5 on the site of the Gravelines NPP (Bq/L)

Monitoring of the nuclear power plant at Nogent-sur-Seine

There is one nuclear power plant on the Seine river, at Nogent-sur-Seine (*Figures V.102* and *V.103*).

It is located on the right bank of the river, 120 km southeast of Paris. The NPP has two 1300 MW pressurized water reactors, put into service in 1987 and 1988.

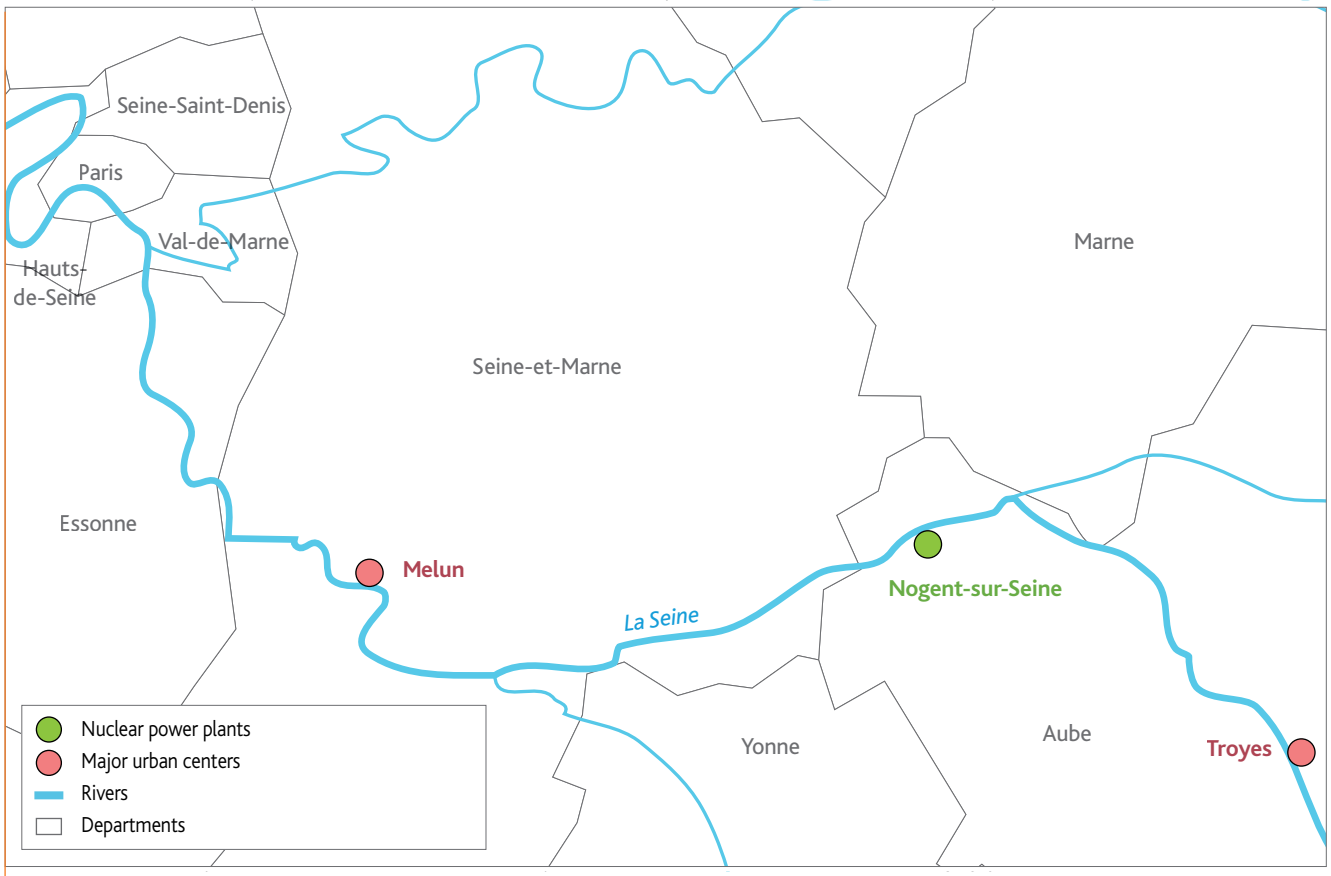

Figure V.102 - Location of the Nogent-sur-Seine NPP

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Figure V.103 - Nogent-sur-Seine NPP

Atmospheric compartment

Atmospheric aerosols

The gamma spectrometry measurements showed that, apart from naturally occurring radionuclides, no artificial radionuclide was detected in the environment above the decision thresholds of the measuring instruments used.

As was observed for the other NPPs, an increase in the gross beta activity related essentially to the fallout from the Fukushima accident was observed between the end of March 2011 and the end of April 2011 (*Table V.40 and Figure V.105*).

For more information

Chapter III – Fukushima accident

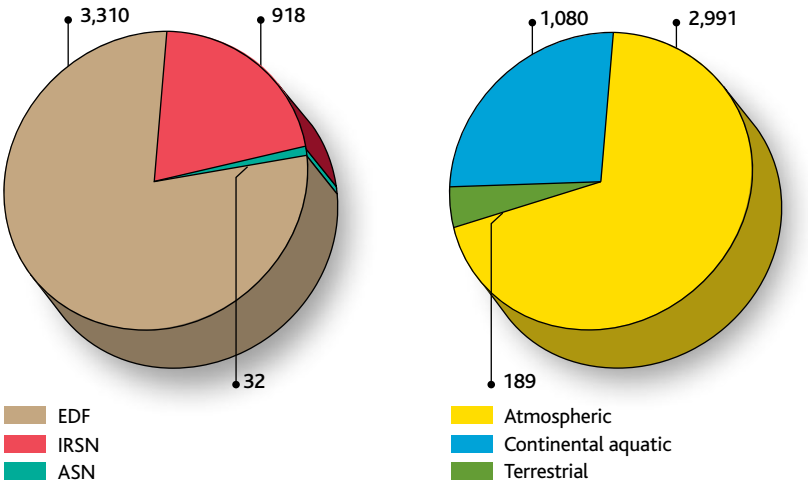

Figure V.104 - Breakdown of the number of samples by data provider and by environment for the Nogent-sur-Seine NPP

Table V.40 - Gross beta activity in atmospheric aerosol samples collected in the environment of the Nogent-sur-Seine NPP (mBq/m³)

Plant	Radionuclide	Mean activity (mBq/m³)
Nogent-sur-Seine NPP	Gross beta activity	0.31 ± 0.01 0.62 ± 0.02*

** Measurements made from March 22 to May 6, 2011 during the period of the Fukushima accident*

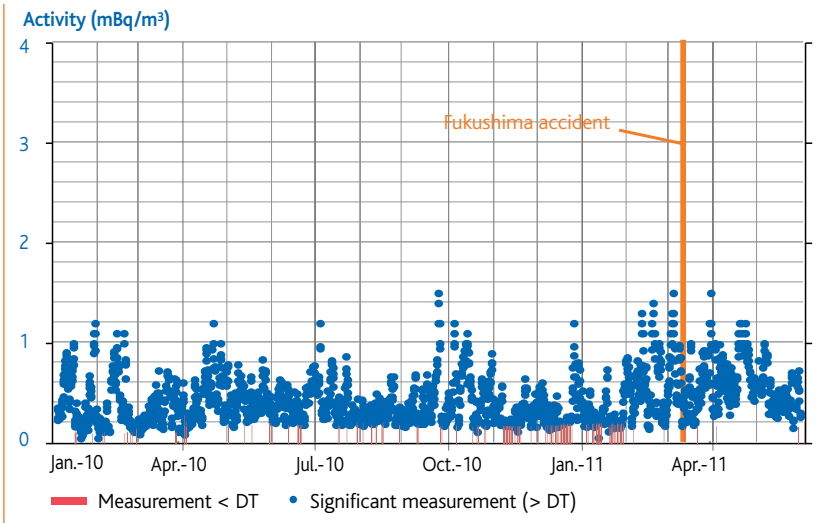

Figure V.105 - Time plot of the gross beta activity in atmospheric aerosol samples collected in the environment of the Nogent-sur-Seine NPP (mBq/m³)

Rainwater and gases collected by bubblers

Rainwater collected in the field near the NPP showed tritium activity levels close to the decision thresholds, with a maximum value between 2009 and 2010 of 4.8 Bq/L.

Air collected by bubbler for analysis of tritium in the form of water vapor did not contain any detectable significant activity in 2010.

Terrestrial compartment

Terrestrial flora

The grass samples collected monthly around the Nogent-sur-Seine plant did not contain any trace of artificial radioactivity attributable to the gaseous discharge from the facility.

Traces of iodine-131 and cesium-134 and -137 were measured at the beginning of April 2011. They can be attributed to the accident on March 11, 2011 at the Fukushima nuclear plant in Japan.

For more information
Chapter III – Fukushima accident

Farm produce and foodstuffs

Cereals

The gamma-emitting radionuclides likely to be discharged by the PWR plants were not detected in the wheat samples collected around the Nogent-sur-Seine NPP.

Milk

No trace of artificial radioactivity (^{131}I, ^{134}Cs, ^{137}Cs, ^{3}H, ^{90}Sr) was measured in samples of cow's milk collected in the vicinity of the Nogent-sur-Seine plant. Only naturally occurring potassium-40 showed significant activity levels, at 51.8 ± 1.9 Bq/L.

Vegetables

The radioactivity measured in vegetables was due to naturally occurring potassium-40; its activity was 130 ± 17 Bq/kg wet in lettuce and 112 ± 15 Bq/kg wet in leeks collected around the Nogent-sur-Seine plant. Artificial radionuclides (^{134}Cs, ^{137}Cs, ^{3}H, etc.) were not detected by the measuring instruments used.

Continental aquatic compartment

The source of the river Seine is at a height of 446 meters on the Langres plateau in Burgundy. The Seine and its main tributary, the Yonne, join at Montereau-Fault-Yonne. The Yonne has a higher flow rate and a larger drainage basin than the Seine: the mean flow rate of the Yonne is 93 m³/s, compared with barely 80 m³/s for the Seine. The Nogent-sur-Seine NPP is located 44 km upstream of the confluence with the Yonne, on the "Petite Seine", as the river is known between its source and Montereau-Fault-Yonne. The flow rate of the river measured near the NPP at Pont-sur-Seine is shown in Figure V.106. At this point the Seine has a shallow gradient and forms many wide meanders. The Seine has a relatively regular flow regime, a consequence of the oceanic climate of its drainage basin. It is nevertheless subject to major floods that have necessitated major control works in the upper part of its course and of its tributaries. Its mean flow rate at Paris is about 328 m³/s, but can exceed 1600 m³/s in flood periods.

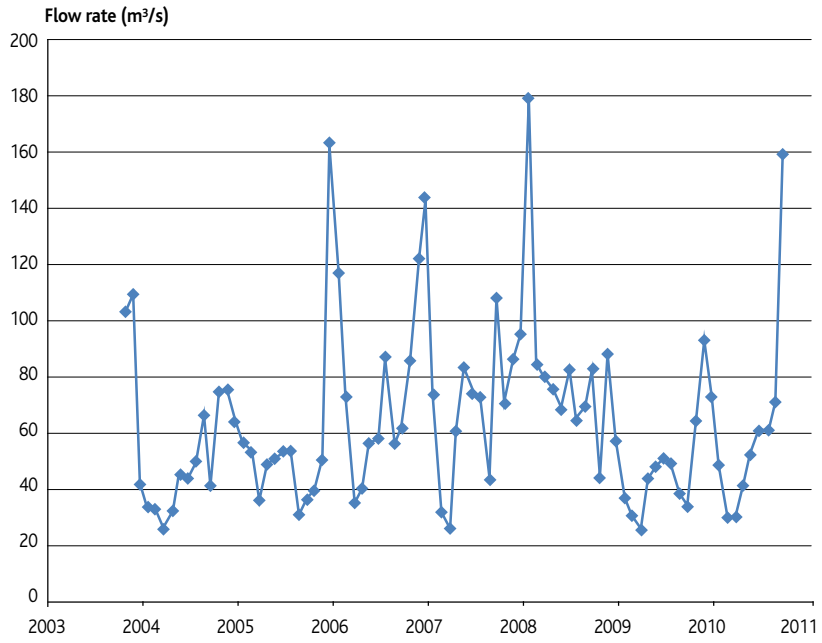

Figure V.106 - Mean monthly flow rate of the Seine at Pont-sur-Seine (source: Banque Hydro) (m³/s)

Surface water

In 2010, no abnormal gross alpha or beta activity was observed in surface water collected upstream and downstream of the Nogent-sur-Seine NPP. Analyses performed on water samples collected from the Seine downstream of the NPP detected tritium activity at a mean value of about 50 Bq/L (*Figure V.108*), and at low water (*Figure V.107*) in June 2010 a maximum activity of 110 Bq/L, due to liquid effluent from the NPP.

The tritium traces in the Seine water sampled downstream of the NPP are characteristic of the operation of the plant (*Figure V.109*).

Sediments

Sediments were sampled in 2010 at the station downstream of the Nogent-sur-Seine NPP, at mid-discharge. Gamma spectrometry analyses detected cesium-137 at an activity of 4.6 ± 0.8 Bq/kg dry. The other gamma-emitting radionuclides potentially present in liquid effluent discharge from PWRs (^{54}Mn, ^{58}Co, ^{60}Co, ^{110m}Ag, ^{134}Cs, etc.) were not detected.

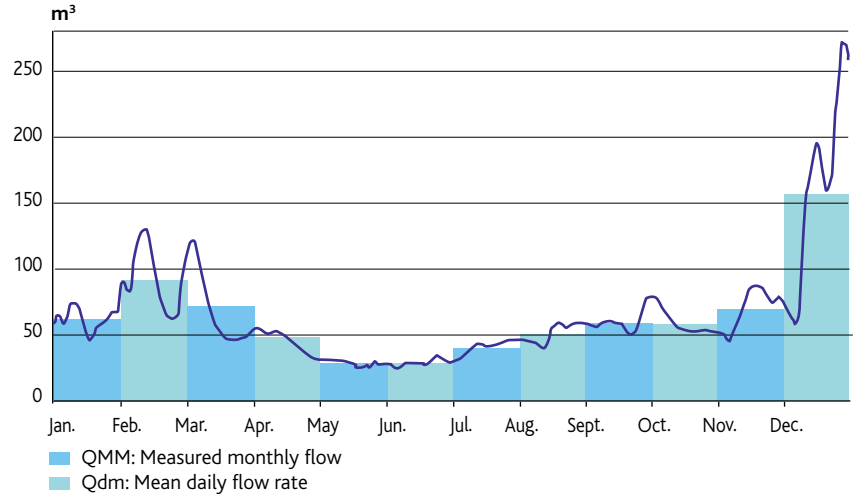

Figure V.107 - Daily flow rate of the Seine at Pont-sur-Seine in 2010 (source: Banque Hydro) (m³)

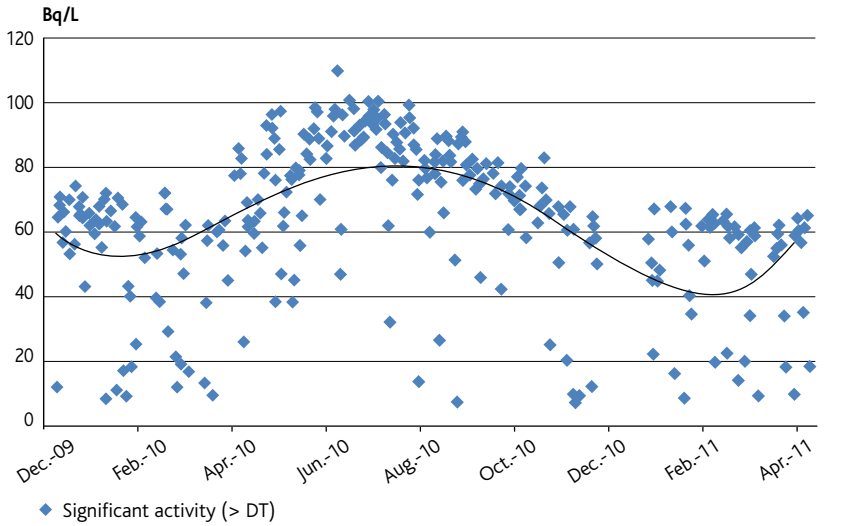

Figure V.108 - Tritium activity measured at the station downstream of the Nogent-sur-Seine NPP (Bq/L)

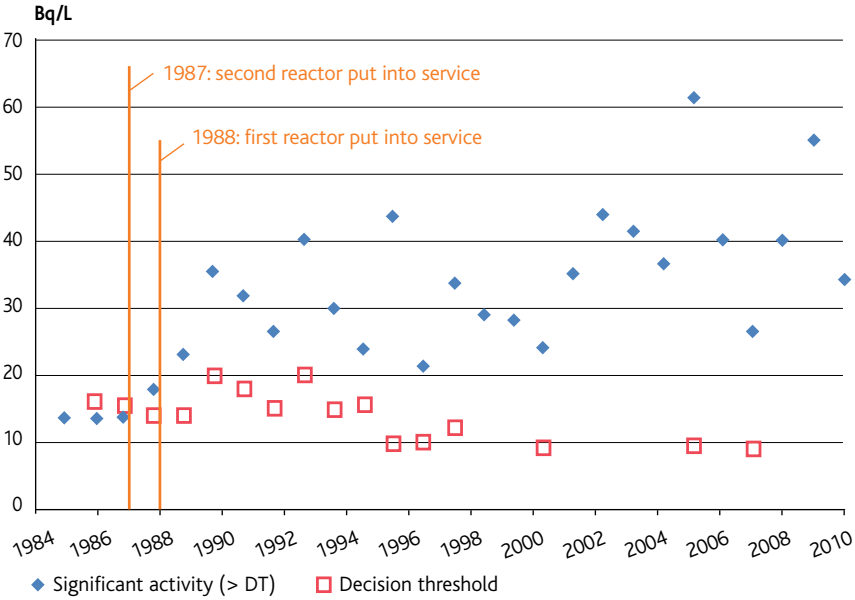

Figure V.109 - History of annual tritium activity measured downstream of the Nogent-sur-Seine NPP (Bq/L)

Monitoring of the Brennilis nuclear power plant

The Brennilis nuclear site is located in western Brittany, about 60 km from Brest, in the Monts d'Arrée area (*Figure V.110*).

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Figure V.111 - *Brennilis NPP*

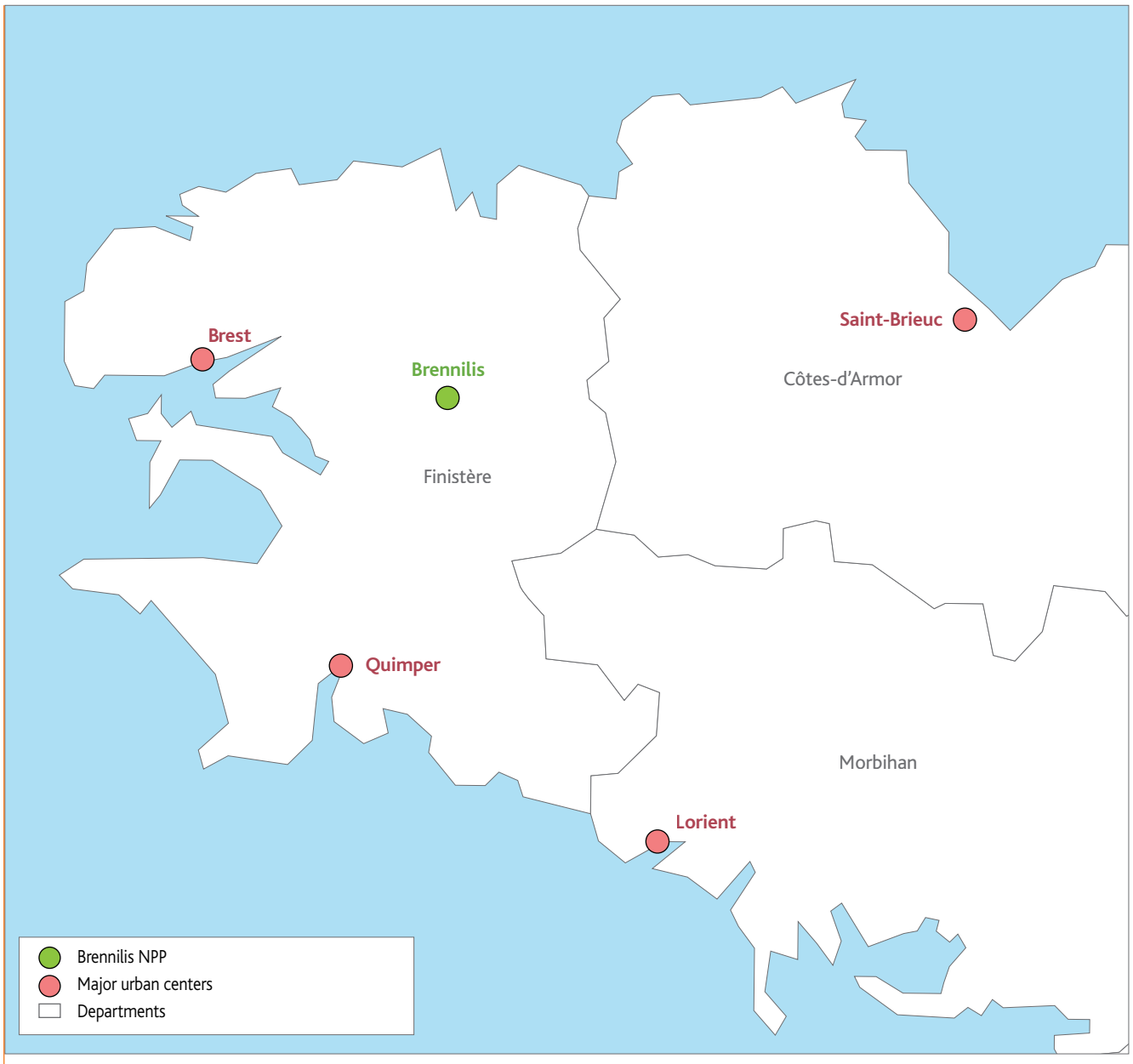

Figure V.110 - *Location of the Brennilis NPP*

The Brennilis reactor (*Figure V.111*), a 70 MWe industrial prototype of the heavy water system, was put into service in 1967 and operated jointly by EDF and the CEA until its final shutdown in 1985, when reactor dismantling operations started. At the end of October 1996, the Monts d'Arrée site (SMA) became a storage facility for equipment from the former nuclear plant, and in September 2000 EDF became the sole operator.

Atmospheric compartment

Atmospheric aerosols

Apart from observations recorded during the period of the Fukushima accident, monitoring of the beta activity index did not show any abnormal value (*Figure V.113*) and, apart from naturally occurring radionuclides (^{7}Be, ^{210}Pb), no other radionuclide was detected by gamma spectrometry above the decision thresholds of the instruments used.

Significant levels of cesium-134, cesium-137 and iodine-131 were also observed at Brennilis between the end of March 2011 and the beginning of May 2011 following the Fukushima accident (*Table V.41*). An increase in the gross beta activity related to fallout from the Fukushima accident was observed during this same period (*Table V.42*).

For more information

Chapter III – Fukushima accident

Rainwater and gases collected by bubblers

Tritium measured in rainwater collected in the vicinity of the Brennilis NPP did not exceed the decision thresholds of the measuring instruments used. Moreover, no tritium activity was detected in ambient air.

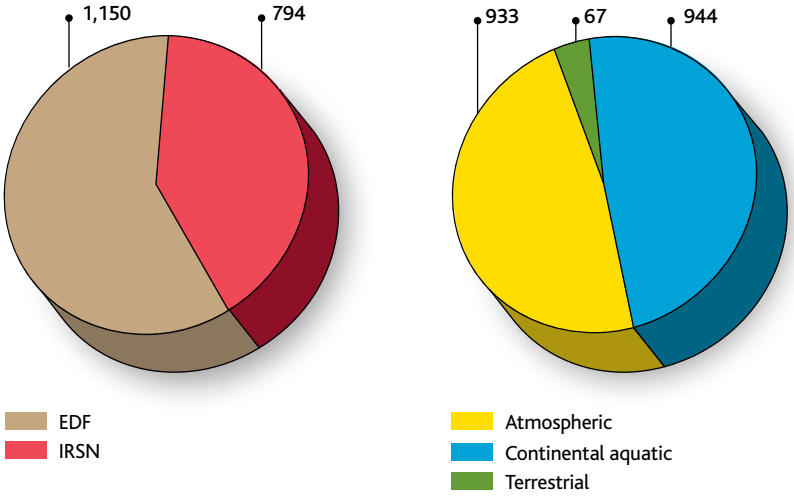

Figure V.112 - Breakdown of the number of samples by data provider and by environment for the Brennilis NPP

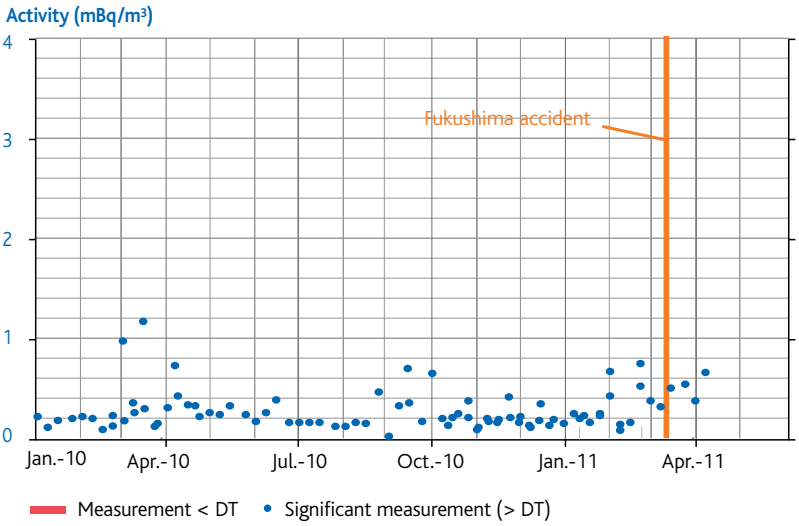

Figure V.113 - Time plot of the gross beta activity in atmospheric aerosol samples collected in the environment of the Brennilis NPP (mBq/m³)

Table V.41 - Radionuclides measured in atmospheric aerosol samples collected in the environment of the Brennilis NPP and measured during the period of the Fukushima accident from March 22 to May 6, 2011 (mBq/m³)

Plant	Radionuclide	Mean activity (mBq/m³)
Brennilis NPP	Cesium-134	0.042 ± 0.010
	Cesium-137	0.048 ± 0.008
	Iodine-131	0.40 ± 0.09

Table V.42 - Gross beta activity of atmospheric aerosol samples collected in the environment of the Brennilis site (mBq/m³)

Plant	Radionuclide	Mean activity (mBq/m³)
Brennilis NPP	Gross beta activity	0.18 ± 0.01 0.51 ± 0.05*

** Measurements made from March 22 to May 6, 2011 during the period of the nuclear accident at the Fukushima nuclear plant*

Terrestrial compartment

Terrestrial flora

Three significant cesium-137 values were measured in grass samples collected in the vicinity of the Brennilis NPP, out of the eight measurements made in 2010 (three-monthly sampling at two monitoring points). The significant specific activity levels measured were 5.4 ± 1.1 Bq/kg dry in June 2010 and 13 ± 3 Bq/kg dry in September 2010 at 1.5 km from the plant under the prevailing winds, and 4.3 ± 1.2 Bq/kg dry at 4 km under the prevailing winds. These results were similar to those obtained away from the influence of atmospheric discharge, evidence that past discharge from the site had no influence on the analyzed radionuclides.

Farm produce and foodstuffs

Cereals
Gamma-emitting radionuclides likely to be discharged by the Brennilis nuclear plant were not detected in the wheat samples collected in the vicinity of the plant.

Milk
The naturally occurring radioactivity measured in cow's milk was due mainly to potassium-40, with a mean activity concentration of 49.1 ± 3.3 Bq/L. The activity concentrations of artificial radionuclides likely to be discharged by the Brennilis site and transferred into the milk (^{131}I, ^{134}Cs, ^{137}Cs, ^{3}H) were below the decision thresholds.

Vegetables
In 2010, no artificial radionuclide was detected in the cabbage sample analyzed by gamma spectrometry.

Cider
The radioactivity measured in the cider produced in the neighbourhood of the Brennilis plant was mainly due to naturally occurring potassium-40, giving an activity of 36.4 ± 3.7 Bq/L. No artificial radionuclide was detected.

Aquatic compartment

The subsoil of the site consists of backfill, alluvium, arenaceous granite, and weathered and sound granite. The ground water under the site circulates mainly in the arenaceous rocks and the backfill, but also in the alluvium and the weathered granite.

No significant tritium activity was measured between 2010 and 2011 in the surface water or ground water analyzed.

V.5 MONITORING OF INDUSTRIES IN THE BACK END OF THE NUCLEAR FUEL CYCLE

Industry in the back end of the cycle receives the fuel unloaded from reactors, maintains or dismantles nuclear equipment, and treats liquid effluent and solid waste.

The Areva site at La Hague carries out the first step in recycling spent fuel from nuclear reactors. The site is adjacent to the CSM waste disposal facility operated by ANDRA and located in the Manche department. As environmental radiological monitoring is common to these two sites, it is described here in a single section.

This section also gives the results of the monitoring of the Somanu nuclear maintenance plant located at Maubeuge. The monitoring results of the Socatri plant located on the Tricastin industrial site are grouped with those of the other facilities on the Tricastin site operated by Areva (*Section V.3*). The monitoring results of the Centraco plant located on the Marcoule site are grouped with those of the CEA (*Chapter VI*).

La Hague site: Areva and ANDRA facilities

For the purpose of environmental monitoring, the La Hague site is considered here to be a unit formed by the Areva La Hague plant and the ANDRA CSM waste disposal facility.

The La Hague site is located in the northwest of the Cotentin peninsula, about 20 km west of Cherbourg and 6 km from the tip of Cap de La Hague. The site occupies parts of four municipalities in the Manche department (*Figure V.114*).

Inaugurated in 1962, initially to process spent fuel from the first graphite-moderated gas-cooled (GCR) plants, the present Areva plant at La Hague processes spent fuel from French pressurized water reactors (PWR) and from some foreign facilities.

Most of the activity in gaseous discharge from the Areva La Hague plant consists of noble gases (226,000 TBq in 2010, 48.2% of the discharge permit limit), tritium (56.8 TBq in 2010, 37.9% of the discharge permit limit), and carbon-14 (16 TBq in 2010, 57% of the permit limits).

The activity in liquid waste, discharged into the sea, is predominantly due to tritium (9,960 TBq in 2010, 53.8% of the permit limit) and carbon-14 (7.34 TBq in 2010). In this discharge, iodine and other fission products (cesium, ruthenium-106, etc.) and activation products accounted for about 5 TBq in 2010.

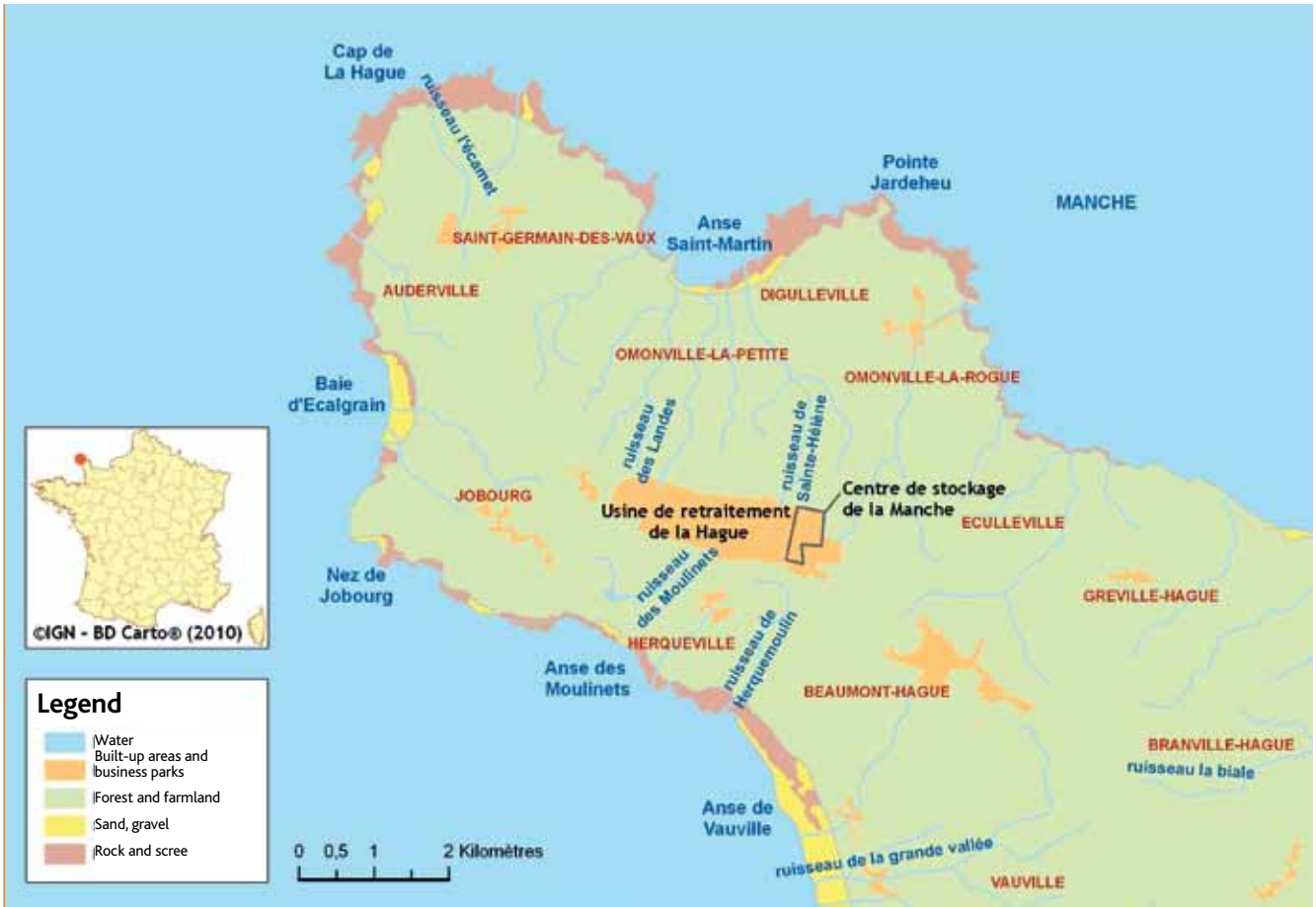

Figure V.114 - Location of the La Hague industrial site

© Andra

Figure V.115 - La Hague industrial site with ANDRA CSM in the foreground

Inaugurated in 1969, the ANDRA waste disposal facility covers an area of 15 hectares (*Figure V.115*). It received its last package in 1994 (giving a total of nearly 530,000 m^3 of waste). After several years of work to complete the cap, the facility entered the monitoring phase in 2003. The radioactive discharge resulting from water draining over and under the facility structures is collected and channeled to the adjacent Areva plant for discharge into the sea (4.04 GBq of ^3H discharged in 2010, 3.2% of the permit limit).

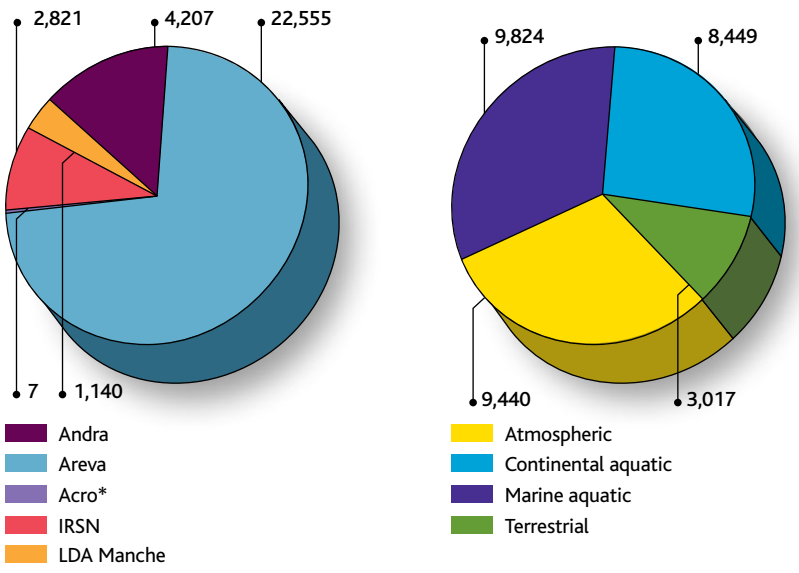

Figure V.116 - La Hague site: breakdown of the number of samples by data provider and by environment
** Additional fresh water and sea water samples were sent by ACRO to the RNM in 2010. The measurements could not be used in this report (communicated after July 2011) but can be consulted on the RNM website (www.mesure-radioactivite.fr).*

Atmospheric compartment

Aerosols

Apart from the observations recorded during the period of the Fukushima accident, no artificial radionuclide activity was detected in the environment over the 2010-2011 period (*Figure V.116 and Figure V.117*).

As is the case for the majority of aerosol samples collected from the environment, significant cesium-134, cesium-137 and iodine-131 activity levels were observed in the vicinity of the La Hague site between the end of March and the beginning of May, 2011 (*Table V.43*). They can be explained by the arrival of air masses contaminated by the accident at the Fukushima nuclear power plant. These air masses also caused an increase in the gross beta activity over the same period (*Figure V.118*).

For more information

Chapter III – Fukushima accident

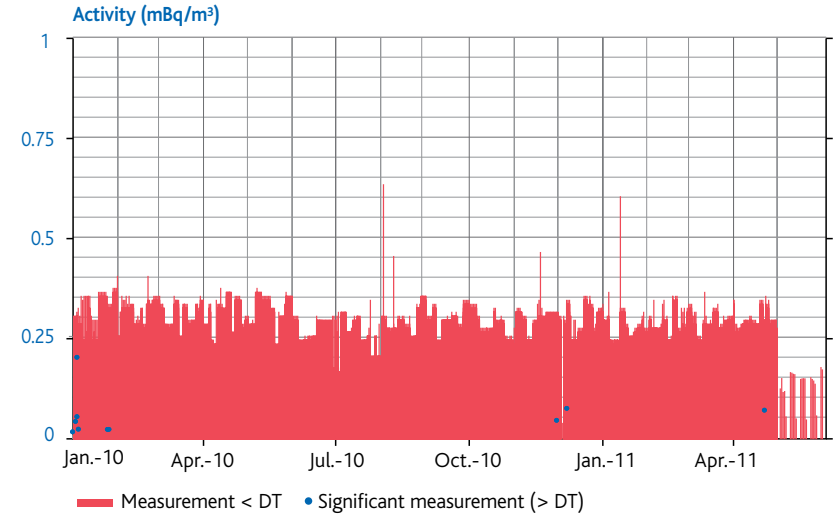

Figure V.117 - Time plot of gross alpha activity in aerosols near the La Hague site (mBq/m³)

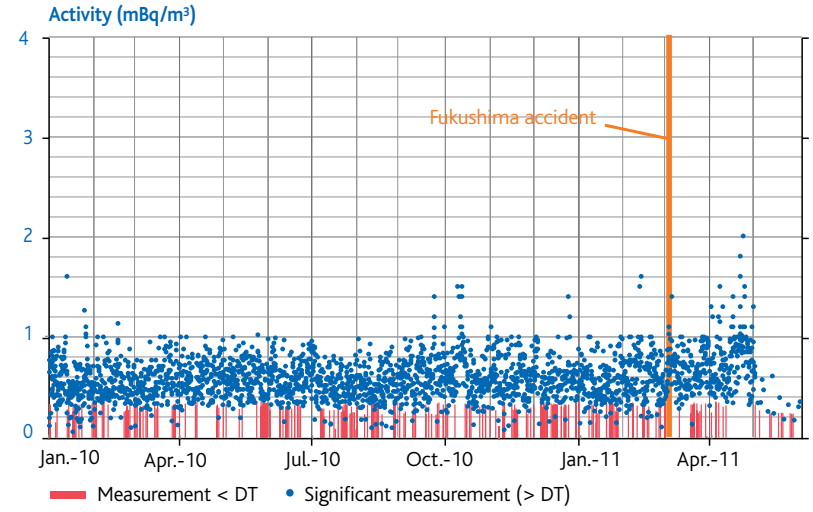

Figure V.118 - Time plot of gross beta activity in aerosols near the La Hague site (mBq/m³)

Table V.43 - Activity measured in aerosol samples collected in the environment of the La Hague site (mBq/m³)

Radionuclide type	Radionuclide	Mean activity (mBq/m)
Gross activity levels	Gross alpha activity	0.77 ± 0.002
	Gross beta activity	0.34 ± 0.01 0.60 ± 0.03*
Artificial radionuclides	Cesium-134	0.045 ± 0.006*
	Cesium-137	0.050 ± 0.007*
	Iodine-131	0.077 ± 0.012*

** Measurements made during the period of the nuclear accident at the Fukushima nuclear power plant between March 22 and May 6, 2011.*

Atmospheric tritium and carbon-14

Gaseous waste discharge is regulated by the 2007 order for operation of the La Hague nuclear site. The gaseous discharge is generated by the ventilation of the workshops and the process apparatus. They undergo various consecutive purification treatments according to the physical-chemical nature of the elements.

Most of the tritium is trapped in the form of tritiated water that is discharged into the sea as liquid effluent. A small fraction of the tritium is discharged in gaseous form. The tritium levels in the atmosphere, measured using bubblers , were not significant. The mean decision threshold observed at La Hague was between 0.60 and 0.78 Bq/m³.

Sampling of atmospheric carbon-14 in the environment using bubblers gave a mean activity of about 0.05 Bq/m³ of air, measured at five sampling stations located near the Areva site (*Figure V.119*).

In comparison, carbon-14 activity in the air in an area not affected by nuclear operations is about 0.03 Bq/m³. A study in which IRSN took part (Fontugne *et al.*) attributed part of the carbon-14 content in vegetation in the vicinity of the coast to degassing of $^{14}CO_2$ from sea water contaminated by the effluent from La Hague.

Othergases (krypton-85, iodine-129, iodine-131)

Monitoring of gaseous iodine-129 and -131 did not reveal any significant releases of iodine into the environment by the La Hague facilities.

In contrast, the krypton-85 discharged by the same facilities during the reprocessing of spent fuel rods was detected regularly in the atmosphere (*Table V.44*).

Table V.44 - Krypton-85 and iodine isotopes in gaseous form measured in the environment near the La Hague site (Bq/m³)

Radionuclide type	Radionuclide	Mean activity or detection limit (Bq/m³)
Artificial radionuclides in gaseous form	Iodine-129	< 0.009
	Iodine-131	< 0.001
	Krypton-85	130 ± 4

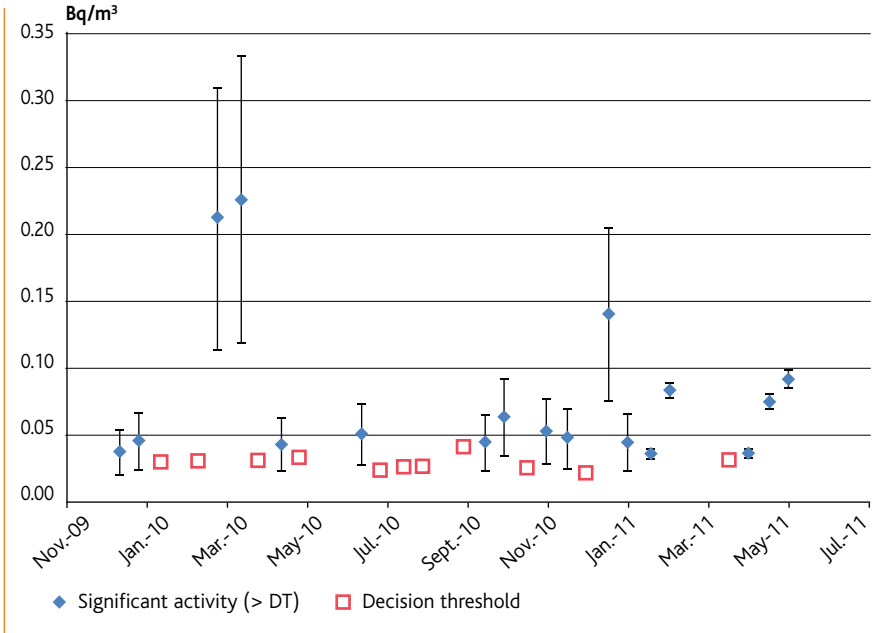

Figure V.119 - Carbon-14 activity measured in air near the La Hague site (Bq/m³)

Rainwater

The prevailing climate type on the Cotentin peninsula is oceanic (900 millimeters of rain in 2010, with an average of 150 rainy days). Rainwater is collected at various points near the La Hague site. Weekly measurements are made on the monthly mixed collection.

No activity of artificial radionuclides, other than tritium, was measured above the decision thresholds in the rainwater. Near the site, a mean tritium activity of 11.5 Bq/L was observed, with a maximum value of 52.5 Bq/L measured by Areva.

Since 1975, IRSN has been measuring the tritium activity in rainwater collected weekly at Gréville-Hague, east of the La Hague site (*Figure V.120*). It is clear that tritium has no longer been detected since the 1980s, despite the improvement in the decision thresholds of the measuring instruments, currently about 5 Bq/L.

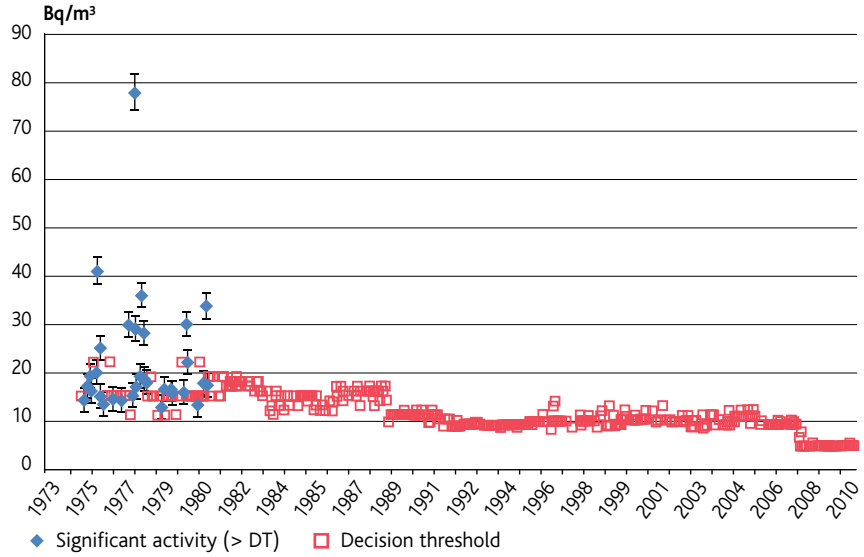

Figure V.120 - Tritium activity measuredi n rainwater near the La Hague site (Bq/m³)

Terrestrial compartment

Monitoring of the environment around the La Hague nuclear site includes regular sampling of plants, soil, milk and various farm produce (vegetables, cider, meat, etc.) in the immediate vicinity of the site and in areas potentially affected by discharge from nuclear facilities.

Flora

Samples of terrestrial plants (grass, pasture) are collected regularly at twelve sampling stations around the site in six municipalities (monthly or three-monthly sampling). In 2011, an additional spot sample was collected in another municipality, Vauville, south of the site following the Fukushima accident (*Table V.45*).

The majority of naturally occurring radioactivity observed in plants was due to potassium-40. Several artificial radionuclides were measured in plants: cesium-137, bound tritium, carbon-14 and iodine-129. The measured levels varied considerably over time, and were correlated with the activity discharged by the La Hague facilities and with the weather conditions at the time of discharge (*Figure V.121*).

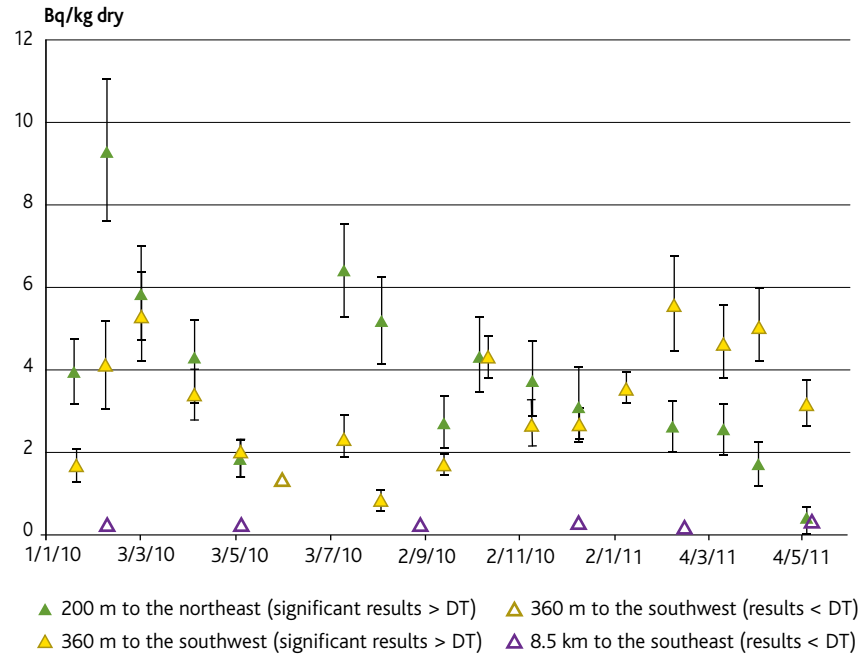

Figure V.121 - Time-related change of iodine-129 activity measured in grass samples collected at the most affected stations (Bq/kg dry)

Table V.45 - Mean activity measured in grass samples collected around the La Hague site (Bq/kg dry)

Radionuclide	Jobourg				Digulleville		
	West site boundary	Southwest 360 m	Southwest 1 km	Northwest 1.1 km	East 110 m	Northeast 200 m	Northeast 1.1 km
^{40}K	610 ± 16	644 ± 15	491 ± 22	826 ± 33	759 ± 33	734 ± 19	755 ± 31
^{129}I	0.41 ± 0.06	2.34 ± 0.12	0.71 ± 0.13	< 0.28	nm	2.01 ± 0.12	1.04 ± 0.15
^{137}Cs*	1.79 ± 0.16	< 0.6	< 0.42	< 0.42	< 3.1	0.59 ± 0.08	0.64 ± 0.14
^{106}Ru	< 9	< 9	< 7	< 7	< 50	< 8	< 10
Other gamma-emitting radionuclides (^{125}Sb, ^{134}Cs, ^{60}Co)	< 2.4	< 2.5	< 1.9	< 1.8	< 13	< 2.3	< 2.6
OBT	8.85 ± 0.41	9.4 ± 0.41	4.46 ± 0.41	3.23 ± 0.34	nm	12.19 ± 0.5	8.3 ± 0.6
^{14}C	137 ± 6	349 ± 9	120 ± 8	77 ± 7	nm	268 ± 8	205 ± 12
^{241}Am	< 0.37	< 0.41	< 0.26	< 0.23	nm	< 0.5	< 0.41
^{238}Pu	< 0.08	< 0.05	< 0.021	< 0.014	nm	< 0.06	< 0.09
$^{239+240}$Pu	< 0.08	< 0.035	< 0.025	< 0.019	nm	< 0.06	< 0.06
^{244}Cm	< 0.046	< 0.039	< 0.014	< 0.021	nm	< 0.027	< 0.048

Radionuclide	Omonville-la-Petite	Herqueville	Beaumont-Hague	Vauville	Biville
	North 660 m	South 250 m	Southeast 1.1 km	Southeast 6 km	Southeast 8.5 km
^{40}K	710 ± 18	719 ± 18	580 ± 26	800 ± 90	830 ± 32
^{129}I	1.79 ± 0.12	0.71 ± 0.07	0.45 ± 0.09	nm	< 0.32
^{137}Cs*	0.51 ± 0.07	0.82 ± 0.1	< 0.5	< 1.7	< 0.45
^{106}Ru	< 8	< 8	< 9	nm	< 7
Other gamma-emitting radionuclides (^{125}Sb, ^{134}Cs, ^{60}Co)	< 2.2	< 2.1	< 2.3	< 1.3	< 2
OBT	7.5 ± 0.34	6.95 ± 0.34	5.4 ± 0.5	nm	2.72 ± 0.35
^{14}C	271 ± 8	207 ± 7	139 ± 10	nm	91 ± 9
^{241}Am	< 0.42	< 0.42	< 0.28	nm	< 0.42
^{238}Pu	< 0.027	< 0.025	< 0.02	nm	< 0.08
$^{239+240}$Pu	< 0.027	< 0.025	< 0.033	nm	< 0.08
^{244}Cm	< 0.039	< 0.042	< 0.023	nm	< 0.031

** Excluding values attributable to the Fukushima accident*
nm: not measured

Other gamma-emitting artificial radionuclides (^{125}Sb, ^{106}Ru, ^{60}Co, etc.) did not give significant measured activity levels. Similarly, the activity levels of alpha-emitting artificial radionuclides (^{241}Am, ^{238}Pu, $^{239+240}Pu$, ^{244}Cm) remained below the decision thresholds.

In general, the highest activity levels of artificial radionuclides were recorded at the stations located directly under the prevailing winds, i.e. in samples collected southwest and northeast of the La Hague site (*Figures V.122 to V.124*).

In the near environment, within a radius of 1 km around the site, the concentrations of carbon-14, bound tritium, and iodine-129 showed an impact on terrestrial plants related to gaseous discharge from the La Hague site. However, these concentrations decreased rapidly with distance from the site (*Figure V.125*).

Cesium-137 was only measured in a few samples in the near environment, and not at all at greater distances. The iodine-129 traces was also limited to an area close to the site.

The activity measured at the most affected station varied between 208 ± 25 and 710 ± 60 Bq/kg dry for carbon-14 and between 6 ± 1.2 and 42 ± 4.4 Bq/kg dry for bound tritium. These values were higher than the values generally observed in areas not affected by discharge from a nuclear facility. At 8.5 km southeast of the La Hague site, the observed activity varied around 100 Bq/kg dry for carbon-14, and between 1.8 ± 0.7 and 5.3 ± 1 Bq/kg dry for bound tritium.

Traces of cesium-134 and -137 were measured at the beginning of April 2011 in four municipalities. The traces were related to the event at the Fukushima nuclear plant on March 11, 2011. Cesium-134 activity measured ranged from 0.79 ± 0.34 to 1.7 ± 0.47 Bq/kg dry.

For more information

Chapter III – Fukushima accident

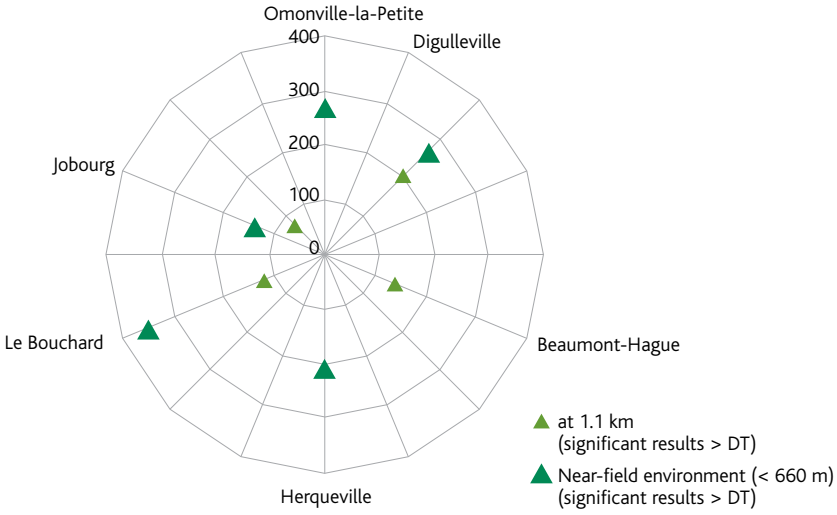

Figure V.122 - Distribution of mean carbon-14 activity measured in grass samples collected around the La Hague site (Bq/kg dry)

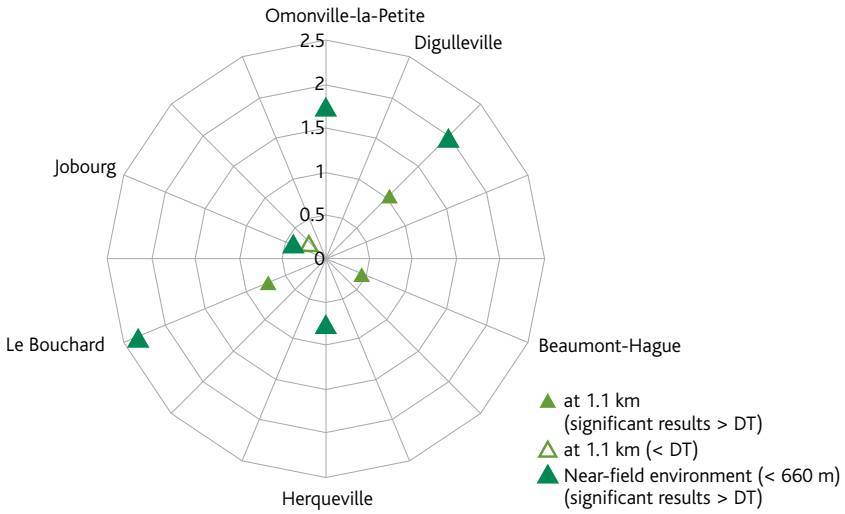

Figure V.123 - Distribution of mean iodine-129 activity measured in grass samples collected around the La Hague site (Bq/kg dry)

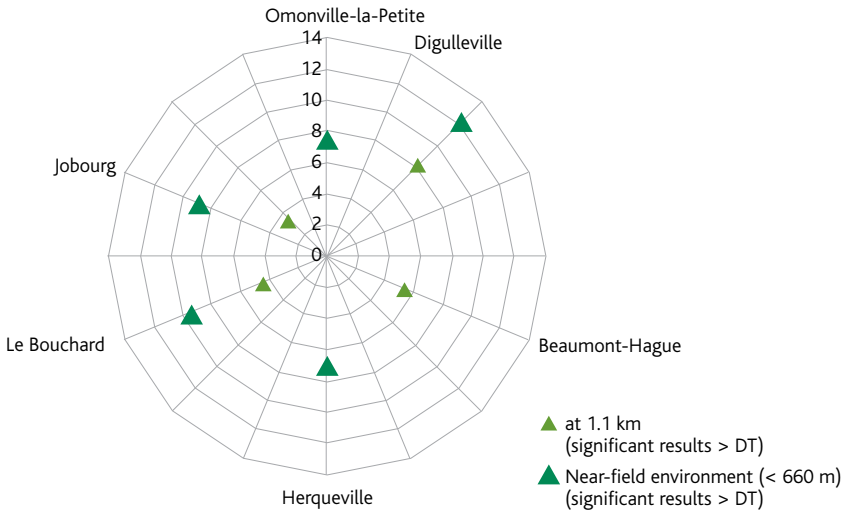

Figure V.124 - Distribtion of mean organically bound tritium (OBT) activity measured in grass samples collected around the La Hague site (Bq/kg dry)

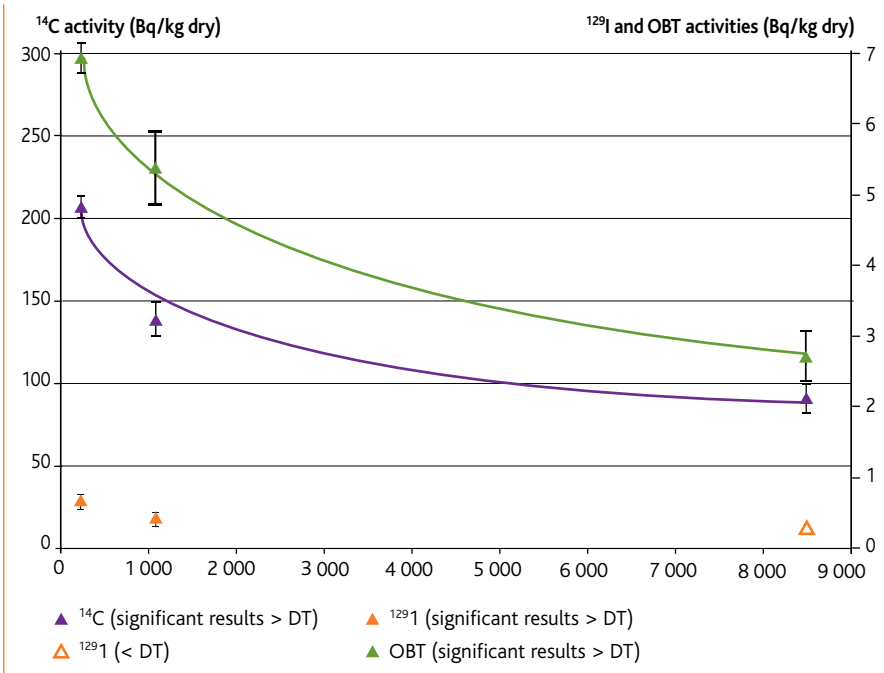

Figure V.125 - Decrease of mean activity of carbon-14, iodine-129 and organically bound tritium measured in grass samples collected along the southeast axis with distance from the La Hague site (Bq/kg dry)

Soil

Cesium-137 was measured in all the soil samples collected every three months in the immediate vicinity of the La Hague site (less than 750 m from the site boundary) at mean activity levels between 6.3 ± 0.9 and 44.3 ± 2.7 Bq/kg dry (*Table V.46*). The majority of this activity can be explained by fallout from past atmospheric nuclear weapons testing and from the Chernobyl accident. Although a contribution attributable to discharge from the La Hague site cannot be excluded, it cannot be quantified.

Activity of the other gamma-emitting artificial radionuclides (^{125}Sb, ^{134}Cs, ^{60}Co, ^{106}Ru + ^{106}Rh) remained below the decision thresholds.

Table V.46 - Mean activity measured in soil samples in the immediate vicinity of the La Hague site (Bq/kg dry)

Radionuclide	Omonville-la-Petite			Jobourg		Digulleville	Herqueville
^{40}K	994 ± 48	670 ± 38	902 ± 46	822 ± 42	847 ± 46	644 ± 36	845 ± 43
^{137}Cs	7.6 ± 0.9	8.9 ± 1.1	6.3 ± 0.9	14.5 ± 1.3	18.3 ± 1.7	11.2 ± 1.2	44.3 ± 2.7
^{134}Cs	< 1.8	< 1.7	< 1.8	< 1.7	< 1.7	< 1.5	< 1.5
^{106}Ru	< 24	< 24	< 24	< 24	< 25	< 21	< 25
^{125}Sb	< 3.8	< 3.7	< 3.8	< 3.6	< 4	< 3.2	< 4
^{60}Co	< 1.5	< 1.2	< 1.4	< 1.5	< 1.5	< 1.2	< 1.2

Table V.47 - Mean activity measured in cow's milk produced around the La Hague site (Bq/L)

Radionuclide	Beaumont-Hague	Digulleville	Herqueville	Jobourg
^{40}K	46.9 ± 0.7	49.9 ± 1	51.8 ± 1	49.1 ± 1
^{129}I	0.0188 ± 0.0017	0.0048 ± 0.001	0.0165 ± 0.0023	< 0.018
^{137}Cs	< 0.039	< 0.04	< 0.04	< 0.04
^{106}Ru	< 0.6	< 0.6	< 0.6	< 0.6
Other gamma-emitting radionuclides (^{125}Sb, ^{134}Cs, ^{60}Co)	< 0.18	< 0.18	< 0.18	< 0.18
^{90}Sr	0.0646 ± 0.0028	0.0491 ± 0.0034	0.0452 ± 0.0012	0.0577 ± 0.0038
HTO	< 9	6 ± 0.8	5.5 ± 0.7	< 9
^{14}C	19 ± 0.5	25.6 ± 0.8	27 ± 0.9	17.5 ± 0.8

Farm produce and foodstuffs

Milk

Cow's milk samples are collected regularly from four farms located near the site at Herqueville, Beaumont-Hague, Digulleville and Jobourg. Of the artificial radionuclides likely to be discharged by the La Hague site, traces of iodine-129, carbon-14 and tritium were observed in some samples (*Table V.47*).

In general, the highest activity was observed in milk collected in the municipalities located directly under the prevailing winds (southwest and northeast sectors) (*Figures V.126 to V.129*).

Iodine-129 was detected fairly regularly in samples collected at Herqueville and Diguelleville, and occasionally in samples collected at the Beaumont-Hague station (two significant values measured between January 2010 and May 2011).

The results for other gamma-emitting radionuclides remained below the decision thresholds for all the stations. The strontium-90 concentrations measured in milk were between 0.023 ± 0.016 and 0.14 ± 0.023 Bq/L, within the range of values measured in areas not affected by industrial discharge.

In addition, traces of iodine-131, related to the nuclear accident at the Fukushima plant in Japan in March 2011, were detected in milk collected at the beginning of April 2011 in farms in Herqueville, Beaumont-Hague and Jobourg (activity between 0.144 ± 0.049 and 0.23 ± 0.1 Bq/L). Cesium-137 was also measured in milk collected at the beginning of May 2011 in Jobourg, with an activity concentration of 0.059 ± 0.035 Bq/L.

For more information

Chapter III – Fukushima accident

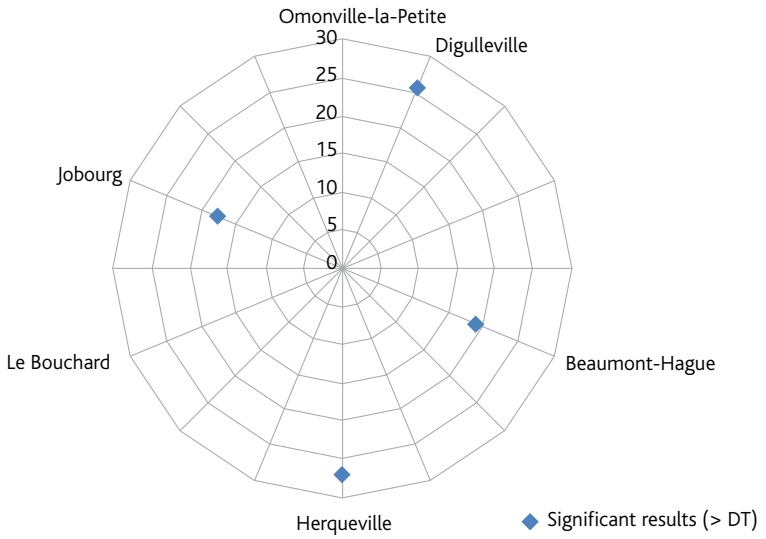

Figure V.126 - Distribution of mean carbon-14 activity measured in milk samples from cows raised near the La Hague site (Bq/L)

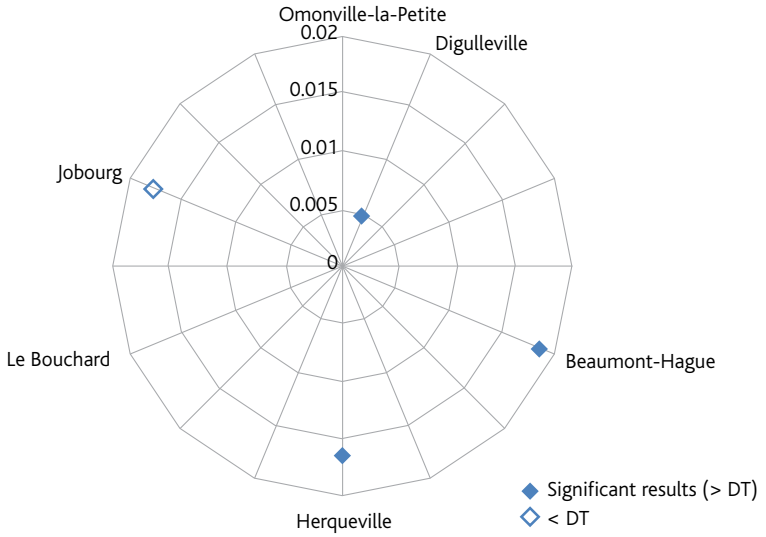

Figure V.127 - Distribution of mean iodine-129 activity measured in milk samples from cows raised near the La Hague site (Bq/L)

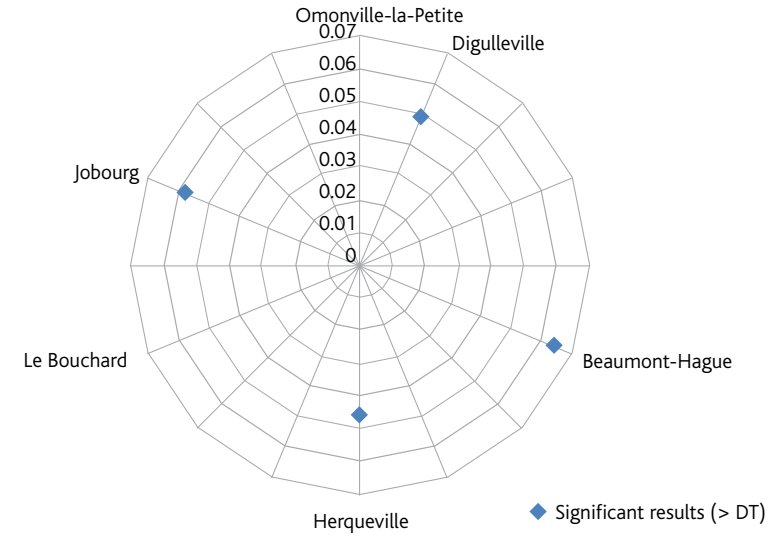

Figure V.128 - Distribution of mean strontium-90 activity measured in milk samples from cows raised near the La Hague site (Bq/L)

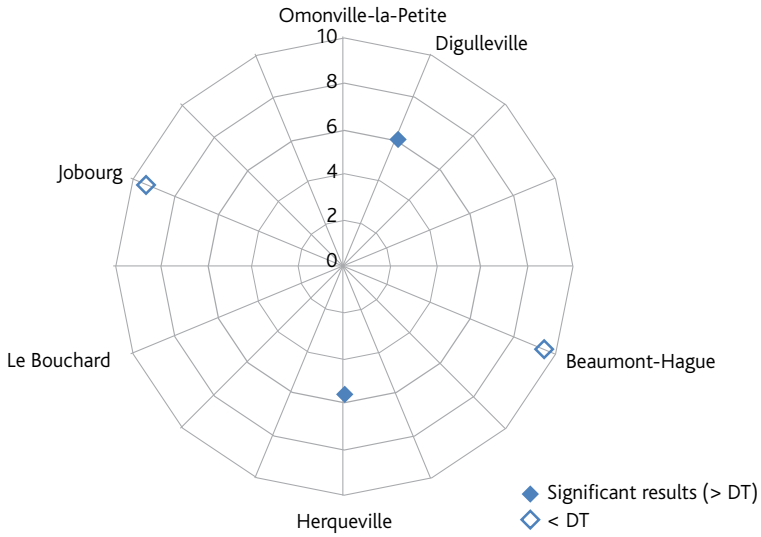

Figure V.129 - Distribution of mean organically bound tritium (OBT) activity measured in milk samples from cows raised near the La Hague site (Bq/L)

Meat

The radioactivity measured in farm meat samples collected in the vicinity of the La Hague nuclear site was due mainly to naturally occurring potassium-40 (*Table V.48*).

Rabbit raised in Herqueville showed traces of strontium-90 (specific activity 0.087 ± 0.033 Bq/kg wet). It is difficult to distinguish between activity attributable to discharge from the La Hague nuclear facilities and that due to past fallout from atmospheric nuclear weapons testing.

The specific activity of carbon-14 measured in beef in 2010 (528.5 ± 2 Bq/kg C) is evidence of livestock exhibiting added concentrations linked with gaseous discharge from the La Hague site: this value is nearly twice as high as the values customarily observed in areas not affected by discharge from nuclear facilities.

These analyses also revealed bound tritium, at low activity levels, attributable to the operation of the La Hague reprocessing plant. Activity levels of other radionuclides remained below the decision thresholds of the instruments used.

*Table V.48 - Mean activity measured in meat produced near the La Hague site (Bq/kg wet)**

Radionuclide	Omonville-la-Petite	Herqueville	Jobourg	Slaughterhouse near the site	Slaughterhouse near the site
	Poultry	Rabbit	Mutton	Beef	Beef
^{40}K	128 ± 13	126 ± 9	92 ± 9	105 ± 13	104 ± 12
^{129}I	< 0.07	< 0.07	< 0.045	nm	nm
^{137}Cs	< 0.11	< 0.09	< 0.07	< 0.18	< 0.15
^{106}Ru	< 1.8	< 1.6	< 1.2	< 1.5	< 2.1
Other gamma-emitting radionuclides (^{125}Sb, ^{134}Cs, ^{60}Co)	< 0.46	< 0.41	< 0.32	< 0.8	< 0.9
OBT	nm	6.3 ± 0.5	0.81 ± 0.38	1.11 ± 0.36	0.344 ± 0.019
^{14}C	27 ± 5	49.7 ± 5	26 ± 8	86.47 ± 0.33 (528.5 ± 2 Bq/kg C)	32.53 ± 0.17 (243.8 ± 1.3 Bq/kg C)
^{90}Sr	nm	0.087 ± 0.033	nm	< 0.035	< 0.026
^{241}Am	< 0.08	< 0.08	< 0.05	nm	nm
^{238}Pu	nm	< 0.005	nm	nm	nm
$^{239+240}$Pu	nm	< 0.008	nm	nm	nm
^{244}Cm	nm	< 0.0042	nm	nm	nm

nm: not measured
** unless otherwise indicated*

Cereals

Wheat samples were collected during the annual harvest in Digulleville. Concentrations of the gamma-emitters, other than potassium-40, remained below the decision thresholds.

Tritium, in a form bound to organic matter, was measured at a specific activity of 4.9 ± 0.25 Bq/kg dry, indicating a slight impact on wheat by discharge from the La Hague site.

Vegetables, mushrooms and aromatic plants

Samples of terrestrial plants intended for human consumption (vegetables, mushrooms, aromatic plants) were collected under the primary prevailing winds in Herqueville, Digulleville and Omonville-la-Petite (*Table V.49*).

Several artificial radionuclides attributable to discharge from the La Hague site were measured in plants: tritium, carbon-14, and iodine-129.

Potatoes grown in Herqueville showed strontium-90 activity within the range of values measured in areas not affected by industrial discharge. This activity can be attributed to past fallout from atmospheric nuclear weapons testing.

The cesium-137 measured in the mushrooms collected in Digulleville (activity 0.55 ± 0.07 Bq/kg wet) can be attributed to past fallout from the Chernobyl accident. Activity of other radionuclides remained below the decision thresholds.

Following the accident at the Fukushima nuclear plant on March 11, 2011, traces of cesium-134 and -137 were measured in the thyme sample collected on April 20, 2011 in Herqueville, at a specific activity of 0.34 ± 0.16 and 0.44 ± 0.21 Bq/kg wet, respectively.

For more information
Chapter III – Fukushima accident

Table V.49 - Mean activity measured in terrestrial plants intended for human consumption produced near the La Hague site (Bq/kg wet)

Radionuclide	Digulleville	Herqueville				Omonville-la-Petite	
	Mushroom	Leek	Potato	Parsley	Thyme	Carrot	Cauliflower
^{40}K	82 ± 7	139 ± 13	169 ± 15	255 ± 25	275 ± 27	119 ± 11	81 ± 5
^{129}I	0.053 ± 0.021	< 0.037	< 0.044	< 0.09	0.39 ± 0.14	< 0.031	< 0.018
^{137}Cs*	0.55 ± 0.07	< 0.042	< 0.05	< 0.14	0.44 ± 0.21	< 0.033	< 0.018
^{106}Ru	< 0.39	< 0.8	< 0.8	< 2.1	< 2.9	< 0.6	< 0.32
Other gamma-emitting radionuclides (^{125}Sb, ^{134}Cs*, ^{60}Co)	< 0.11	< 0.21	< 0.24	< 0.54	< 0.62	< 0.16	< 0.09
OBT	0.68 ± 0.11	1.46 ± 0.16	0.75 ± 0.24	2.31 ± 0.32	3.8 ± 0.5	2.23 ± 0.21	1.22 ± 0.09
^{14}C	9.4 ± 1.6	16.4 ± 2.2	34 ± 5	26.9 ± 4.7	45 ± 7	15.2 ± 2.2	9.7 ± 1.1
^{90}Sr	nm	nm	0.29 ± 0.11	nm	nm	nm	nm
^{241}Am	< 0.019	< 0.033	< 0.041	< 0.09	< 0.14	< 0.028	< 0.016
^{238}Pu	nm	nm	< 0.01	nm	nm	nm	nm
$^{239+240}$Pu	nm	nm	< 0.0048	nm	nm	nm	nm
^{244}Cm	nm	nm	< 0.009	nm	nm	nm	nm

** Excluding significant results attributable to the Fukushima accident*
nm: not measured

Cider

Analysis of cider collected at Saint-Germain-des-Vaux did not detect any artificial radionuclides: only naturally occurring potassium-40 was measured, at an activity concentration of 44.2 ± 3.7 Bq/L.

Other farm produce (eggs, honey)

In 2010, annual samples of eggs and honey were collected in the immediate vicinity of the La Hague nuclear plant, in Herqueville and Beaumont-Hague (*Table V.50*).

The radioactivity measured in the honey and eggs was mainly due to carbon-14 and potassium-40. Traces of bound tritium attributable to discharge from the La Hague site were detected in the two samples, and traces of strontium-90 in the eggs collected in Herqueville.

Table V.50 - Mean activity measured in eggs and honey produced near the La Hague site (Bq/kg wet)

Radionuclide	Beaumont-Hague	Herqueville
	Honey	Eggs
^{40}K	16.2 ± 4.3	51 ± 6
^{129}I	< 0.07	< 0.047
^{137}Cs	< 0.12	< 0.07
^{106}Ru	< 1.8	< 1.2
Other gamma-emitting radionuclides (^{125}Sb, ^{134}Cs, ^{60}Co)	< 0.52	< 0.31
OBT	4.2 ± 1.3	2.9 ± 0.6
^{14}C	102 ± 22	35 ± 15
^{90}Sr	nm	0.27 ± 0.11
^{241}Am	< 0.08	< 0.046
^{238}Pu	nm	< 0.013
$^{239+240}$Pu	nm	< 0.013
^{244}Cm	nm	< 0.011

nm: not measured

Continental aquatic compartment

Surface water

The general configuration of the relief of the Cotentin isthmus and the narrowness of the peninsular leave space only for small coastal rivers flowing into the Channel. These include the Sainte-Hélène, Landes and Moulinets streams, which are affected by the La Hague site. They are used as historic reference sites for radiological impact related to the La Hague industrial site. Rainwater and site drainage water that are not radioactive contamination risks are collected and transferred to a storm water basin located at the Areva facility, then discharged into the Sainte-Hélène stream.

The analyses performed on this water in the vicinity of the La Hague site did not reveal americium-241, cobalt-60 or plutonium-238, -239 or -240 at quantifiable levels. However, cesium-137, radium-226 and the uranium isotopes were detected occasionally.

Since 1996, IRSN has been collecting surface water samples from the Landes stream, northwest of the site. These samples had added concentrations of strontium-90, an artificial radionuclide produced in fission reactions, which has a radioactive half-life of 28 years. These activity levels can be related to the strontium-90 contamination of the ground water by waste stored on the surface at the site in the 1980s (*Figure V.130*).

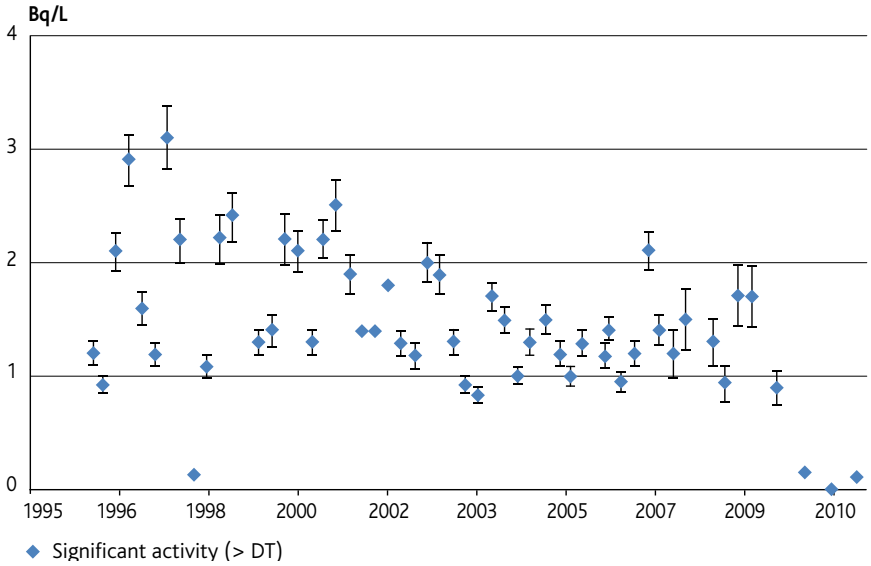

Figure V.130 - Strontium-90 activity in water from the Landes stream (Bq/L)

Tritium remains in the vicinity of the La Hague site. It is detected in water of all the streams located in the immediate environment of the site, with maximum values recorded in the Sainte-Hélène stream at Digulleville (*Figure V.131*). This contamination is linked with the historic presence of tritium in ground water contaminated by a disposal incident that occurred at the ANDRA facility in 1976. This contamination is recorded in measurements made by IRSN since 1973. The activity level started to decrease from the 1990s. Since then, the measured tritium activity has been approximately 100 Bq/L.

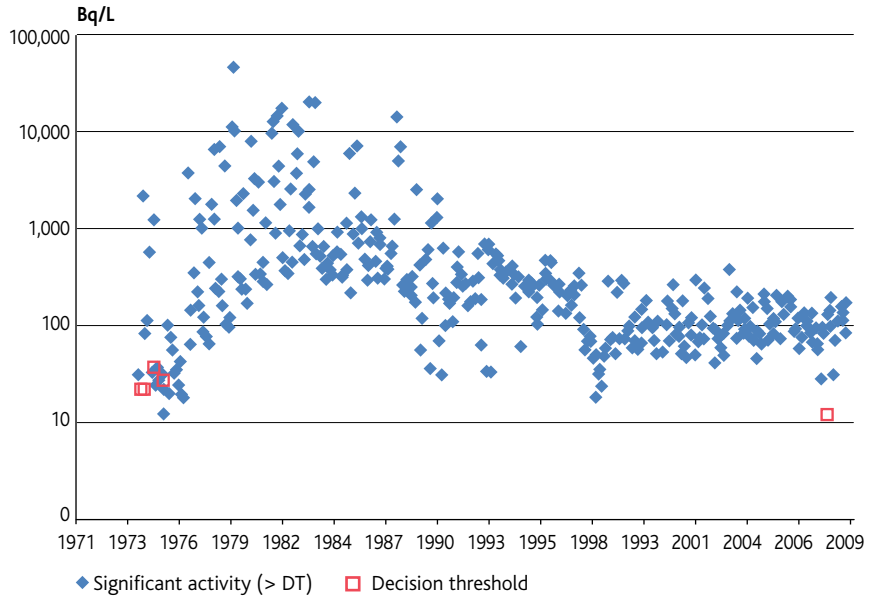

Figure V.131 - Tritium activity in water from the Sainte-Hélène stream (Bq/L)

Sediments

Sediment samples were collected every three months from the Landes, Combes, Sainte-Hélène, Grand-Bel and Moulinets streams (*Table V.51*). Monthly samples were collected from the Sainte-Hélène stream at the "la Brasserie" site. Analyses revealed artificial radionuclides (^{134}Cs, ^{137}Cs, ^{60}Co, ^{238}Pu, $^{239+240}$Pu) attributable to discharge from the La Hague site (*Table V.51*).

Only cesium-137 was detected in all the sediment samples, at a mean specific activity between 1.85 ± 0.24 and 50.4 ± 1.8 Bq/kg dry in the Grand-Bel and Moulinets streams. Large fluctuations were observed during the year: the cesium-137 activity measured in the Sainte-Hélène stream at the "le Pont-Durand" site ranged from 5.6 ± 0.6 to 70 ± 7 Bq/kg dry. Although cesium-137 concentrations due to discharge from the site, mainly in the past, cannot be excluded, they are also a result of past atmospheric fallout.

Cesium-134 was measured occasionally in the Sainte-Hélène stream (maximum activity 35.9 ± 1.4 Bq/kg dry recorded at the "la Brasserie" site) and in the Grand-Bel stream (3 ± 0.8 Bq/kg dry). The sediments of the Sainte-Hélène and Moulinets streams showed occasional traces of cobalt-60 at specific activity levels between 0.39 ± 0.12 and 2.05 ± 0.38 Bq/kg dry.

Plutonium activity recorded in the Sainte-Hélène and Moulinets streams demonstrate a slight impact due to discharge from the site. The ^{238}Pu/$^{239+240}$Pu activity ratio of about 0.5 is characteristic of civil spent fuel (the ratio characteristic of atmospheric fallout from nuclear weapons testing in the 1960s is about 0.025). According to time plots of $^{239+240}$Pu concentrations, added concentration levels in sediments in the Landes stream seems to date mainly from contamination incidents during the period 2001-2003 (concentration time plots on page 118 of the IRSN *Report on the Radiological State of the Environment in France in 2009*).

In addition, analysis of sediment samples collected every three months from a stream 100 m from the Valognes railroad terminal, used for shipments of nuclear material to and from the Areva site, did not detect any radiological anomaly. Only cesium-137, attributable to past atmospheric fallout, was measured at a mean specific activity of 3.1 ± 0.7 Bq/kg dry. The other artificial gamma-emitting radionuclides analyzed (^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{60}Co, ^{54}Mn, ^{106}Ru) were not detected by the measurement techniques used.

Table V.51 - Mean activity measured in sediment samples from the freshwater environment collected from the streams located near the La Hague site (Bq/kg dry)

Radionuclide	Landes stream	Combes stream	Sainte-Hélène stream			Grand-Bel stream	Moulinets stream
	150 m downstream of the La Hague site Hameau des Landes	500 m downstream of L'arsenal near La Hague site	200 m downstream of Le Pont Durand near the La Hague site	1.1 km downstream of La Brasserie near the La Hague site	2.2 km downstream of La Fosse near the La Hague site	750 m downstream of the La Hague site Hameau les Clerges	Downstream of the La Hague site
^{40}K	359 ± 14	848 ± 29	425 ± 12	nm	900 ± 70	890 ± 80	941 ± 31
^{137}Cs	6.9 ± 0.5	4.06 ± 0.23	10.24 ± 0.44	43.7 ± 1.5	13.9 ± 0.9	1.85 ± 0.24	50.4 ± 1.8
^{134}Cs	< 0.38	< 0.38	< 0.31	0.58 ± 0.07	0.32 ± 0.07	0.45 ± 0.09	< 0.5
^{60}Co	< 0.3	< 0.39	0.44 ± 0.05	< 0.7	< 0.31	< 0.6	0.7 ± 0.12
Other gamma-emitting radionuclides (^{125}Sb, ^{106}Ru, etc.)	< 5	< 6	< 1	< 7	< 6	< 5	< 9
^{226}Ra	nm	nm	nm	nm	65 ± 32	nm	nm
^{238}Pu	0.132 ± 0.035	< 0.13	0.261 ± 0.032	nm	< 0.14	nm	0.174 ± 0.042
$^{239+240}$Pu	1.86 ± 0.2	0.183 ± 0.048	0.365 ± 0.044	nm	< 0.15	nm	0.35 ± 0.08

nm: not measured

Flora

Aquatic phanerogam samples were collected every three months from the Sainte-Hélène, Combes and Landes streams (*Table V.52*). Apart from the customary presence of potassium-40, the analyses detected artificial radionuclides such as cesium-137, iodine-129, americium-241, tritium, and, more occasionally, cobalt-60. The recorded activity levels increased with the proximity of the sampling points to the La Hague nuclear facilities, indicating the impact of the operations on this site on the near-field continental aquatic environment.

The measured values varied considerably over time. They varied in particular according to the vegetative stage of the sampled phanerogams. Specific activity between 7.4 ± 0.9 and 36.3 ± 4.4 Bq/kg dry for americium-241 and between 2.3 ± 0.6 and 23.7 ± 2.7 Bq/kg dry for tritium were observed 150 m from the La Hague site in the Landes stream. Similarly, spot measurements of cobalt-60 closest to the site in the Landes stream showed values varying between 2.6 ± 0.6 and 6.4 ± 0.7 Bq/kg dry.

Table V.52 - Mean activity measured in aquatic phanerogam samples collected near the La Hague site (Bq/kg dry)

Radionuclide	Landes stream	Sainte-Hélène stream	Combes stream
	150 m dowstream of the La Hague site	At the waterfall	500 m downstream of the La Hague site
^{40}K	338 ± 15	608 ± 25	355 ± 17
^{129}I	0.45 ± 0.1	11.4 ± 1	2.85 ± 0.3
^{137}Cs	3.31 ± 0.28	45.6 ± 2.1	< 0.42
^{60}Co	< 0.5	1.04 ± 0.16	< 0.46
^{241}Am	9.4 ± 0.5	1.54 ± 0.25	< 0.32
Other gamma-emitting radionuclides (^{125}Sb, ^{134}Cs, ^{106}Ru)	< 9	< 11	< 8
OBT	5.17 ± 0.34	14.5 ± 0.8	5.03 ± 0.38

Ground water

Ground water is drained mainly towards the Sainte-Hélène and Grand-Bel streams. It also has outlets to the Combes, Landes and Moulinets streams. The La Hague ground water is analyzed mainly by the nuclear operators (Areva and ANDRA) by means of more than 240 piezometers, half of which are checked periodically.

The CSM waste disposal facility is monitored using 60 piezometers, 48 of which are sampled for radiological analyses. Significant tritium activity levels can be measured, with a mean in 2010 of 4821 Bq/L and a maximum measured value of 168,000 Bq/L. These measurements at the CSM result from past pollution of the ground water with tritium. The piezometer located within the nuclear facility is subject to systematic monitoring to check changes in pollution and its lack of dosimetric impact outside the site.

Traces of artificial radionuclides such as cobalt-60 and cesium-137 are detected occasionally at 12 piezometers on the La Hague site.

The majority of the ground water measurements made on the La Hague site showed gross alpha and beta activity values below the limits recommended by the WHO for the consumption of potable water. Some piezometers still show additional concentrations at values above these limits due to past events. The mean tritium activity measured in the ground water was 345 Bq/L, with a maximum value of 19,000 Bq/L. These occasional added concentrations concerned a piezometer located at the edge of the CSM waste disposal facility site, near the ANDRA piezometer showing past pollution (see above). IRSN monitors some ground water outside the La Hague site (*Figures V.132 and V.133*). The trend shows decreasing tritium activity since the early 2000s. However, the ground water under and around the La Hague site is not used for human consumption.

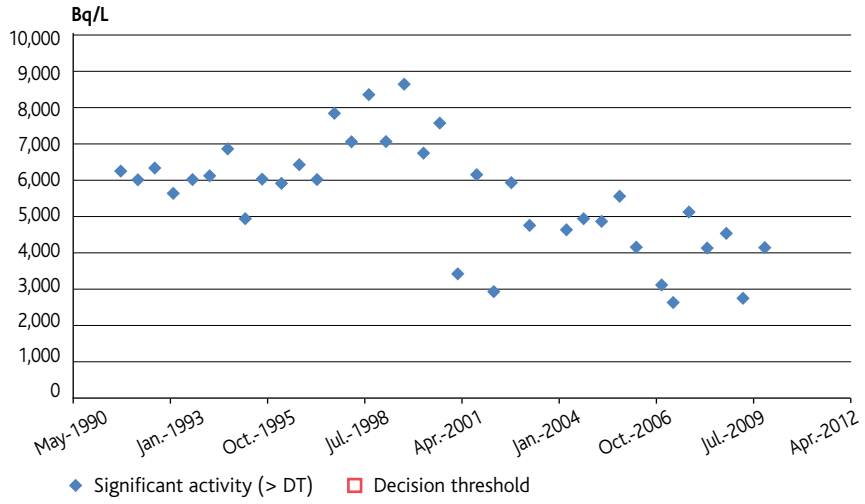

Figure V.132 - Tritium activity in ground water samples collected at point Z702 located to the northwest of the CSM site (Bq/L)

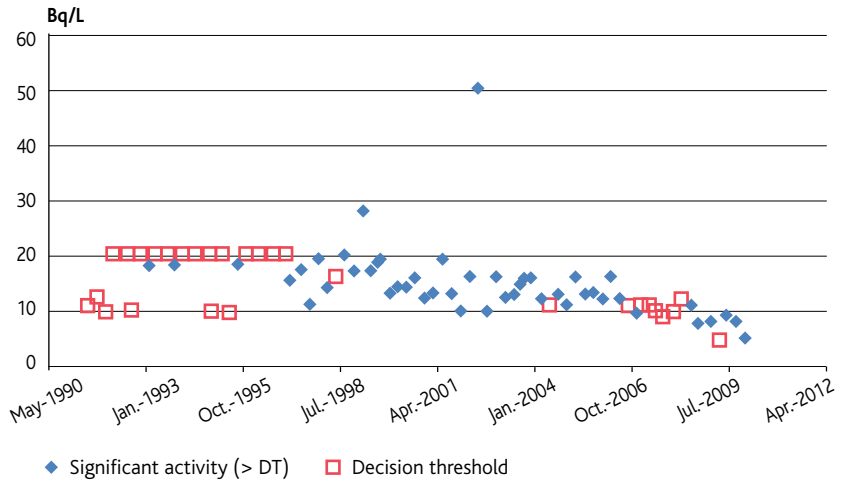

Figure V.133 - Tritium activity in ground water samples collected at point Z106 near the La Hague site (Bq/L)

Somanu

The Somanu site is a nuclear maintenance plant located at Maubeuge in northern France, near the Belgian border. Listed as a basic nuclear installation (INB), the site has facilities for maintenance and repair of certain nuclear components outside their original installation site.

The equipment and tool maintenance carried out at the Somanu plant can include disassembly, decontamination, machining, repair, reassembly, and testing. Somanu also organizes and manages transport on the public highway for reception and shipment of equipment belonging to nuclear operators.

Figure V.134 - Somanu plant workshop ("hot workshop")

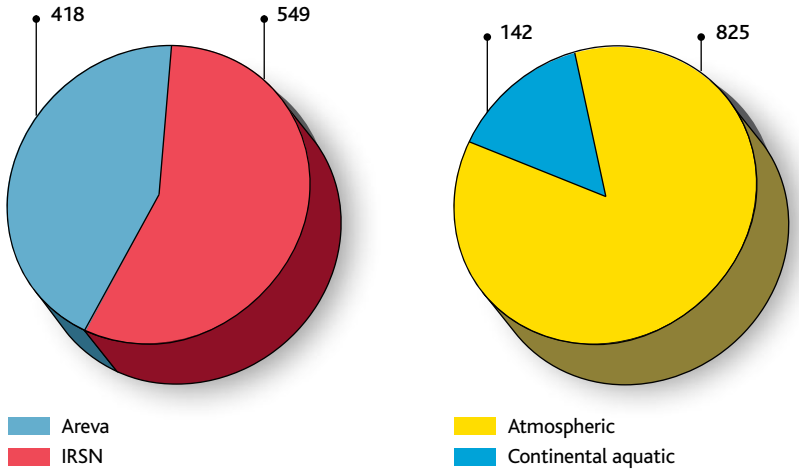

Figure V.135 - Somanu plant: breakdown of the number of samples by data provider and by environment

Atmospheric compartment

Aerosols

Monitoring of the gross beta activity in aerosol samples collected in the environment of the Somanu site did not reveal any abnormal value (*Table V.53 and Figure V.136*). The gamma spectrometry analyses showed that no artificial radionuclide was detected in the environment.

Table V.53 - Activity measured in atmospheric aerosol samples collected in the environment of the Somanu plant (mBq/m³)

Radionuclide type	Radionuclide	Activity (mBq/m³)
Gross activity levels	Beta activity	0.42 ± 0.02
Naturally occurring radionuclides	Beryllium-7	2.37 ± 0.1
	Lead-210	0.41 ± 0.03

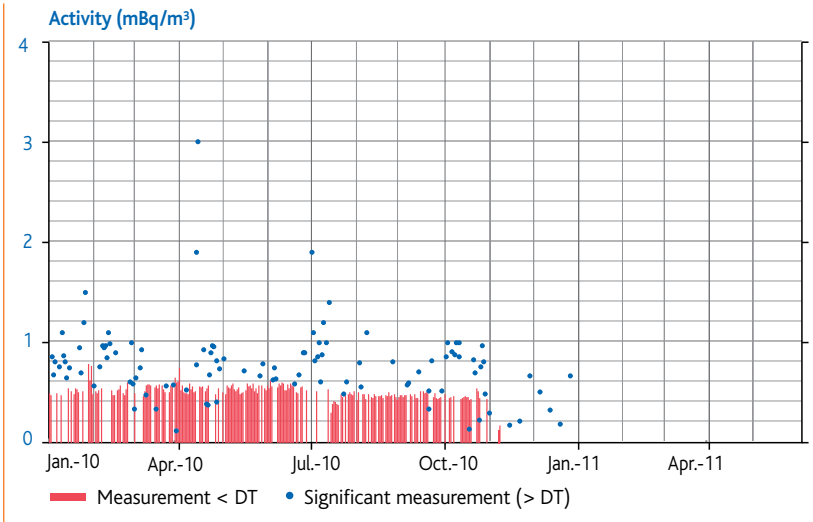

Figure V.136 - Time plot of gross beta activity in atmospheric aerosol samples collected near the Somanu plant (mBq/m³)

Continental aquatic compartment

Surface water

Water samples are collected every month from the La Flamenne stream at mid-discharge.

The measurements of tritium in water from this stream were all below the decision threshold (4 Bq/L).

The gross beta activity varied between 0.12 and 0.6 Bq/L. These values are below the reference value recommended by the French public health code for water intended for human consumption (gross beta activity 1 Bq/L).

The gross alpha activity measurements were generally below or close to the decision threshold (0.04 Bq/L). Only two analyses (0.18 ± 0.07 Bq/L on September 1, 2010 and 0.19 ± 0.07 Bq/L on June 6, 2010) showed activity levels above the reference value recommended by the French public health code for water intended for human consumption (gross alpha activity 0.1 Bq/L).

It should be noted that there are no artificial alpha emitters in the equipment received for maintenance in the plant.

Ground water

The ground water is subject to regular monitoring by means of several piezometers at several points on the Somanu site.

Measurements of tritium in this water were all below the decision threshold (4 Bq/L).

The gross beta activity varied between the decision threshold (0.03 Bq/L) and 0.27 Bq/L. As in the case of the water from La Flamenne, the gross alpha activity measurements were generally below or close to the decision threshold (0.04 Bq/L). Only one spot measurement in June 2011 showed activity greater than 0.1 Bq/L (0.27 ± 0.06 Bq/L).

Monitoring of surface water and ground water did not reveal evidence of added concentrations due to the operations on the Somanu industrial site.

V.6 MONITORING OF WASTE DISPOSAL FACILITIES

For the disposal of low- and intermediate-level short-lived radioactive waste, the National Radioactive Waste Management Agency (ANDRA) first operated the CSM waste disposal facility, now closed and in the monitoring phase. ANDRA now operates the low- and intermediate-level short-lived radioactive waste disposal facility (CSFMA) and the very-low-level waste disposal facility (CSTFA), both located about 175 km east of Paris. These two "surface disposal" facilities are sited at Soulaines and Morvilliers in the Aube department (*Figure V.137*).

These disposal sites are subject to the regulations applicable to basic nuclear installations (INB) (CSM and CSFMA), or those applicable to regulated facilities (ICPE) (CSTFA), which require the operator to implement environmental monitoring including radiological and chemical measurements on rainwater, surface water (streams), ground water, and ambient air. After the operation (conditioning and storage) phase, the regulations stipulate that ANDRA must continue to monitor the site and the environment for several decades to make sure that the disposal facility has no health impact on persons or its environment.

As the monitoring system of the CSM is combined with that of the Areva plant at La Hague, the results of the CSM monitoring are given in the section on the monitoring of the La Hague site (*Section V.5*).

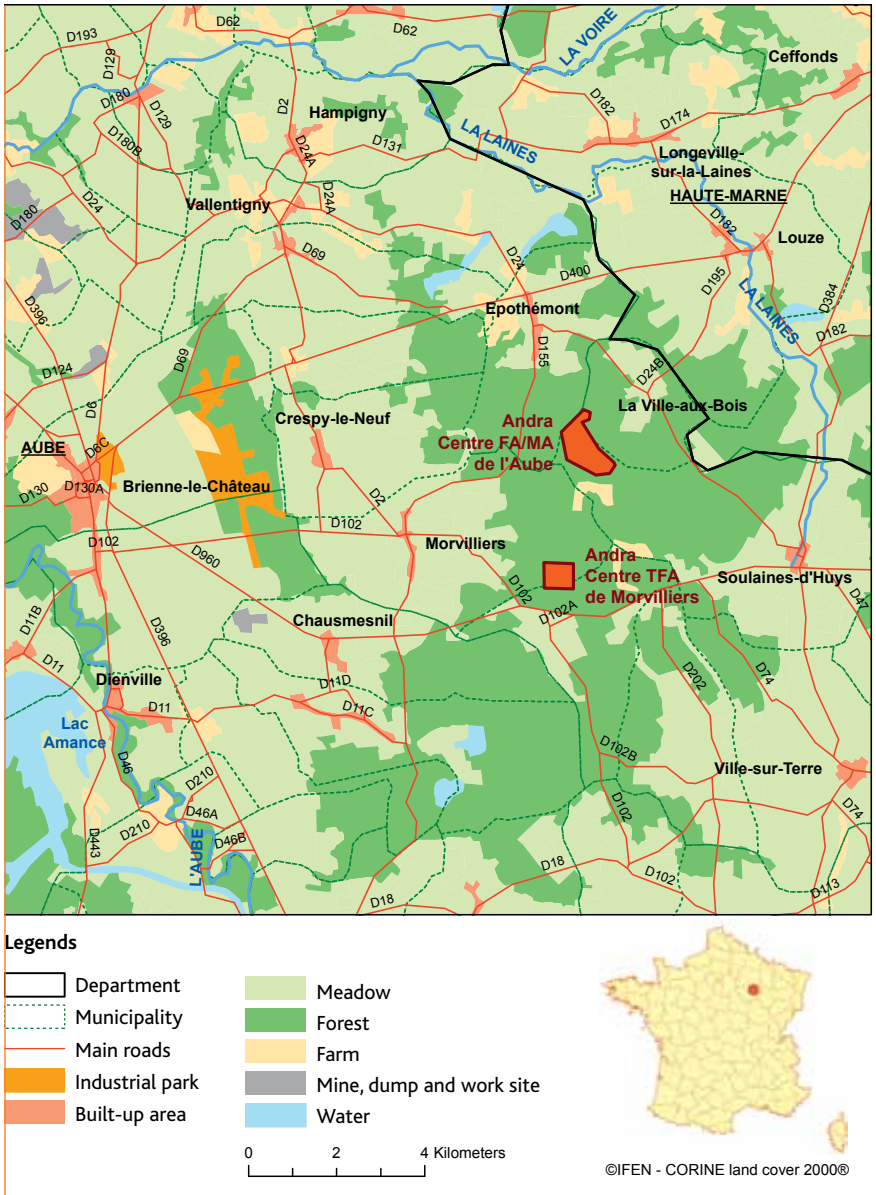

Figure V.137 - Geographic locations of the CSFMA and CSFTA waste disposal facilities

CSFMA waste disposal facility and CSTFA waste disposal facility

The CSFMA waste disposal facility has been used since 1992 for surface disposal of low- and intermediate-level short-lived radioactive waste (LILW-SL). The facility is situated in three municipalities: Soulaines-Dhuys, Épothémont and La-Ville-aux-Bois.

Most LILW-SL waste is generated by maintenance (clothing, tools, filters, etc.) and operation of nuclear facilities, research centers and medical centers.

LILW-SL waste is managed by the CSFMA in solid form. Some waste may be compacted on site in the ANDRA facilities to reduce its volume. For disposal, the waste is placed in concrete or metal containers, and mixed with an embedding material (concrete, for example). The waste is stored on the surface in reinforced concrete structures. When the structures are full, they are closed by a concrete slab sealed with an impermeable coating (*Figure V. 138*).

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Figure V.138 - CSFMA waste disposal facility at Soulaines

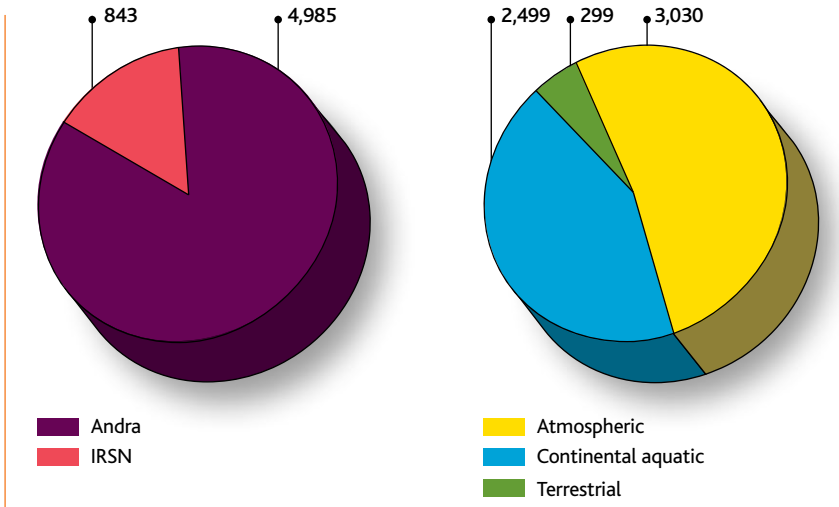

Figure V.139 - ANDRA – CSFMA site: breakdown of the number of samples by data provider and by compartment

Located a few kilometers from the CSFMA, **the CSTFA waste disposal facility** has been used since 2003 for the surface disposal of very-low-level waste. The facility is located in Morvilliers and La Chaise.

The waste accepted by the CSTFA comes from French nuclear facilities, laboratories and research centers, mostly from dismantling operations. Other waste is received from the chemicals and metallurgical industries and from cleanup of polluted sites.

The levels of radioactivity of waste categorized as vert low-level waste (VLLW) are very close to the level of naturally occurring radioactivity. This waste is conditioned in drums or big bags, then stacked in disposal caverns excavated in a clay layer (*Figure V.140*). When the maximum disposal height is reached, the cavern is capped with compacted clayey backfill to restore its original impermeability.

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Figure V.140 - CSTFA waste disposal facility at Morvilliers

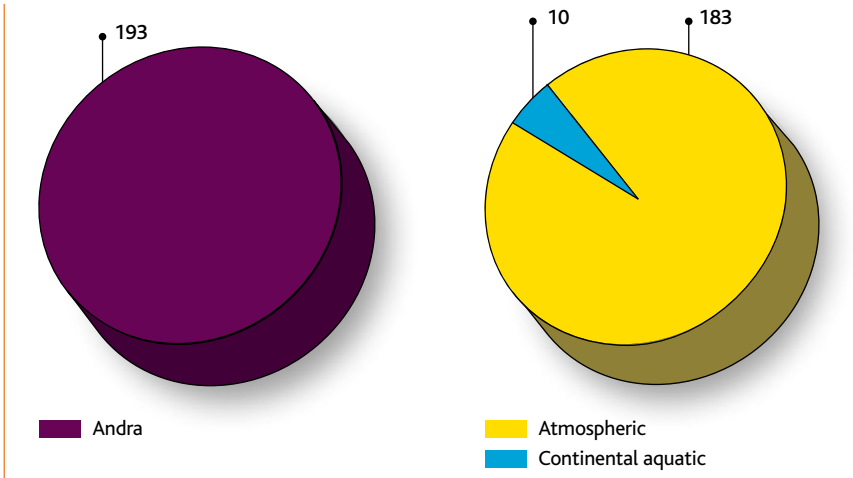

Figure V.139 - ANDRA – CSFTA site: breakdown of the number of samples by data provider and by compartment

Atmospheric compartment

Atmospheric aerosols

In the environment of the CSFMA and CSFTA sites, the atmospheric aerosol monitoring showed no impact of site operation. Just a few unusual gross alpha activity values were measured simultaneously at the two monitoring points located at the CSFMA, in Soulaines-Dhuys and La Ville-aux-Bois (*Table V.54 and Figure V.142*).

Additional measurements made on these samples confirmed the absence of artificial radionuclides in the environment. The investigations were able to explain these particular values by a measurement incident.

Table V.54 - Abnormally high gross alpha activity levels at the CSFMA waste disposal facility (mBq/m³)

Location	Sampling period	Gross alpha activity (mBq/m³)
CSFMA (Soulaines-Dhuys)	March 16-17, 2010	0.52 ± 0.07
CSFMA (La Ville-aux-Bois)		0.47 ± 0.07
CSFMA (Soulaines-Dhuys)	March 4-7, 2011	0.86 ± 0.09
CSFMA (La Ville-aux-Bois)		0.79 ± 0.08
CSFMA (Soulaines-Dhuys)	April 22-26, 2011	0.67 ± 0.07
CSFMA (La Ville-aux-Bois)		0.72 ± 0.08

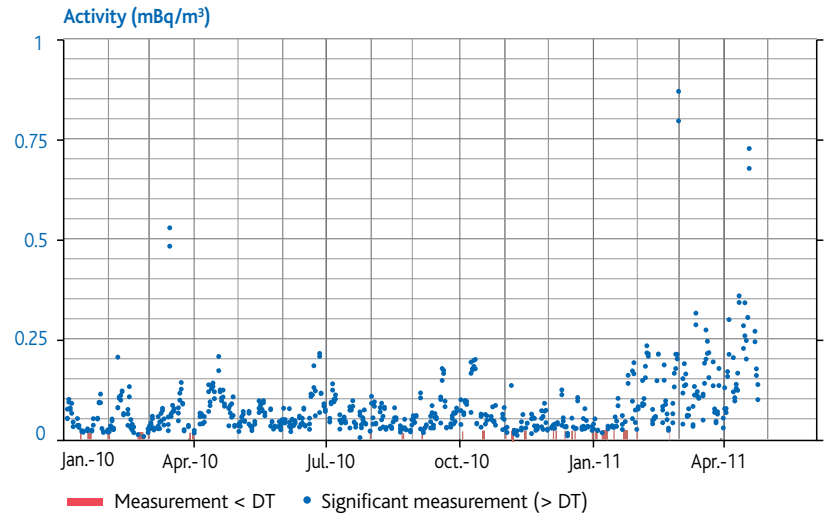

Figure V.142 - Time plot of the gross alpha activity of aerosols over the ANDRA CSFMA and CSFTA waste disposal facilities (mBq/m³)

No artificial radionuclide was detected in the environment of the disposal facilities.

During the period of fallout in France from the Fukushima accident, significant activity levels of cesium-134, cesium-137 and iodine-131 were observed between the end of March and the beginning of May 2011 (*Table V.55, Figure V.143*).

For more information

Chapter III – Fukushima accident

Gases (Iodine-125, -129 and -131)

The presence of iodine-125, -129 and -131 in gas form was also checked in air samples collected in cartridges. This monitoring did not reveal evidence of significant releases of these radionuclides into the environment. However, iodine-131 was measured during the period of the accident at the Fukushima nuclear plant (*Table V.56*).

Rainwater

Two collectors installed on the CSFMA site, in Soulaines-Dhuys and La Ville-aux-Bois, are used to collect rainwater. Weekly samples are taken.

The results of the gross alpha, gross beta and tritium measurements of this water showed no impact from the site operations. The only outliers were analyses performed on the samples collected at the two stations from April 7 to 14, 2011 (0.25 and 0.29 Bq/L), which were ten times higher than the values generally observed. These results were linked with low rainfall during this period and with the presence of suspended solids of diverse origins (atmospheric dust, pollen, etc.). Additional analyses (gamma spectrometry) performed on these raw (unfiltered) samples showed no evidence of artificial radionuclides.

Table V.55 - Activity measured in aerosols in the environment of the ANDRA CSFMA and CSFTA waste disposal facilities (mBq/m³)

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
artificial radionuclides	Cesium-134	0.008 ± 0.002*
	Cesium-137	0.007 ± 0.002*
	Iodine-131	0.013 ± 0.003*

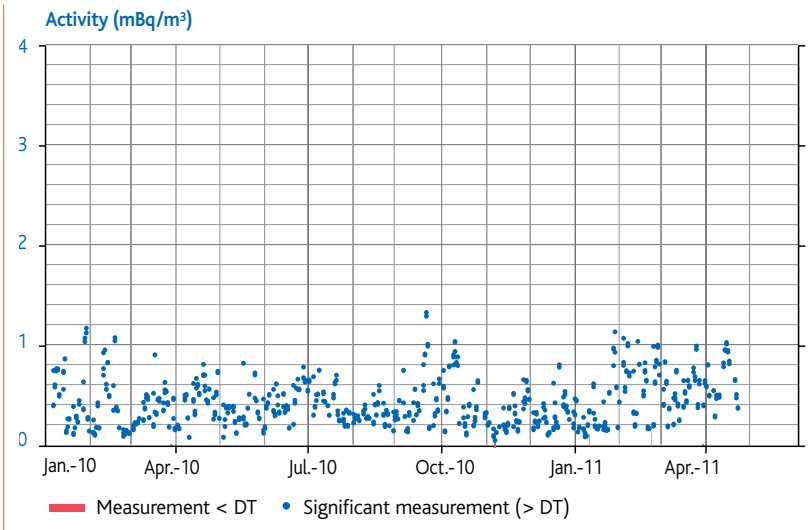

Figure V.143 - Time plot of the gross beta activity of aerosols near the ANDRA CSFMA and CSFTA waste disposal facilities (mBq/m³)

Table V.56 - Gaseous iodine isotopes measured in the environment of the CSFMA and CSTFA sites (mBq/m³)

Radionuclide type	Radionuclide	Mean activity or decision threshold (mBq/m³)
artificial radionuclides in gaseous form	Iodine-125	< 0.040
	Iodine-129	< 0.068
	Iodine-131	< 0.087 0.063 ± 0.01*

** Measurements made during the period of the nuclear accident at the Fukushima nuclear power plant between March 22 and May 6, 2011.*

Terrestrial compartment

The immediate environment of the CSFMA and CSFTA disposal facilities is subject to regular monitoring by sampling of grass, milk, cereals and mushrooms.

Terrestrial flora

Monthly grass samples are collected in three municipalities located in the immediate proximity of the radioactive waste disposal facilities (*Table V.57*). These are supplemented by three-monthly sampling at two other sampling points.

In normal situations, only three samples gave significant results for cesium-137, out of the 53 analyses performed. These values were still close to the decision thresholds of the instruments used, and could be attributed to past fallout from the Chernobyl accident in 1986.

The low activity of bound tritium observed was close to values that can be observed customarily in areas not affected by discharge from nuclear facilities.

*Table V.57 - Mean activity measured in grass samples collected in the immediate vicinity of the waste disposal facilities and the railroad terminal (Bq/kg dry)**

Radionuclide	La Ville-aux-Bois Monitoring of the CSFMA site at Soulaines	Soulaines-Dhuys Monitoring of the CSFMA site at Soulaines Sampling on site		Brienne-le-Château Monitoring of the railroad terminal	
^{40}K	760 ± 70	269 ± 18	228 ± 21	126 ± 23	258 ± 18
^{137}Cs**	< 1.3	< 1.1	1.14 ± 0.16	< 0.9	1.05 ± 0.14
^{134}Cs**	< 1	< 0.9	< 0.9	< 0.8	< 0.9
^{60}Co	< 1.4	< 1.2	< 1.2	< 1.1	< 1.2
OBT	2.3 ± 1.2	3.3 ± 1.3	nm	nm	3.5 ± 1.1
^{14}C (Bq/kg C)	280 ± 90	260 ± 100	nm	nm	200 ± 30

** Unless otherwise indicated*
*** Excluding values attributable to the Fukushima accident*
nm: not measured

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Figure V.144 - Oven drying of a grass sample

The carbon-14 activity measured corresponded to the activity levels normally observed away from any nuclear facility.

Some samples collected on April 6, 2011 showed traces of cesium-134 and -137. The activity ratio of the cesium isotopes measured in grass samples, close to 1, was representative of the atmospheric fallout related to the accident at the Fukushima nuclear plant.

For more information
Chapter III – Fukushima accident

Soil

Analysis of annual soil samples collected at the low- and intermediate-level waste disposal facility did not detect any radiological anomaly related to the CSFMA site (*Table V.58*). The cesium-137 measured can be attributed to past fallout from the Chernobyl accident. Measured uranium-234 and -238 activity levels were compatible with the naturally occurring isotopes.

Table V.58 - Mean activity measured in soil samples collected at the CSFMA waste disposal facility (Bq/kg dry)

	Soulaines-Dhuys Monitoring of the CSFMA site at Soulaines	
Radionuclide	Sampling on site	
^{40}K	330 ± 50	410 ± 60
^{137}Cs	6.3 ± 0.9	3.9 ± 0.6
^{134}Cs	< 0.35	< 0.6
^{60}Co	< 0.42	< 0.5
^{241}Am	< 1.3	< 0.8
^{238}Pu	< 1.4	< 0.9
^{239}Pu	< 2.4	< 1.2
^{240}Pu	< 3	< 1.5
^{234}U	6.6 ± 0.9	6.2 ± 0.9
^{238}U	6.5 ± 0.9	7.3 ± 1

Farm produce and foodstuffs

Milk

The radioactivity measured in cow's milk samples collected every three months from farms located in La Ville-aux-Bois and Longeville-sur-la-Laines was mainly due to naturally occurring potassium-40, with a mean activity concentration of 53.7 ± 2.1 Bq/L.

No artificial radionuclide activity could be measured above the decision thresholds associated with the measurement techniques used.

Cereals

No radiological anomaly was observed in wheat and maize samples collected in La Ville-aux-Bois (*Table V.59*).

The low levels of tritium (free and bound) observed conform to the background level measured in France.

The carbon-14 activity was close, allowing for uncertainty, to the background (about 235 Bq/kg carbon).

*Table V.59 - Activity measured in cereals harvested in La Ville-aux-Bois in 2010 (Bq/kg dry)**

Radionuclide	Wheat	Maize
^{40}K	160 ± 50	111 ± 16
^{137}Cs	< 0.7	< 0.08
^{134}Cs	< 0.6	< 0.08
^{60}Co	< 0.7	< 0.1
HTO (Bq/kg wet)	nm	0.6 ± 0.6
OBT	2.4 ± 1.3	2.2 ± 1.1
^{14}C (Bq/kg C)	200 ± 80	260 ± 70

** Unless otherwise indicated*
nm: not measured

Mushrooms

The results of radiological analyses performed on the mushroom sample collected in La Ville-aux-Bois did not show any anomaly due to the operations on the ANDRA sites (*Table V.60*). They corresponded to the values normally observed in France away from the influence of any nuclear facility.

*Table V.60 - Activity measured in mushrooms collected in La Ville-aux-Bois (Bq/kg wet)**

Radionuclide	Activity
^{40}K	97 ± 17
^{137}Cs	0.54 ± 0.1
^{134}Cs	< 0.041
^{60}Co	< 0.06
HTO	< 2.5
OBT	0.06 ± 0.06
^{14}C (Bq/kg C)	270 ± 90

** Unless otherwise indicated*

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Figure V.145 - Collection of a milk sample

Continental aquatic compartment

Surface water

Water collected at the CSFMA disposal facility is subject to checks before it is channeled to a specific outlet. A storm water basin collects all the rainwater of the site. After checking, this water is discharged into the Les Noues d'Amance stream. The sampling frequency is weekly for the point located in the stream immediately downstream of the site, and monthly at the other points located upstream or further downstream. The results of the gross alpha, gross beta and tritium measurements taken on this water showed no impact due to the operations of the site. Only traces of naturally occurring uranium-234 and -238 were observed occasionally in the samples collected in La Ville-aux-Bois.

Ground water

The environmental monitoring of the water of these sites also covers the ground water. The geological environment below and downstream of the CSFMA consists of a layer of sand containing the unconfined ground water and a clay layer about 25 meters thick protecting the deeper ground water aquifers.

The radiological monitoring of the ground water at these facilities is accomplished using more than 30 piezometers installed on and near the sites, in Soulaines-Dhuys, La Ville-aux-Bois, Épothémont, Morvilliers, La Chaise and Brienne-le-Château. The sampling frequency is either monthly (for the samples collected near the disposal structures), or three-monthly for samples collected further away and consequently less exposed to any ground water contamination from operations on the sites.

The tritium measurements were below the decision thresholds of the instruments used. Only twelve spot measurements of gross alpha activity gave activity levels between 0.15 and 0.33 Bq/L in Morvilliers, and between 0.12 and 0.14 Bq/L in Soulaines, above the reference value recommended by the French public health code for water intended for human consumption (0.1 Bq/L).

Overall, examination of the gross alpha, gross beta and tritium measurements did not show any radiological anomaly linked with the industrial operations on these sites.

Aquatic fauna

No artificial radionuclide activity was detected in the fish sample caught in La Ville-aux-Bois (*Table V.61*).

Table V.61 - Activity measured in fish caught in La Ville-aux-Bois (Bq/kgwet)

Radionuclide	Activity
^{40}K	18 ± 6
^{137}Cs	< 0.027
^{134}Cs	< 0.023
^{60}Co	< 0.033
^{241}Am	< 0.0036
^{238}Pu	< 0.0042
^{239}Pu	< 0.01
^{240}Pu	< 0.015
^{234}U	< 0.008
^{238}U	< 0.008

Continental aquatic flora

In 2010, no artificial radionuclide activity attributable to operations at the ANDRA waste disposal facilities was detected in the aquatic renunculus samples collected monthly from the Les Noues d'Amance stream (*Table V.62*).

The detection of cesium-137 (main source: Chernobyl accident) and isotopes -234 and -238 (naturally occurring) of uranium in November 2010 was probably related to resuspension of ground dust.

Table V.62 - Activity measured in aquatic renunculus samples collected in the Noues d'Amance stream (Bq/kg dry)

Radionuclide	June 2010	November 2010
^{40}K	630 ± 120	500 ± 140
^{137}Cs	< 0.45	1.13 ± 0.45
^{134}Cs	< 0.4	< 0.41
^{60}Co	< 0.6	< 0.5
^{241}Am	< 0.15	< 0.32
^{238}Pu	< 0.18	nm
^{239}Pu	< 0.22	< 0.33
^{240}Pu	< 0.29	< 0.38
^{234}U	< 0.6	3.9 ± 1.6
^{238}U	< 0.48	4 ± 1.2

nm: not measured

Sediments

Sediment samples are collected regularly at four sampling stations near the CSFMA and CFTFA disposal facilities: in a small pond located between the CSTFA storm water basin and the Loriguette brook, in the Saint Victor brook, in the Noues d'Amance stream, and in the Voire river (monthly, three-monthly, or six-monthly sampling). Samples are also collected from two ditches near the railroad terminal at Brienne-le-Château (*Table V.63*).

Cesium-137 was measured in all the sediment samples: it can be attributed to past fallout from atmospheric nuclear weapons testing and from the Chernobyl accident.

The samples contained similar activites of uranium isotopes 234 and 238, between 4.46 ± 0.34 and 8.2 ± 0.9 Bq/kg dry, compatible with naturally occurring uranium.

Four significant cesium-134 values, attributable to fallout in France from the Fukushima accident, were measured in April and May 2011 in sediment samples collected in Morvilliers, Soulaines-Dhuys, and La Ville-aux-Bois, at low specific activity levels between 1.1 ± 0.37 and 1.6 ± 0.6 Bq/kg dry.

Analysis of sediment samples collected from a ditch close to the railroad terminal at Brienne-le-Château revealed artificial cobalt-60, related to present or past operations at the terminal (one significant value of 2.2 ± 0.7 Bq/kg dry, out of the three measurements taken).

Other artificial radionucleides investigated were not detected by the measuring instruments used.

Table V.63 - Mean activity levels measured in sediment samples collected near the CSFMA and STFA waste disposal facilities and the railroad terminal (Bq/kg dry)

Radionuclide	Morvilliers Monitoring of the CSTFA facility Small pond located between the CSFTA storm water basin and the Loriguette brook	Soulaines-Dhuys Saint Victor brook	La Ville-aux-Bois Les Noues d'Amance stream	Rosnay-l'Hôpital Voire river	Brienne-le-Château Monitoring of the railroad terminal Sampling in ditches, in the immediate vicinity of the terminal	
^{40}K	nm	168 ± 17	310 ± 17	348 ± 32	367 ± 34	255 ± 41
^{137}Cs	0.31 ± 0.07	1.99 ± 0.24	0.81 ± 0.09	4.64 ± 0.46	5.1 ± 0.6	4.2 ± 0.8
^{134}Cs*	nm	< 0.38	< 0.38	< 0.47	< 0.5	< 0.46
^{60}Co	< 0.1	< 0.5	< 0.5	< 0.6	0.84 ± 0.23	< 0.6
^{241}Am	nm	< 0.9	< 0.9	< 1.6	< 1	< 1.1
^{238}Pu	< 0.019	< 1.2	< 0.6	< 1.3	< 1	< 1.1
^{239}Pu	nm	< 1.7	< 1.3	< 2.1	< 1.5	< 0.9
^{240}Pu	nm	< 2.2	< 1.8	< 2.9	< 2.2	< 1.1
^{234}U	8 ± 1.1	8.2 ± 0.9	5.38 ± 0.39	7.4 ± 0.7	nm	nm
^{238}U	6.5 ± 0.8	7.5 ± 0.9	4.46 ± 0.34	6.8 ± 0.6	nm	nm

** Excluding values measured occasionally in April and May 2011 attributable to the Fukushima accident*
nm: not measured

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Figure V.146 - The Tricastin nuclear power plant

VI

MONITORING OF RESEARCH CENTERS AND NUCLEAR NAVAL BASES

The results shown in this chapter concern the environmental monitoring conducted on the research centers and nuclear naval bases whose locations are shown in Figure VI.1 below.

Figure VI.1 – Geographical location of the research centers and nuclear naval bases.

VI.1 CEA NUCLEAR RESEARCH CENTERS AND THE INSTITUT LAUE-LANGEVIN (ILL) INTERNATIONAL RESEARCH CENTER

The monitoring set up around the research centers is suited to the different potential sources of radiological exposure present on these sites (as a single center may contain several types of nuclear installations) and the environmental characteristics of each of these sites. For this reason, the monitoring programs (frequency, sample matrices and radionuclide analysis) and the associated results differ from one site to another.

This chapter presents the radiological monitoring results for the Cadarache, Saclay, Bruyères-le-Châtel, Marcoule and Valduc CEA centers as well as for Fontenay-aux-Roses, whose nuclear activities are greatly reduced. As ILL has been responsible for the environmental monitoring of both its own sites and the Grenoble CEA center since 2010, the results are presented in a single chapter.

The Codolet Centraco facility's measurements are jointly analyzed with those of the adjoining Marcoule CEA center.

Cadarache CEA center

The Cadarache CEA center, which was built in October 1959 in the Bouches-du-Rhône department in southern France, is located in Saint-Paul-Lez-Durance 40 kilometers north of Aix-en-Provence. This center's activities are structured around several R&D technological platforms mainly relating to nuclear energy but also to new energy technologies (biomass and hydrogen), as well as to studies on the effects of radiation on plants (plant ecophysiology and microbiology).

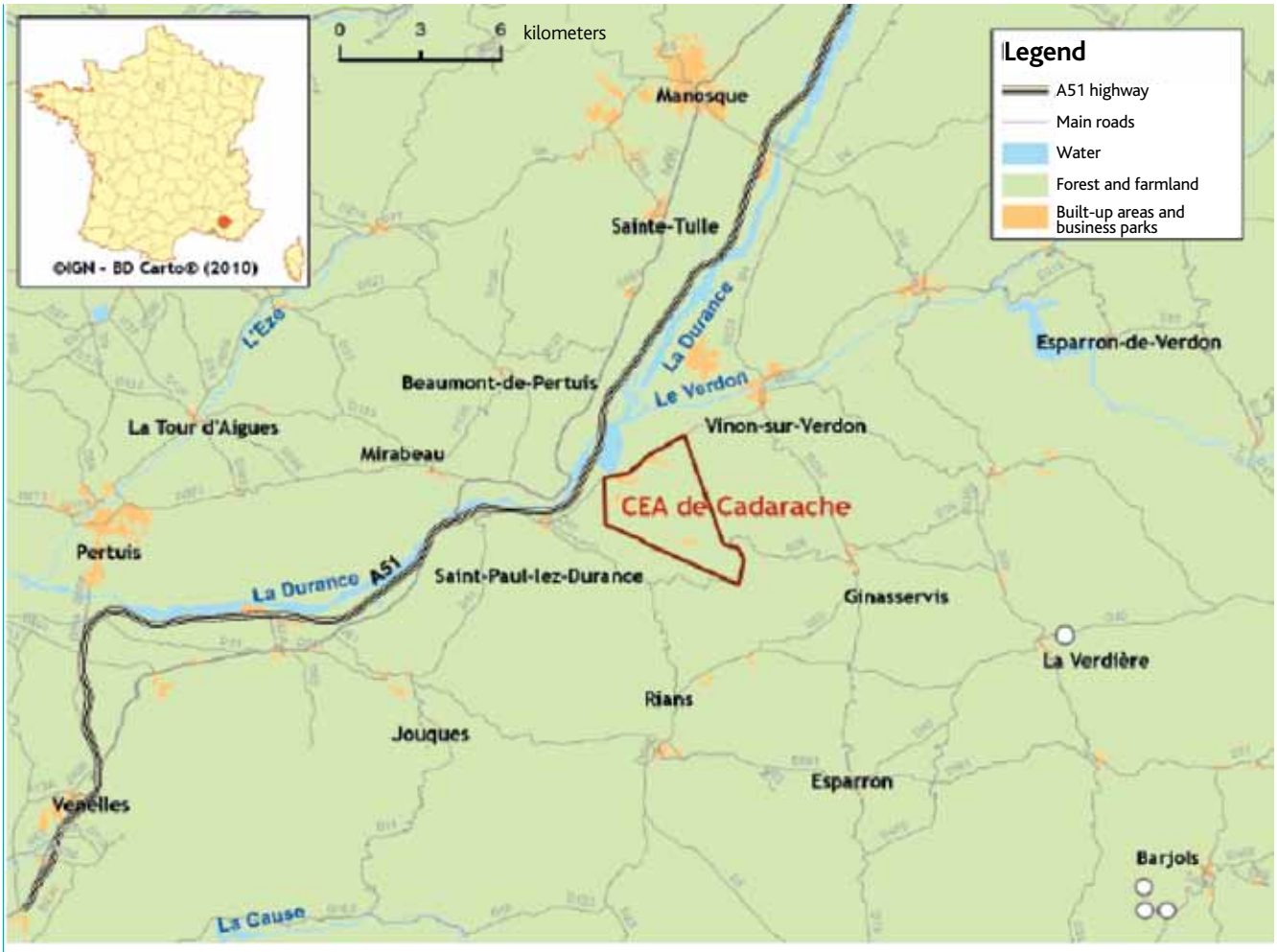

Figure VI.2 – Geographical location of Cadarache CEA center.

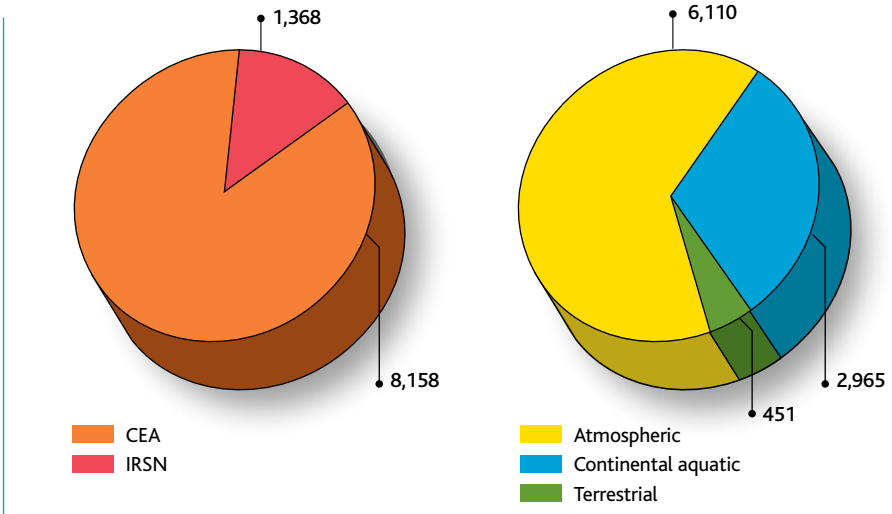

Figure VI.3 – Cadarache CEA center: sample distribution by data producer and by compartment.

Atmospheric compartment

Atmospheric aerosols

The monitoring of beta and alpha activity indices (*Figures VI.4 and VI.5*) has not revealed any abnormal values related to the Cadarache center's activities. No artificial gamma-emitting radionuclide activity above the decision thresholds of the measurement protocols used could be measured.

In the Cadarache CEA site's environment, some significant cesium-134, cesium-137 and iodine-131 activity levels were observed between the end of March and the beginning of May 2011 (*Table VI.1*). These findings can be attributed to air masses contaminated by the Fukushima nuclear power plant accident passing over France. An increase in the gross beta activity was also observed during this period (*Figure VI.4*). This is due to the presence of artificial radionuclides linked with the Fukushima accident.

For more information

Chapter III – The Fukushima Accident

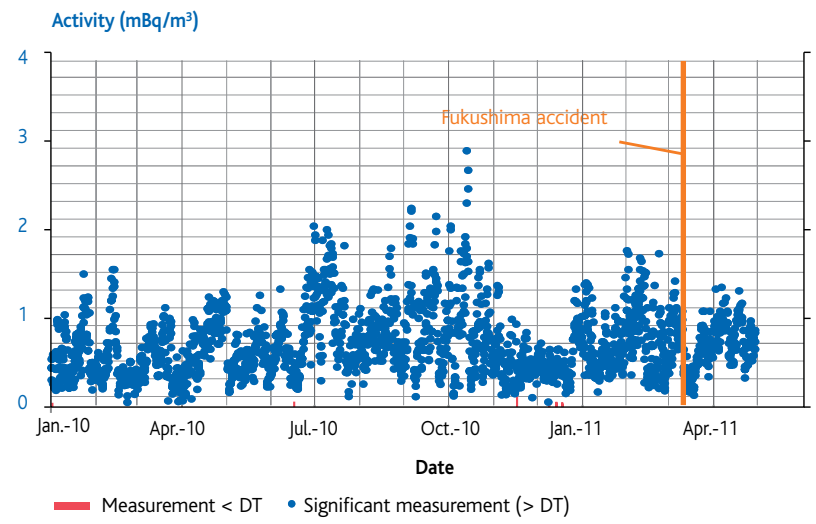

Figure VI.4 *– Gross beta activity of aerosols near the Cadarache CEA center (mBq/m³).*

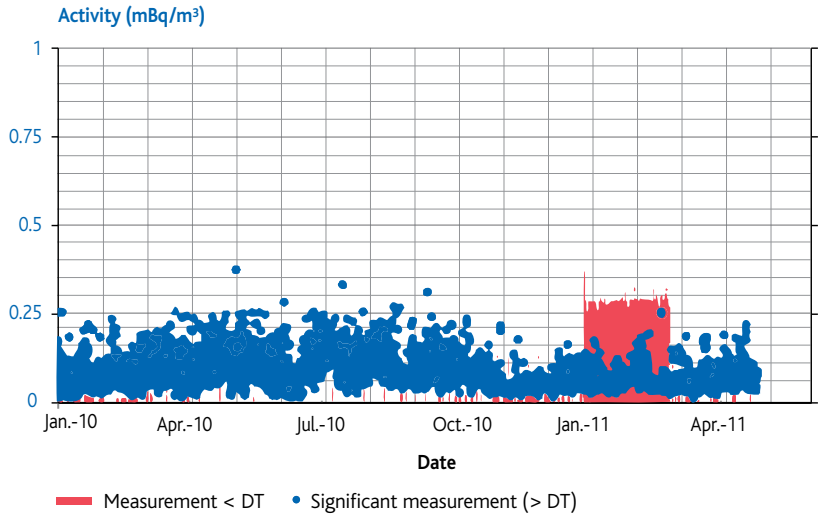

Figure VI.5 *– Gross alpha activity of aerosols near the Cadarache CEA center (mBq/m³).*

Table VI.1 *– Activities in aerosol samples taken in the Cadarache CEA center's environment (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Gross activity	Alpha activity	0.032 ± 0.001
	Beta activity	0.32 ± 0.01 0.68 ± 0.02*
Artificial radionuclides	Cesium-134	0.032 ± 0.008*
	Cesium-137	0.036 ± 0.008*
	Iodine-131	0.13 ± 0.02*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

Gases sampled by bubblers

Atmospheric tritium and carbon-14 are collected using bubblers. The activities measured for these two radionuclides are rarely above the decision thresholds (their respective mean activities are 0.18 Bq/m³ for tritium – see *Figure VI.6* – and 0.06 Bq/m³ for carbon-14).

Other gases (iodine-131)

The monitoring of gaseous iodine-131 activity revealed the presence of this radionuclide during the Fukushima nuclear power plant accident (*Table VI.2*). Except during this period, no significant activity was measured because there is very little of this radionuclide in the discharge from the center's installations.

***Table VI.2** – Gaseous iodine-131 activity measured in the ambient air near the Cadarache CEA center (mBq/m³).*

Radionuclide type	Radionuclide	*Mean activity or decision threshold (mBq/m³)*
Radionuclide in gaseous form – of artificial origin	Iodine-131	< 2.9 0.14 ± 0.04 *

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

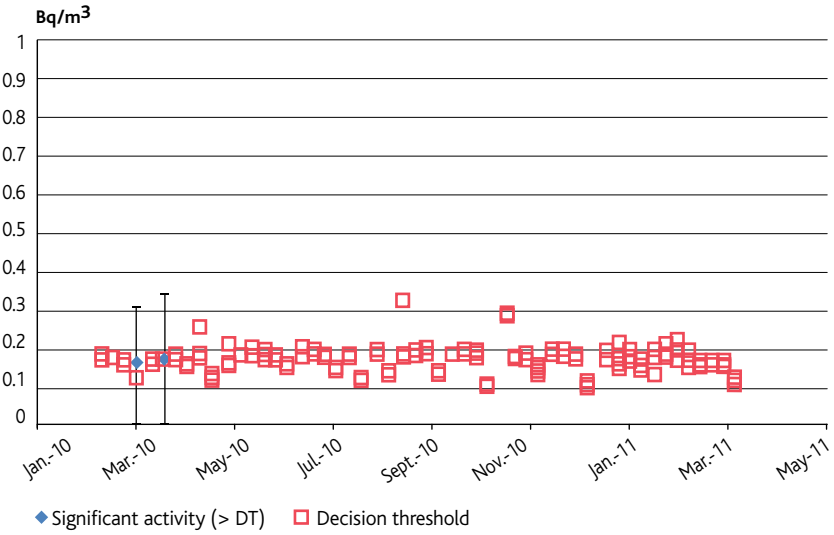

***Figure VI.6** – Atmospheric tritium activity near the Cadarache CEA center (Bq/m³).*

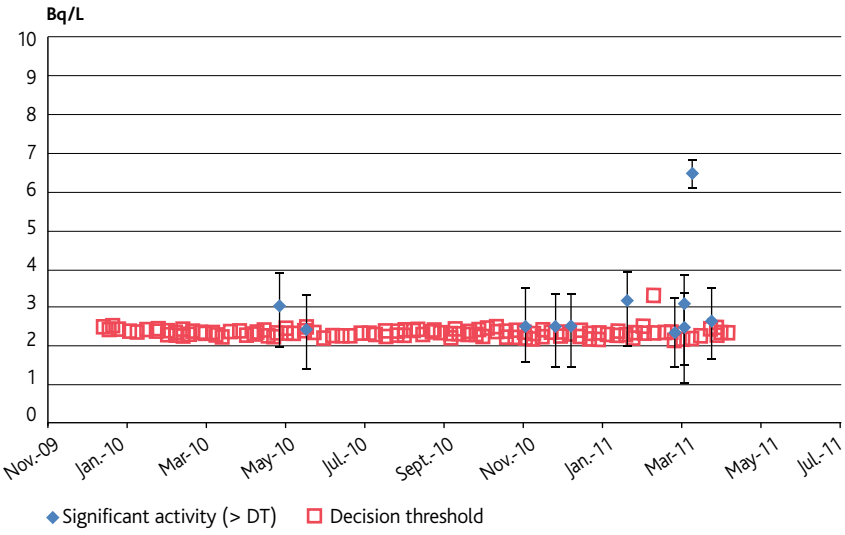

***Figure VI.7** – Tritium activity measured in rainwater near the Cadarache CEA site (Bq/L).*

Rainwater

The measured tritium activities in the rainwater samples taken near the site vary between the decision thresholds (in 95% of cases) and 6.5 Bq/L between 2009 and mid-2011 (*Figure VI.7*). As the site discharges little tritium, the tritium levels observed in the environment are very low and usually unquantifiable.

Terrestrial compartment

The terrestrial monitoring of the Cadarache CEA center is based on the regular sampling and analysis of milk and agricultural plants and cereals produced in areas potentially influenced by the facilities' discharge, within a 20 km radius of the site.

Agricultural production and foodstuffs

Milk

Monthly or quarterly goat's and cow's milk samples are taken at three farms in the municipalities of Gréoux-les-Bains, Meyrargues and Jouques around the Cadarache center. The measured radioactivity is mainly due to natural potassium-40, whose mean activity concentration is 49.6 ± 2.8 Bq/L in cow's milk and 61 ± 2.2 Bq/L in goat's milk.

Normally, artificial gamma-emitting radionuclides (^{134}Cs, ^{137}Cs and ^{131}I), like free tritium, are not detected by routine monitoring methods. Traces of iodine-131 were, however, detected in the goat's milk sample taken on April 8, 2011 in Gréoux-les-Bains (0.55 ± 0.3 Bq/L); this was due to long-range atmospheric fallout caused by the damaged Fukushima nuclear plant.

For more information
Chapter III – The Fukushima Accident

Cereals

No gamma-emitting radionuclides likely to be released by the Cadarache CEA center's facilities have been detected in the wheat samples taken in the area around this site. Only natural potassium-40 is measured, with a mean specific activity of 137 ± 29 Bq/kg dry.

Leafy vegetables and aromatic plants

Analysis of monthly or annual samples of thyme, chives and spinach grown near the Cadarache center has not revealed any anomalies (*Table VI.3*). Cesium-137 is regularly measured in the thyme samples, probably as a result of fallout from the Chernobyl accident. The traces of strontium-90 measured in the spinach samples taken in Vinon-sur-Verdon can be attributed to past atmospheric fallout from nuclear weapons testing.

Following the nuclear disaster at the Fukushima-Daiichi power plant in Japan on March 11, 2011, traces of iodine-131 were detected in the four thyme samples taken on April 3, 2011. Their measured activities are between 0.36 ± 0.26 and 0.99 ± 0.43 Bq/kg wet. Similarly, low cesium-134 activities were also detected in the thyme sample taken on April 3, 2011 in Ginasservis (a specific activity of 0.26 ± 0.13 Bq/kg wet).

For more information
Chapter III – The Fukushima Accident

Table VI.3 – Mean activity levels measured in the vegetable and aromatic herb samples taken around Cadarache CEA center (Bq/kg wet).

Radionuclide	Saint-Paul-lez-Durance			Ginasservis	Vinon-sur-Verdon	
	300 m south of the site (under the prevailing winds)	3.8 km southeast of the site (under the prevailing winds)	1.7 km northeast of the site (out of the prevailing winds)	7.6 km southeast of the site (under the prevailing winds)	5.5 km northeast of the site (out of the prevailing winds)	
	Thyme	Thyme	Thyme	Thyme	Chives	Spinach
^{40}K	229 ± 7	233 ± 8	202 ± 6	201 ± 6	35 ± 10	185 ± 23
^{137}Cs	0.24 ± 0.03	0.24 ± 0.03	0.22 ± 0.03	0.20 ± 0.03	< 0.12	< 0.06
^{134}Cs*	< 0.16	< 0.15	< 0.14	< 0.14	< 0.1	< 0.05
^{210}Pb	37.4 ± 3.3	54 ± 5	33.8 ± 3.3	61 ± 5	nm	nm
^{90}Sr	nm	nm	nm	nm	nm	0.08 ± 0.015
HTO	nm	nm	nm	nm	nm	< 8

** Excluding a significant value measured following the Fukushima accident nm: not measured*

Continental aquatic compartment

Surface water

The Cadarache CEA center is the only nuclear site on the banks of the Durance river. The discharge is monitored downstream of the site by means of automatic sampling at the Mirabeau bridge. The tritium activity measured at this point ceased to be quantifiable at the beginning of the '90s, as the levels have been below 5 Bq/L since then (*Figure VI.8*).

Sediments

In 2010, three sediment samples were taken in the Durance river, 400 meters downstream of the Cadarache site's liquid waste discharge point.

Of the three artificial gamma-emitting radionuclides being monitored, only traces of cesium-137 were detected. The annual mean value in 2010 for this radionuclide (1.07 ± 0.17 Bq/kg dry) is similar to the levels observed in previous years. Given the low levels of cesium-137 discharged in the Cadarache site's liquid waste (< 10 Bq/L in the waste before it enters the river), the presence of this radionuclide in the sediments is mainly due to residue from atmospheric fallout (nuclear weapons testing in the atmosphere, and fallout from the Chernobyl accident). The other radionuclides' measurement results were all below the decision threshold (*Table VI.4*).

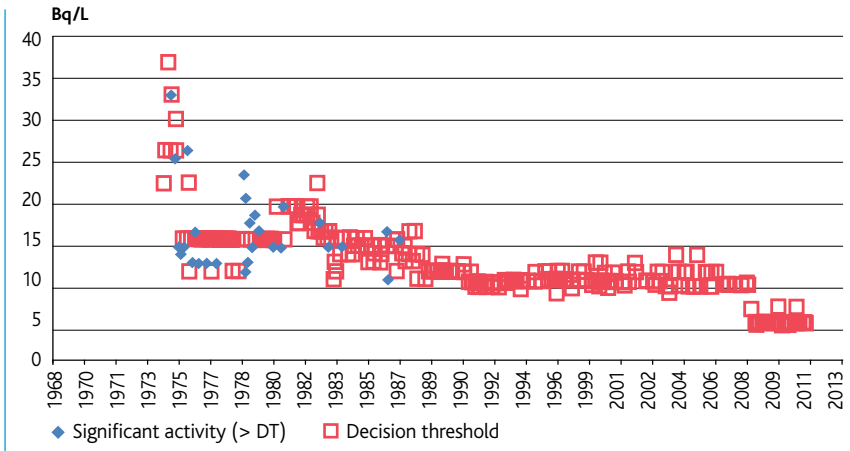

Figure VI.8 – Tritium activity in Durance river water downstream of the Cadarache CEA site (Bq/L).

Table VI.4 – Mean activity levels measured in Durance river sediment samples taken 400 meters from the Cadarache CEA center's discharge point (Bq/ kg dry).

Radionuclide	Activity
^{40}K	253 ± 20
^{137}Cs	1.07 ± 0.17
Other gamma-emitting radionuclides (^{110m}Ag, ^{124}Sb, ^{125}Sb, ^{134}Cs, ^{58}Co, ^{60}Co, ^{131}I, ^{54}Mn, ^{106}Ru)	< 6
^{241}Am	0.16 ± 0.05
^{238}Pu	< 0.05
$^{239+240}$Pu	< 0.05

Ground water

Other spot sampling points exist, notably a piezometer network for monitoring ground water activity levels. The site is located on two aquifers, the upper consisting of Miocene and Quaternary detrital formations while the lower consists of karstic limestone. The ground water finally enters the Durance river via its tributaries.

A slight total alpha concentration (0.11 Bq/L) is observed in the piezometer "CHAU02" located near the Magenta facility on the site (*Figure VI.9*). This piezometer already detected natural gross alpha activity values slightly above the decision threshold before this facility entered into operation.

The tritium measurements vary between the decision thresholds and 50 Bq/L at the "SD5" point (*Figure VI.10*). This point also detected gross beta activity, with levels fluctuating between 3 and 71 Bq/L from 2009 to mid-2011 (*Figure VI.11*). This layer's historic concentration level has no impact outside the site.

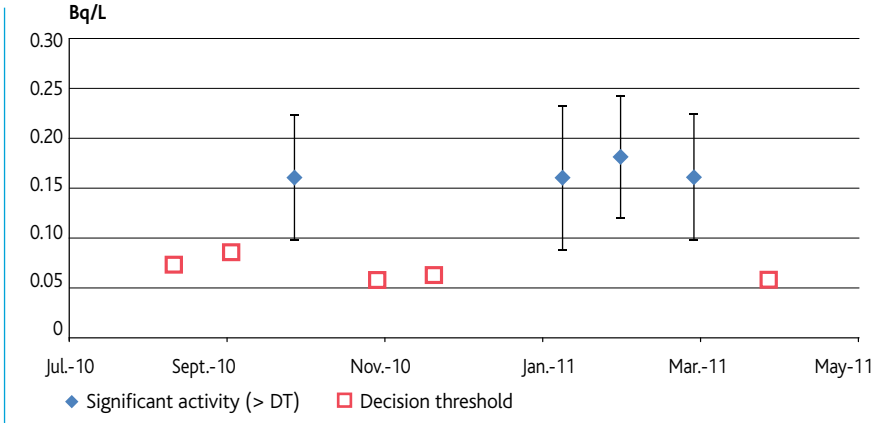

Figure VI.9 – Gross alpha activity measured in ground water at piezometer "CHAU02" (Bq/L).

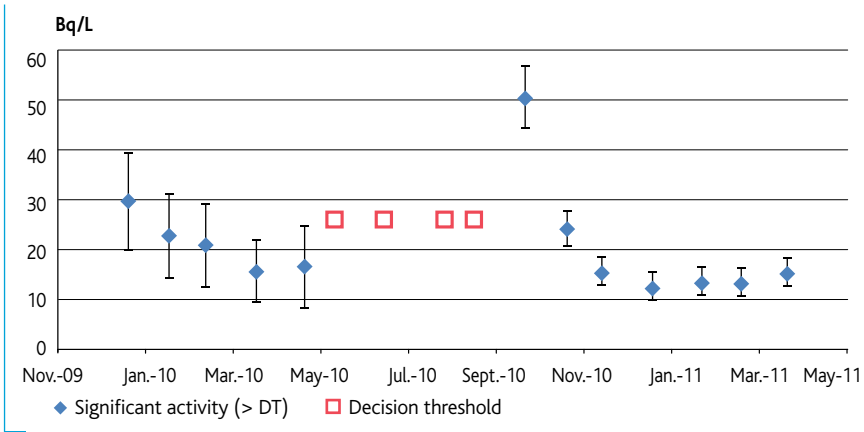

Figure VI.10 – Tritium activity measured in ground water at piezometer "SD5" (Bq/L).

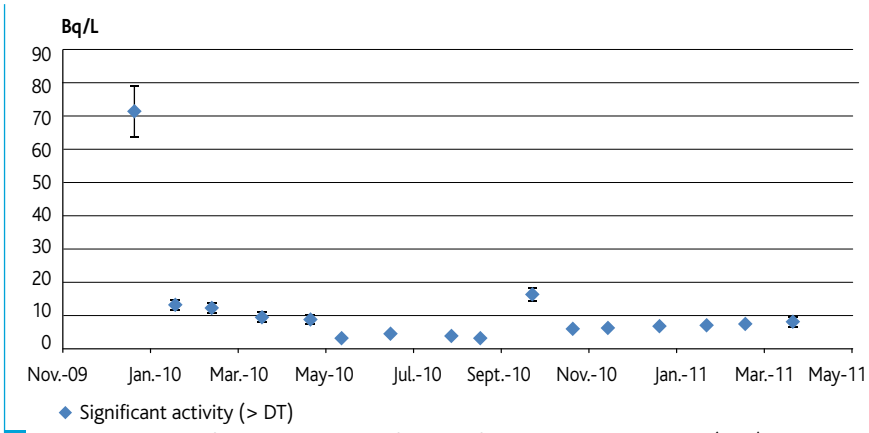

Figure VI.11 – Gross beta activity measured in ground water at piezometer "SD5" (Bq/L).

Bruyères-le-Châtel CEA center

The Bruyères-le-Châtel CEA center, which was created in 1955 in the Paris region, conducted the first metallurgical studies of the nuclear materials used in weapons.

Today, this center is a research facility where work is grouped into different areas of expertise (simulating and modeling the operation of nuclear weapons, assisting in the monitoring of disused French firing ranges, supporting international organizations in checking compliance with the Nuclear Test Ban Treaty, and managing nuclear facility construction, clean-up and decommissioning projects).

All of the site's military activities were transferred to the Valduc center in 1996.

Since 1997, clean-up operations conducted during nuclear facility decommissioning have continued to produce tritium releases in the gaseous waste, although their annual activity levels are gradually decreasing (from more than 100 TBq released in 2005 to less than 50 TBq in 2009).

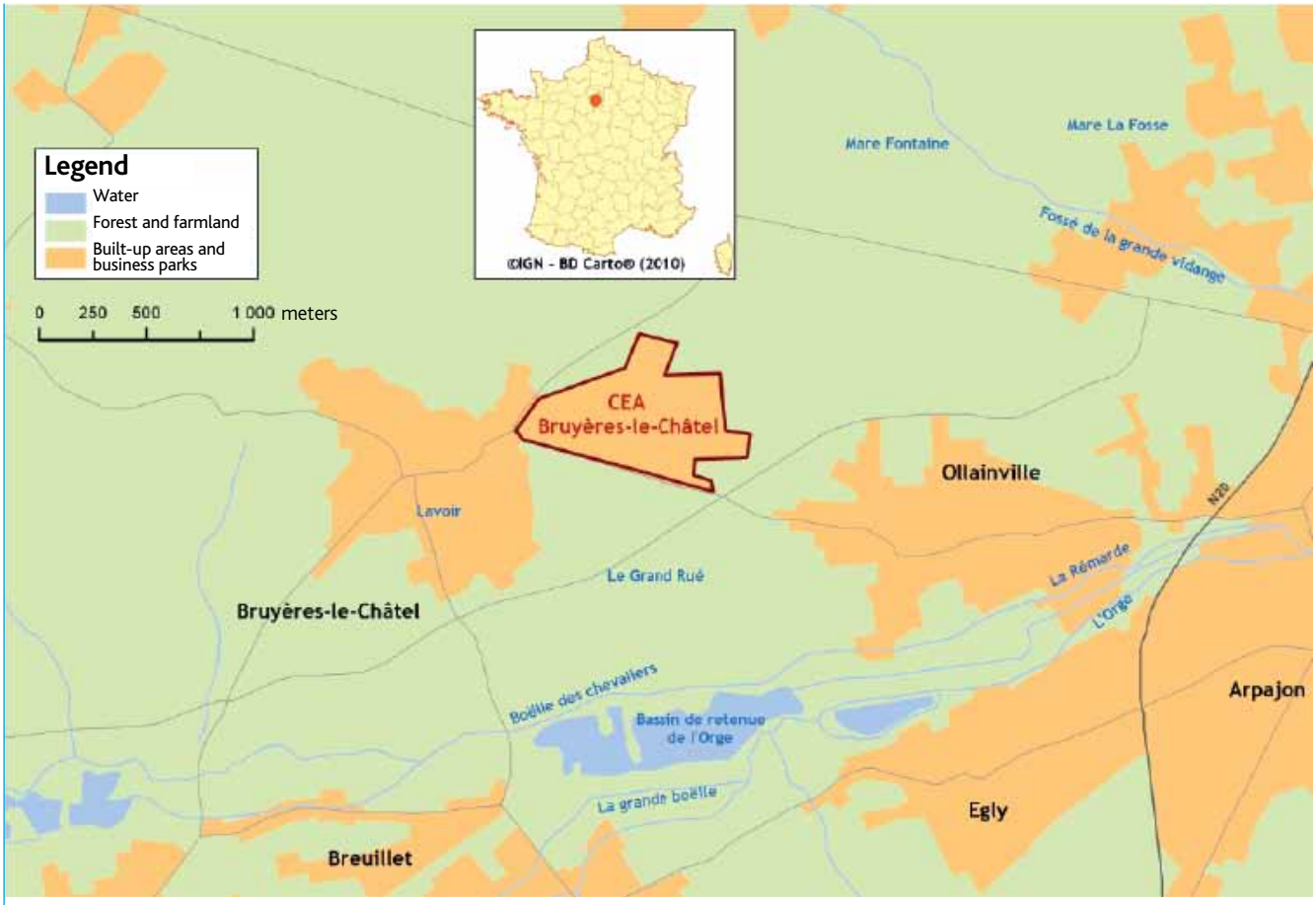

Figure VI.12 – Geographical location of Bruyères-le-Châtel CEA center.

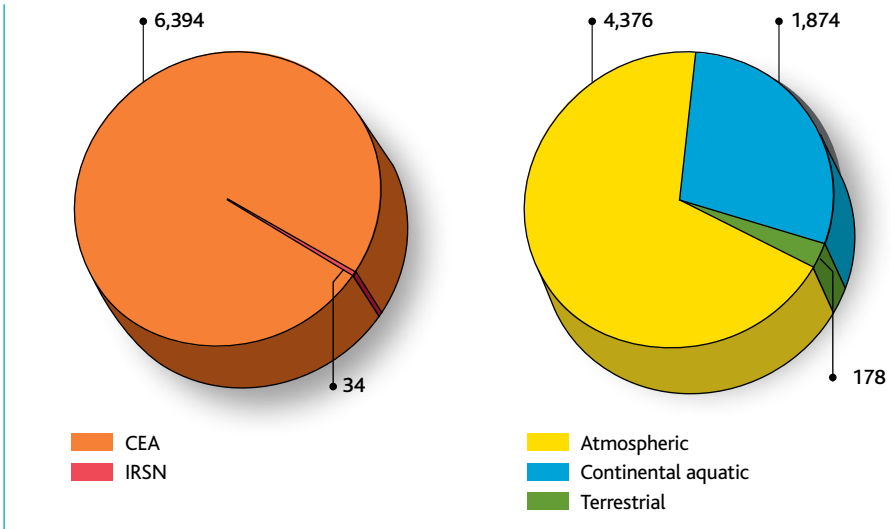

Figure VI.13 – Bruyères-le-Châtel CEA center: sample distribution by data producer and by compartment.

Atmospheric compartment

Atmospheric aerosols

Apart from the readings taken during the period of the Fukushima accident, no other abnormal alpha activity index values (*Figure VI.15*) and beta activity index values (*Figure VI.14*) or artificial radionuclides have been detected.

In the Bruyères-le-Châtel site's environment, the monitoring of atmospheric aerosols revealed an increase in gross beta activity between the end of March and the end of April 2011 (*Table VI.5 and Figure VI.14*), which can be attributed to the presence of artificial radionuclides released in the Fukushima nuclear power plant accident.

For more information

Chapter III – The Fukushima Accident

Table VI.5 – Alpha and beta activity indices of the Bruyères-le-Châtel CEA center's environmental aerosols (mBq/m³).

Radionuclide type	Radionu-clide	Mean activity (mBq/m³)
Gross activity	Alpha activity	0.024 ± 0.001
	Beta activity	0.25 ± 0.01 0.47 ± 0.01*

** Measurements taken during the period of the Fukushima nuclear power plant accident.*

Rainwater

Rainwater is drained at the site's four cardinal points. The activity levels of the water samples taken there vary depending on the gaseous releases and the wind direction. Only the tritium activity levels measured in the water in the drain at the site's east side exceed 5 Bq/L, with maximum values of nearly 30 Bq/L in 2010 reflecting the site's activities (*Figure VI.16*).

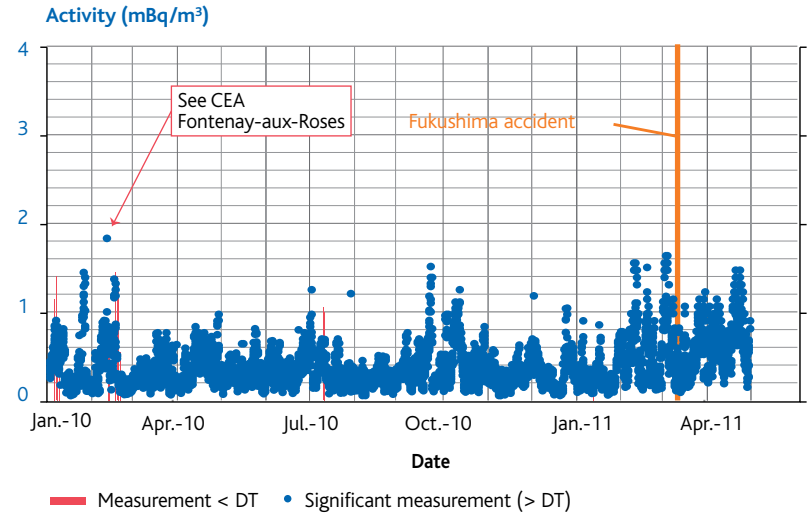

Figure VI.14 – Time plot of the gross beta activity of aerosols near the Bruyères-le-Châtel, Saclay and Fontenay-aux-Roses CEA centers (mBq/m³).

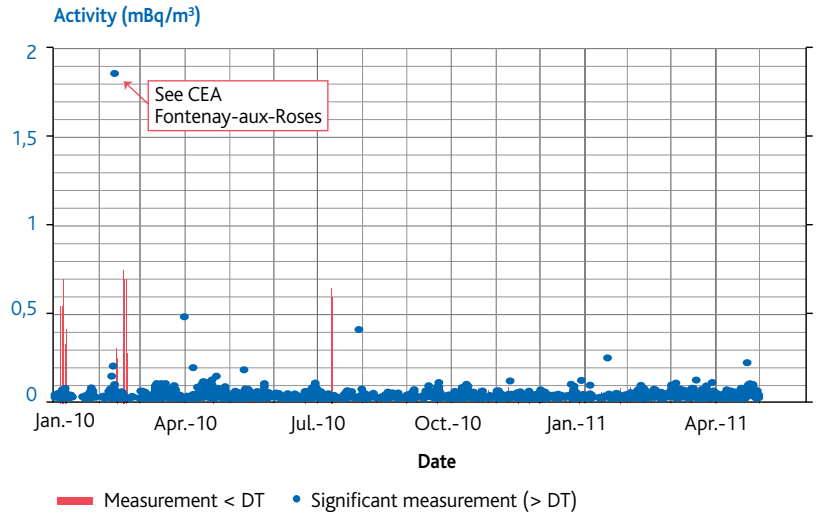

Figure VI.15 – Time plot of the gross alpha activity of aerosols near the Bruyères-le-Châtel, Saclay and Fontenay-aux-Roses CEA centers (mBq/m³).

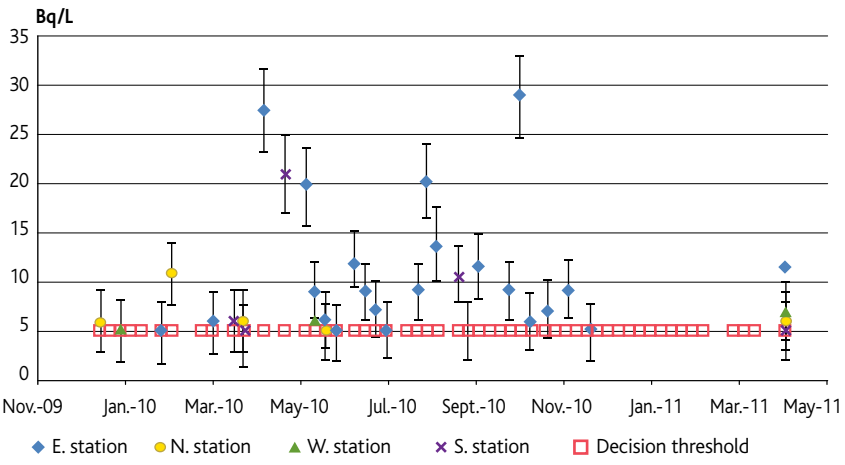

Figure VI.16 – Tritium activity in rainwater near the Bruyères-le-Châtel CEA site (Bq/L).

Terrestrial compartment

The area surrounding the Bruyères-le-Châtel CEA center is monitored by means of monthly grass and milk samples. The site's monitoring also includes the analysis of vegetable samples.

Terrestrial flora

Tritium is occasionally measured in the grass samples taken within a 1.7 km radius of the Bruyères-le-Châtel CEA center. The significant free tritium values, which vary between 3.2 ± 1.9 and 6.7 ± 2.1 Bq/kg wet, are close to the decision thresholds and show little added environmental concentraion by the Bruyères-le-Châtel center's environmental discharge (*Table VI.6*).

Agricultural production and foodstuffs

Milk

The radioactivity measured in the cow's milk samples taken each month at farms in Saint-Sulpice-de-Favières and Cheptainville is mainly due to natural potassium-40, whose mean activity concentration is 35.6 ± 0.6 Bq/L. Between January 2010 and the end of May 2011, the milk from Cheptainville occasionally contained traces of tritium (10 ± 4 Bq/L in September 2010 and 3.6 ± 1.9 Bq/L in March 2011). These activities should be viewed in relation to the concentration level in grass due to the site's discharge.

Leafy vegetables

The OBT specific activity measured in the carrot samples taken in Saint-Yon in 2010 was 0.123 ± 0.006 Bq/kg wet. This is close to the value that is naturally found in the environment.

Continental aquatic compartment

The Bruyères-le-Châtel CEA center is located in the basin of the Orge river, which flows into the left side of the Seine at a rate of nearly 5 m^3/s.

Surface water

The cesium-134, cesium-137, cobalt-60, selenium-75 and strontium-90 levels in the surface water samples taken near the Bruyères-le-Châtel CEA center are too low to be measured. The mean total alpha concentration at a surface water source near the side of the Orge river's retaining basin is 0.07 Bq/L, which is slightly higher than at the other sampling points (0.04 Bq/L) (*Figure VI.17*). This concentration level is mainly due to naturally occurring radionuclides.

The gross alpha activity in the water of the pond named "Mare 6" west of the Orge river's retaining basin is approximately 1 Bq/L. Added concentrations were detected only at this sampling point. In the other ponds, this activity varies between 0.05 Bq/L and 0.1 Bq/L (*Figure VI.18*).

The presence of alpha-emitting radionuclides in pond "Mare 6", whose activity concentration is higher than that of the other ponds, is of natural origin (natural uranium decay chain products are present). This pond is located in an agricultural environment (the ^{238}U content is increased through the use of fertilizers).

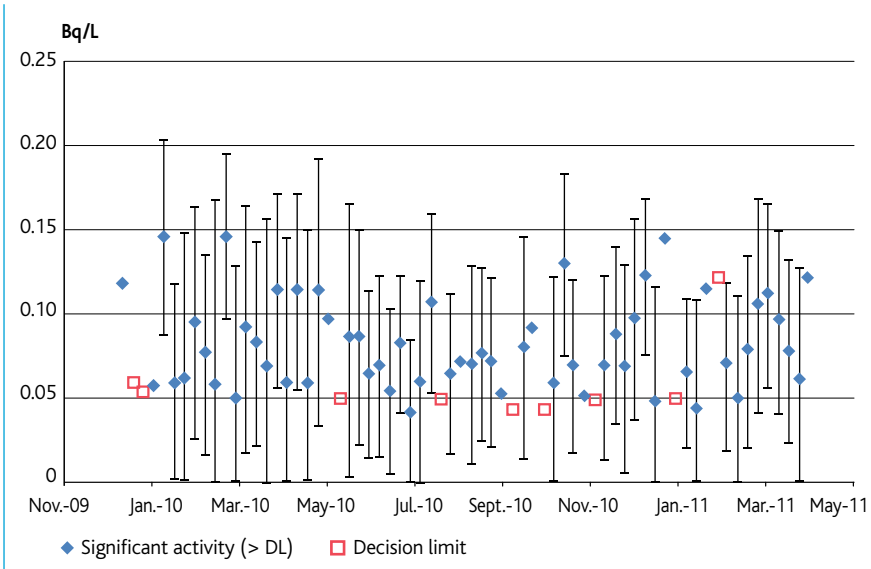

Figure VI.17 – Gross alpha activity in surface water samples taken near the Orge river's retention basin (Bq/L).

Table VI.6 – Mean tritium activity levels measured in grass samples taken around Bruyères-le-Châtel CEA center.

Sampling location	Number of significant results/total number of HTO measurements	HTO (Bq/kg wet)	OBT (Bq/kg dry)
Bruyères-le-Châtel West of the site	0/17	< 3.2	nm
Bruyères-le-Châtel Southwest of the site	2/17	3.2 ± 0.39	nm
Ollainville Southeast of the site	3/17	3.33 ± 0.41	nm
Ollainville Northeast of the site	5/17	3.41 ± 0.41	2.34 ± 0.12

nm: not measured

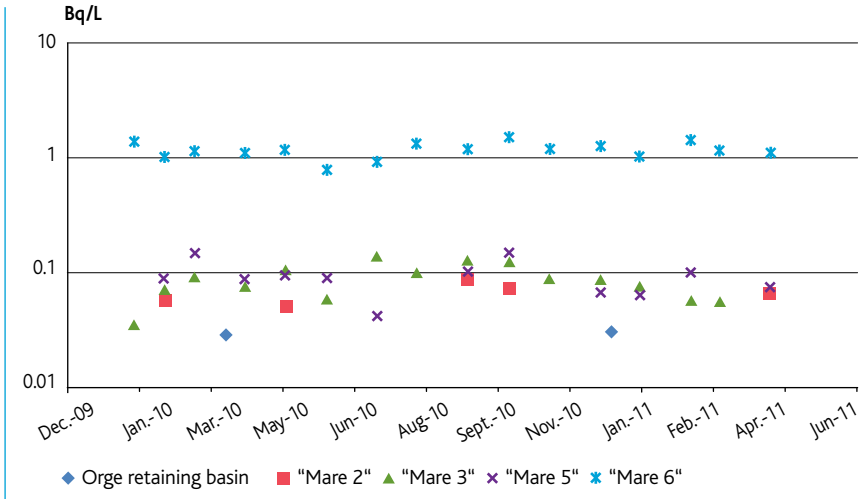

Figure VI.18 – Gross alpha activity in water samples taken in the ponds near the Bruyères-le-Châtel CEA center (Bq/L).

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Figure VI.19 – Taking a water sample in the Fontaine pond near Bruyères-le-Châtel CEA center.

Sediments

In 2008, IRSN conducted an exploratory environmental sampling campaign near this center in order to measure the radioactivity levels of the river and lake sediments. Two sampling points were chosen to provide the site's routine monitoring, one in the Rémarde river and other in the Grand Rué stream, both of which flow into the Orge river. The presence of transuranium radionuclides such as plutonium-239+340 and americium-241 can be attributed to past liquid waste discharge (*Table VI.7*). As in 2008 and 2009, the uranium-234 and uranium-238 isotope ratios measured in 2010, the values of which were approximately 1, show the natural presence of uranium.

Table VI.7 – Activities measured in the sediment samples taken in 2010 near the Bruyères-le-Châtel site (Bq/kg dry).

Radionuclide	Le Grand Rué stream	La Rémarde
^{137}Cs	1.02 ± 0.28	2.6 ± 1
Other gamma-emitting radionuclides (^{124}Sb, ^{125}Sb, ^{134}Cs, ^{54}Mn, ^{58}Co, ^{60}Co, ^{106}Ru)	< 4.6	< 6
^{241}Am	0.59 ± 0.16	0.16 ± 0.08
^{238}Pu	< 0.08	nm
$^{239+240}$Pu	3.2 ± 0.5	nm
^{234}U	15.3 ± 3.2	12.9 ± 1.2
^{235}U	0.84 ± 0.18	0.68 ± 0.16
^{238}U	16.3 ± 3.3	13.1 ± 1.2
^{234}U/^{238}U activity ratio	0.941	0.980

nm: not measured

Fontenay-aux-Roses CEA center

The Fontenay-aux-Roses CEA center, which is located in the Paris region and was the first CEA center, was built on the premises of the historical Châtillon fort in 1946. For nearly ten years, all French nuclear research and development activities, including the first French atomic pile ("Zoé"), were conducted at this site in Fontenay-aux-Roses.

After orienting the site's activities towards plutonium and transuranium chemistry, radiation and the examination of fuels, radiation metallurgy and controlled fusion, CEA ceased all its nuclear research activities at Fontenay in 1995. The center's research now concentrates on public health matters of great socioeconomical importance in the radiobiology and toxicology, neurovirology and prion diseases, robotics and virtual reality fields.

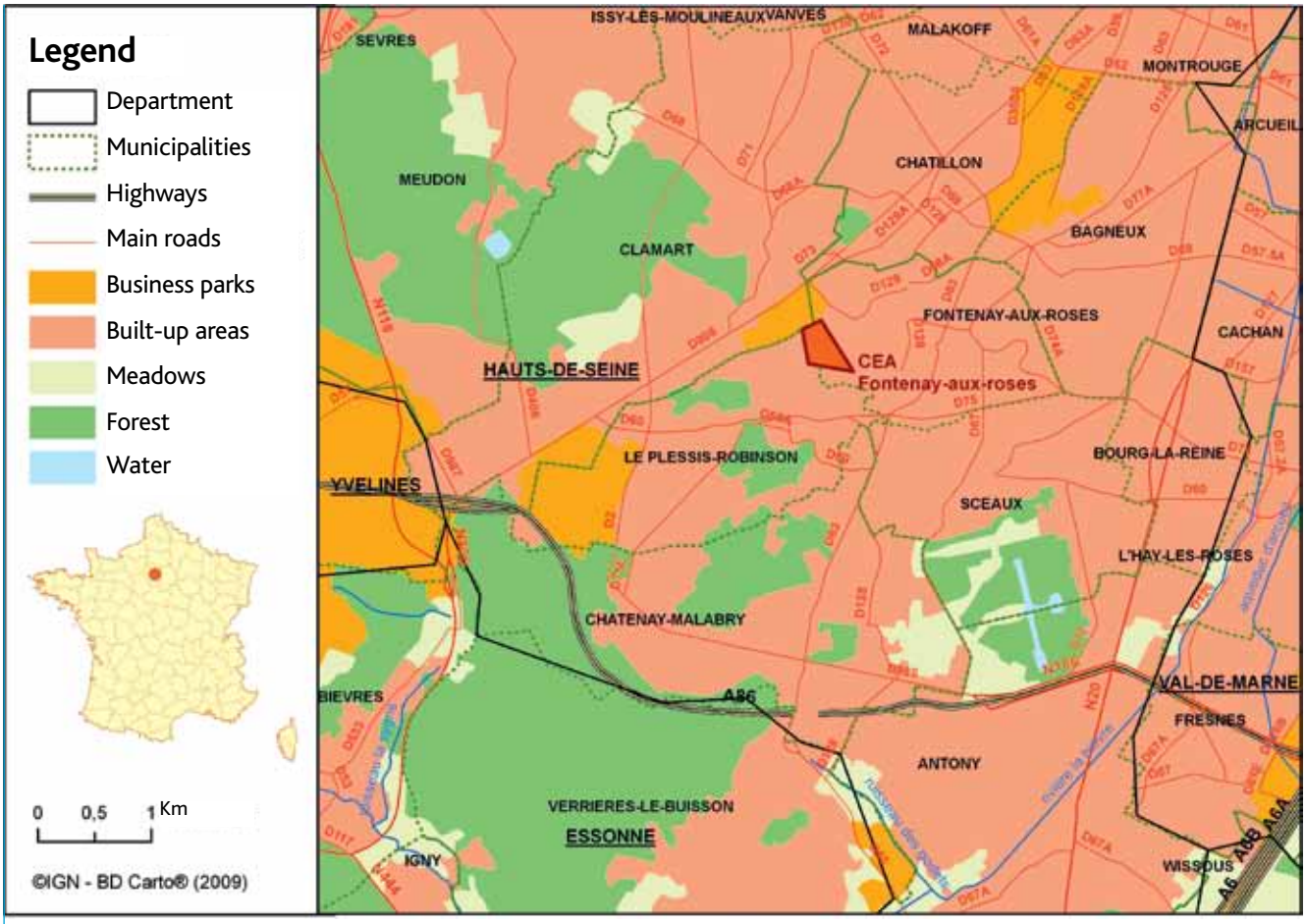

Figure VI.20 – Geographical location of Fontenay-aux-Roses CEA center.

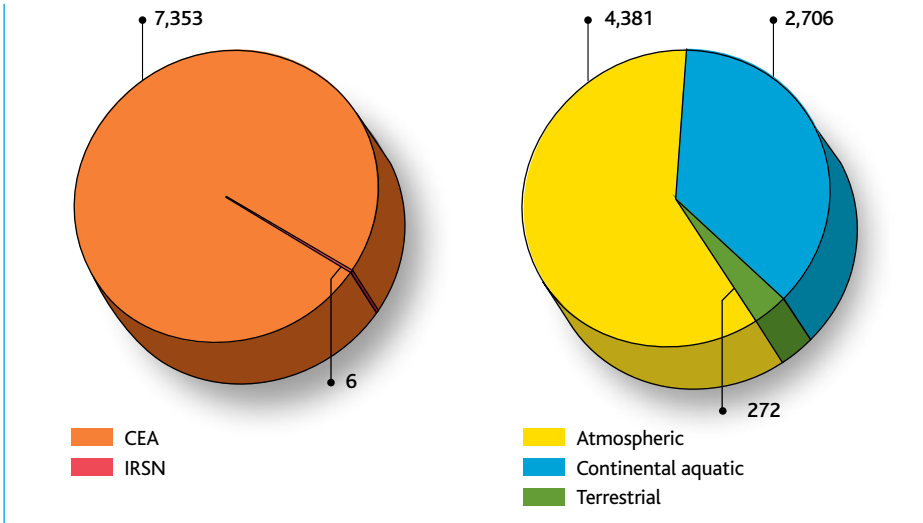

Figure VI.21 – Fontenay-aux-Roses CEA center: sample distribution by data producer and by compartment.

Atmospheric compartment

Atmospheric aerosols

The monitoring of atmospheric aerosols in the Fontenay-aux-Roses CEA site's environment by checking gross alpha and gross beta activity (*Figures VI.14 and VI.15*) revealed unusually high levels in a sample taken in Fontenay-aux-Roses on February 11–12, 2010 (its beta activity index was 1.8 ± 0.9 mBq/m³, and its alpha activity index was 1.9 ± 0.9 mBq/m³). Further investigations concluded that these unusually high activities were not due to artificial radionuclides.

Apart from this finding and the readings taken during the period of the Fukushima accident, no other abnormal alpha activity and beta activity index values or artificial radionuclides have been detected in the environment.

An increase in the gross beta activity between the end of March and the end of April 2011 was also observed, however (*Table VI.8*). This can be attributed to the presence of artificial radionuclides released at the time of the Fukushima nuclear power plant accident.

Gases sampled by bubblers

The mean activity of atmospheric tritium, which was sampled using bubblers, was approximately 0.3 Bq/m³ in 2010 (*Figure VI.23*). Tritium oxide (HTO) activity increased slightly in the first half of 2011 (between 0.6 and 0.8 Bq/m³). Until January 2011, only the first bubbler tank's measurement was used to calculate atmospheric tritium activity. Following an inspection in December 2010, however, the French Nuclear Safety Authority (ASN) asked CEA to also use the second sparge tank so that the two tanks' activities could be added together. This explains the increased activity values from January 2011 onwards.

Table VI.8 – *Alpha and beta activity indices of aerosols in the Fontenay-aux-Roses CEA center's environment (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Gross activity	Alpha activity	0.025 ± 0.001
	Beta activity	0.29 ± 0.01 0.57 ± 0.01*

** Measurements taken during the period of the Fukushima nuclear power plant accident from March 22 to May 6, 2011.*

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Figure VI.22 – *Daily retrieval and conditioning of the aerosol filter.*

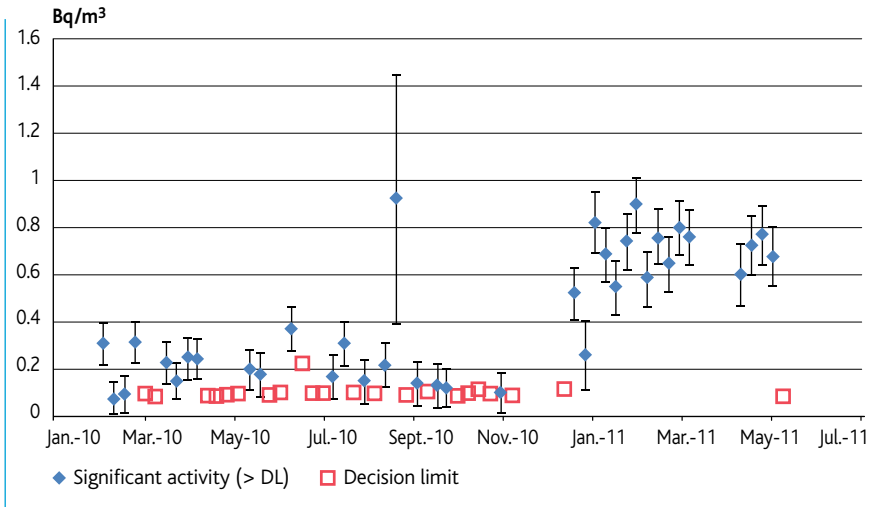

Figure VI.23 – *Atmospheric tritium (HTO) activity measured near the Fontenay-aux-Roses CEA center (Bq/m³).*

Other gases

The monitoring of gaseous iodine-131 activity revealed the presence of this radionuclide during the period of the Fukushima nuclear power plant accident (*Table VI.9*).

For more information

Chapter III – The Fukushima Accident

Except during this period, no significant activity has been measured, as the discharge from the Fontenay-aux Roses center's facilities contain little or no iodine-131.

Rainwater

A total alpha activity of 1.17 Bq/L was detected in rainwater samples taken in Bagneux in June 2010 (*Figure VI.24*). This activity is linked with a fire near the environmental monitoring station, causing considerable diffusion of solid particles in the air; these particles then settled in the rainwater drain due to gravity and air column leaching. The supplementary measurements, which CEA took using spectrometry, indicate natural radioactivity levels similar to those found in the sludge.

Terrestrial compartment

The area surrounding the Bruyères-le-Châtel CEA center is monitored by means of monthly grass samples.

Terrestrial flora

Analysis of the monthly grass samples taken in Fontenay-aux-Roses, Bagneux and Clamart has not revealed any abnormal activity levels. Between January 2010 and the end of May 2011, only three samples had significant cesium-137 activities of between 1.2 ± 0.9 and 1.8 ± 1.1 Bq/kg wet.

Table VI.9 – Gaseous iodine-131 activity measured in the ambient air near the Fontenay-aux-Roses and Saclay CEA centers (mBq/m³).

Radionuclide type	Radionuclide	Mean activity or detection limit (mBq/m³)
Artificial gaseous radionuclide	Iodine-131	< 0.51 0.21 ± 0.026*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

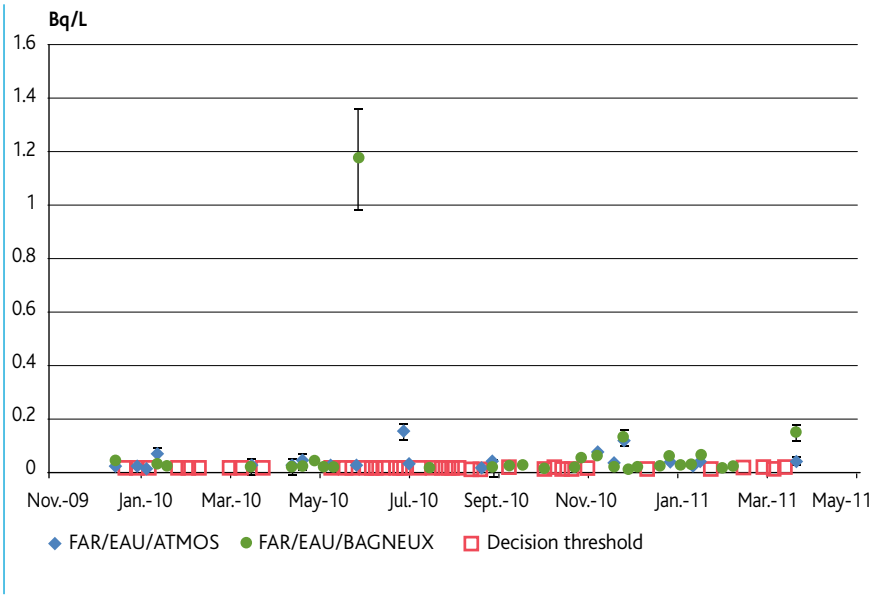

Figure VI.24 – Gross alpha activity in rainwater near the Fontenay-aux-Roses CEA site (Bq/L).

Continental aquatic compartment

Surface water

Surface water monitoring is conducted at the Colbert pool, which collects rainwater and is situated less than 2 km from the site. Analysis of radionuclides in its water has not revealed any abnormal total alpha concentration levels (0.06 Bq/L). No americium-241, cesium-134 or cesium-137 has been detected there. Tritium has been detected in 20% of the samples, at levels below 4 Bq/L.

Ground water

The Fontenay-aux-Roses CEA center is situated directly above ground water 65 meters below the site. This ground water emerges at two points: the Lavoir and Moulin fountains in Fontenay-aux-Roses, both of which are monitored as part of CEA's hydrological monitoring plan. The ground water's total alpha activity varies between 0.05 and 0.3 Bq/L depending on the sampling point (*Figure IV.25*).

The points with the highest tritium activities (*Figure VI.26*) differ from those with alpha-emitting radionuclide activities. The activity in the point named "Nappe G" (or Level G) has been increasing for a year, whereas that in the other points is residual. This short-term trend should, however, be put into perspective by comparing it with the historical chronicles, which show that these measurements are cyclical (*Table VI.10*). No other artificial radionuclides have been measured at this point.

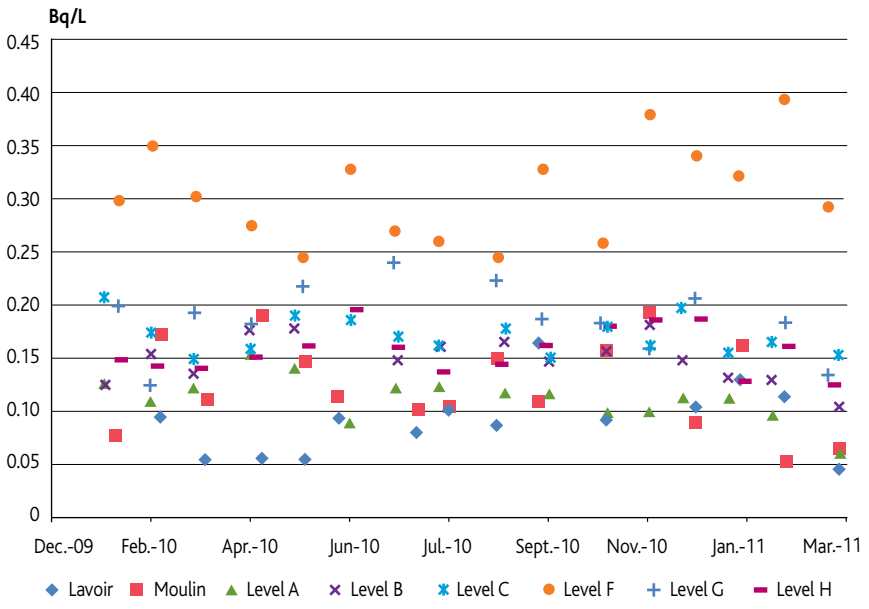

Figure VI.25 – Gross alpha activity in ground water near the Fontenay-aux-Roses CEA site (Bq/L).

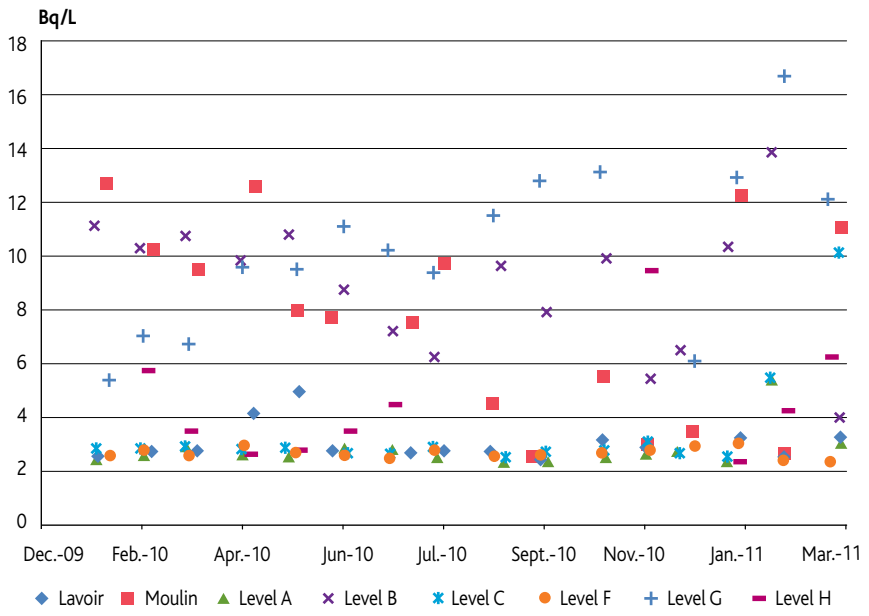

Figure VI.26 – Tritium activity in ground water near the Fontenay-aux-Roses CEA site (Bq/L).

Figure VI.27 – Tritium activity in ground water at sampling point "Nappe G" near the Fontenay-aux-Roses CEA site (Bq/L).

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Maximum ^{3}H activity (Bq/L)	9.1	12.4	15	13	18.3	16.8	6.5	8.7	12.8	16.7
Mean ^{3}H activity (Bq/L)	/	/	/	/	13.1	7.2	4.7	5.8	9.4	10.6
Standard deviation	/	/	/	/	2.92	3.54	1.18	1.34	2.61	3.33

Marcoule site

The Marcoule site in southern France is one of the country's largest nuclear sites and performs a wide range of activities, conducting scientific and technological studies that assist manufacturers in improving the performance of their existing fuel cycle plant processes. Its work is mainly concerned with the processing and recycling of nuclear fuels following their use in reactors, with the aim of optimizing the recycling of reusable energy materials, reducing the quantity of the final waste and ensuring the waste's safety. At the front end of the cycle, the Marcoule CEA center performs research to maintain the technical and economic competitiveness of French industry and reduce the environmental effects of these steps. The site consists of 18 facilities including reactors (Phénix), a fuel production plant (Melox) and a high-radioactivity radiochemistry research facility (Atalante). It formerly housed the first French electricity production generator (G1) as well as facilities that preceded those now forming part of the La Hague plant: the reprocessing plant (UP1), and the vitrification workshop (AVM). Most of these old facilities have now ceased operation and are currently being dismantled. Marcoule's 50 years of operation have also created nuclear waste, some of which is still awaiting safe disposal.

Figure VI.27 – Geographical location of the Marcoule CEA center.

Centraco, the French nuclear center for processing and conditioning radioactive waste, which is also located on the Marcoule site, is managed by SOCODEI, the French company for the conditioning of industrial waste and effluents. The Centraco plant processes metal and fuel waste with the aim of reducing its volume, recycling it whenever possible, and conditioning it in the ultimate waste forms accepted by ANDRA, the French National Radioactive Waste Management Agency. This site's monitoring measurement values are discussed with those of the Marcoule CEA center in this chapter.

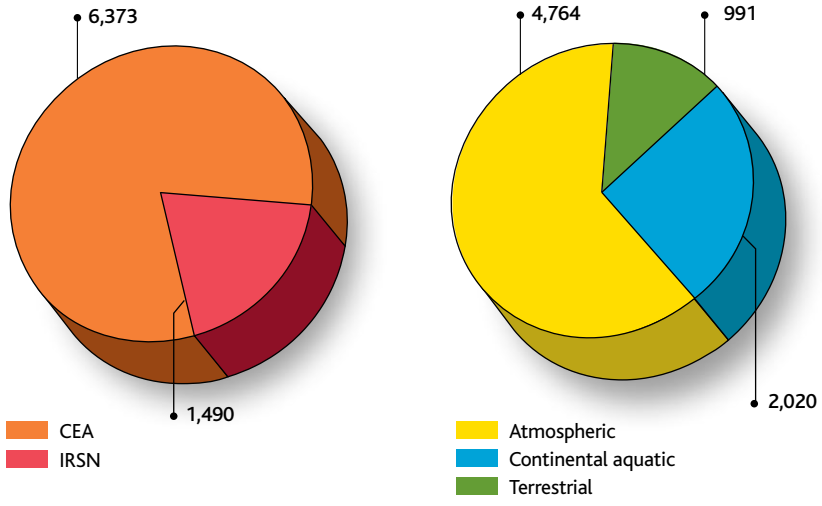

Figure VI.28 – Marcoule CEA center: sample distribution by data producer and by compartment.

Atmospheric compartment

Atmospheric aerosols

Except during the Fukushima accident period, no other abnormal gross alpha activity (*Figure VI.30*) and gross beta activity values have been observed. Only lead-210 and beryllium-7, both of which are natural radionuclides, are regularly measured.

In the Marcoule site's environment, an increase in the beta activity index measured in the aerosols was observed between the end of March and the end of April 2011 (*Table VI.11* and *Figure VI.29*). This increase is mainly due to the presence of artificial radionuclides linked with the Fukushima nuclear power plant accident's atmospheric fallout over France.

For more information

Chapter III – The Fukushima Accident

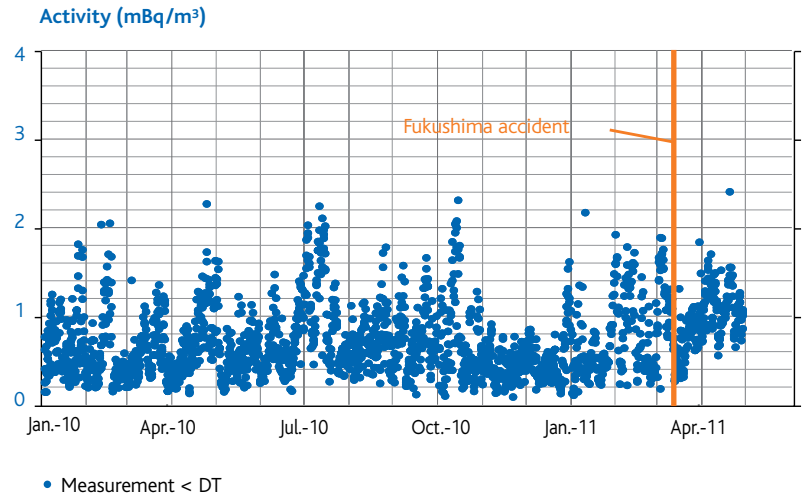

Figure VI.29 *– Time plot of the gross beta activity of the aerosols near the Marcoule site (mBq/m³).*

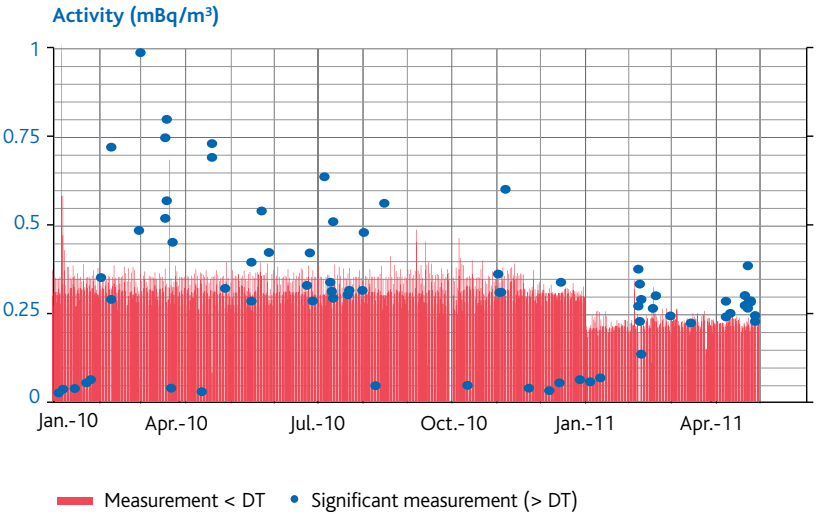

Figure VI.30 *– Time plot of the total alpha activity index of the aerosols near the Marcoule site (mBq/m³).*

Table VI.11 *– Activities in the atmospheric aerosol samples taken in the Marcoule site's environment (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Total activity indices	Alpha activity	0.13 ± 0.01
	Beta activity	0.49 ± 0.01 0.96 ± 0.02*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

Gases sampled by bubblers

Significant quantities of atmospheric tritium have been measured at the Codolet monitoring station south of the site and at Saint-Étienne-des-Sorts north of the site. The influence of the prevailing winds, which mainly blow southwards, can be seen in Figure VI.31. The activity concentration of the atmospheric tritium is generally higher and usually significant in Codolet (south of the site) than in Saint-Étienne-des-Sorts (north of the site).

Other gases

Gaseous iodine-129 is monitored by means of air cartridge sampling. It has not revealed any significant activity levels (*Table VI.12*).

Rainwater

Analysis of the rainwater samples taken at the Codolet monitoring station south of the Marcoule site has revealed the continued presence of atmospheric tritium, confirming the measurements obtained using the bubblers. Figure VI.32 shows the variability of the tritium concentrations measured in 2010 at this station. This variability depends on the level of the discharge from the site's facilities and the wind direction.

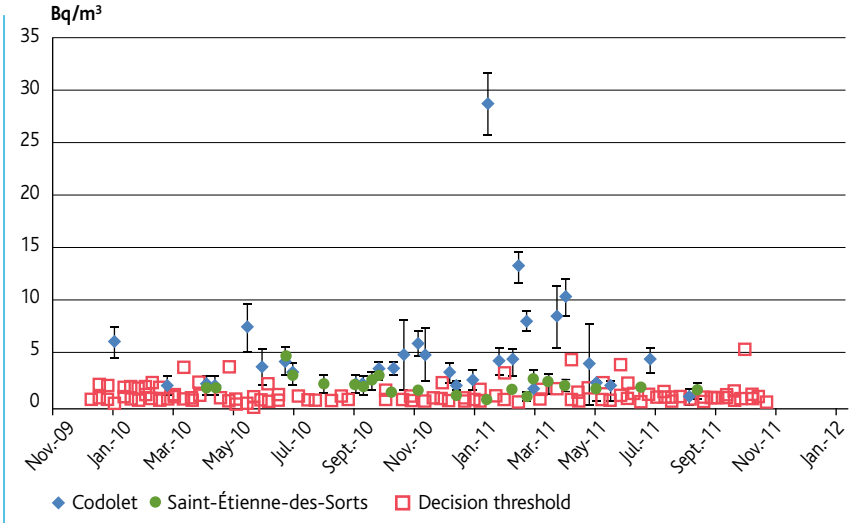

***Figure VI.31** – Atmospheric tritium activity measured near the Marcoule site (Bq/m³).*

***Table VI.12** – Gaseous iodine-129 activity measured in the ambient air near the Marcoule site (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity or detection limit (mBq/m³)
Artificial gaseous radionuclide	Iodine-129	< 0.32

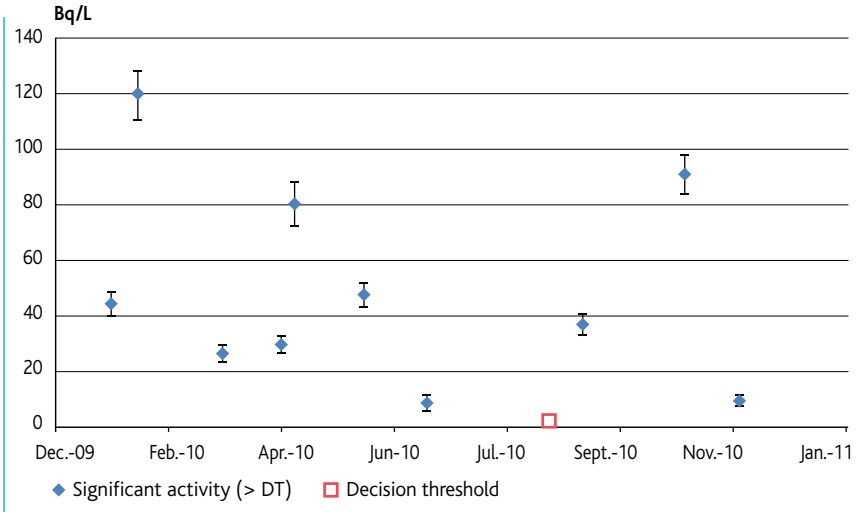

***Figure VI.32** – Tritium activity in the rainwater samples taken near the Marcoule site (Bq/L).*

Terrestrial compartment

The Marcoule nuclear site's monitoring includes regular sampling of terrestrial plants (grass, vegetables and fruit), milk, cereals and wine in zones potentially influenced by the facilities' discharge, within a 20 km radius of the CEA center.

Terrestrial flora

Monthly grass samples are taken at ten sampling points around the Marcoule site, seven of which are within 300 meters of its boundary. This monitoring is supplemented by two twice-yearly samples taken in Codolet and Saint-Étienne-des-Sorts. The main results are shown in Table VI.13.

Low cesium-137 activities are occasionally measured at five sampling points directly under the main and secondary prevailing winds. These are between 0.8 ± 0.7 Bq/kg dry and 3.6 ± 1.3 Bq/kg dry. The two strontium-90 analyses conducted in 2010 revealed the presence of this radionuclide in the grass samples taken north and south of the site; their activities were similar to those observed throughout France as a result of past atmospheric fallout from nuclear weapons testing.

Between January 2010 and the end of May 2011, very low plutonium-239 activity levels were occasionally detected at four sampling points under the main prevailing winds, in the immediate vicinity of the Marcoule site (one significant measurement for each of the sampling points for the entire period). These activities, which were between 0.007 ± 0.006 Bq/kg dry and 0.077 ± 0.014 Bq/kg dry and were not to be found above a certain distance away from the site, are partly due both to past atmospheric fallout from nuclear weapons testing and to past waste from the Marcoule site's facilities. The other artificial alpha- and gamma-emitting radionuclides' activities are below the decision thresholds.

The free tritium activity levels measured in the grass samples are, however, considerably higher than the mean values recorded for France (generally below 3.6 Bq/kg wet). These activity levels can be attributed to the Marcoule site's atmospheric discharge, which contribute to this radionuclide's added environmental concentration. The stations most affected are those directly under the main prevailing winds south of the Marcoule site and the secondary prevailing winds north of the site, as Figure VI.33 shows.

It should be noted that these activity levels vary greatly over time, depending on the activity level of discharge and the meteorological conditions when the sample is taken. As a result, the free tritium activity levels measured 200 m south of the Marcoule site vary between 76 ± 6 Bq/kg wet and 1,270 ± 60 Bq/kg wet for the period from January 2010 to May 2011 (*Table VI.14*).

***Table VI.13** – Mean activities measured in the grass samples taken around the Marcoule site (Bq/kg dry)*.*

Radionuclide	Codolet					Caderousse
	Southwest Site boundary	South – 200 m	South – 900 m	South – Southwest – 1.8 km	East – Site boundary	East – Southeast – 2.2 km
^{40}K	407 ± 20	248 ± 15	549 ± 22	422 ± 20	292 ± 15	376 ± 17
^{137}Cs	0.68 ± 0.08	0.77 ± 0.1	0.69 ± 0.08	< 0.7	0.6 ± 0.08	< 0.7
^{106}Ru	< 11	< 12	< 11	< 12	< 10	< 11
^{90}Sr	nm	nm	0.23 ± 0.05	nm	nm	nm
^{241}Am	nm	nm	< 0.0027	nm	nm	nm
^{238}Pu	< 0.0018	< 0.011	< 0.0038	< 0.0039	< 0.0035	< 0.0022
^{239}Pu	0.0058 ± 0.0014	0.0188 ± 0.004	0.011 ± 0.0042	< 0.009	< 0.012	< 0.008
HTO (Bq/kg wet)	10.4 ± 1.1	120.8 ± 4.6	30.7 ± 2.5	16.5 ± 1.8	17.8 ± 1.4	6.1 ± 1
OBT	nm	nm	135 ± 7	nm	nm	nm
^{14}C	nm	nm	173 ± 24	164 ± 22	nm	nm

Radionuclide	Chusclan				Saint-Étienne-des-Sorts
	Northeast Site boundary	North Site boundary	Northwest – 300 m	West Site boundary	North – 5.1 km
^{40}K	288 ± 14	229 ± 12	233 ± 12	211 ± 11	610 ± 60
^{137}Cs	< 0.7	0.61 ± 0.08	< 0.6	< 0.7	< 0.8
^{106}Ru	< 11	< 9	< 11	< 10	< 7
^{90}Sr	nm	nm	nm	nm	0.39 ± 0.06
^{241}Am	nm	nm	nm	nm	< 0.0045
^{238}Pu	< 0.0013	< 0.0024	< 0.0039	< 0.0036	< 0.0021
^{239}Pu	< 0.0048	< 0.006	0.006 ± 0.0016	< 0.0025	< 0.0021
HTO (Bq/kg wet)	37.1 ± 1.5	16 ± 1.1	41.2 ± 1.7	11.5 ± 0.9	< 1.5

** Unless specified otherwise*
nm: not measured

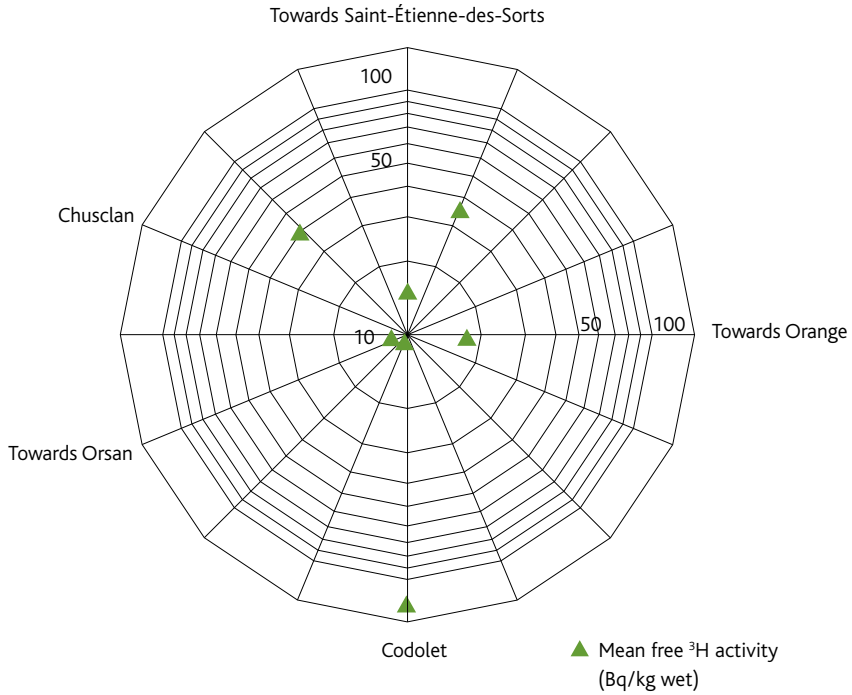

Figure VI.33 *– Geographical distribution of mean free tritium activity levels measured in the grass samples taken in the immediate vicinity of the Marcoule site (< 300 meters from the nuclear facilities) (Bq/kg wet).*

Table VI.14 *– Range of free tritium activity levels measured in the grass samples taken near the Marcoule site (Bq/kg wet).*

Municipality	Location relative to the Marcoule site	Range of HTO activities (Bq/kg wet)
Codolet	Southwest Site boundary	< 3.2 / 145 ± 10
	South – 200 m	76 ± 6 / 1270 ± 60
	South – 900 m	3.5 ± 3 / 526 ± 26
	South – 1.8 km	< 4 / 566 ± 28
	East – Site boundary	4.7 ± 1.5 / 135 ± 9
Caderousse	East – Southeast 2.2 km	< 2.3 / 151 ± 11
Chusclan	Northeast Site boundary	16.5 ± 2.5 / 113 ± 8
	North – Site boundary	2.7 ± 1.7 / 180 ± 13
	Northwest – 300 m	30 ± 3.9 / 443 ± 24
	West – Site boundary	5.2 ± 1.4 / 54 ± 4.4
Saint-Étienne-des-Sorts	North – 5.1 km	< 1.5

** Unless specified otherwise*

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Figure VI.34 *– Taking grass samples south of the Marcoule CEA center.*

Agricultural production and foodstuffs

Milk

The milk produced in the farms around the Marcoule site is regularly analyzed for radioactivity: monthly cow's milk samples are taken in Pontet, and quarterly or annual goat's milk samples are taken at three farms in Laudun-l'Ardoise, Roquemaure and Saint-Laurent-des-Arbres.

Like the milk samples taken in zones considered as being unaffected by the site's releases, the highest level of activity is that of potassium-40, whose mean activity concentration is 46.9 ± 1.4 Bq/L in cow's milk and 65.2 ± 3.7 Bq/L in goat's milk.

A significant strontium-90 activity level has been detected in the milk from Laudun-l'Ardoise (0.044 ± 0.01 Bq/L): this is close to the levels generally found in France as a result of past atmospheric fallout from nuclear weapons testing.

Lastly, the milk samples taken near the Marcoule center under the prevailing winds show low levels of tritium activity, which should be viewed in relation to the site's releases.

The other artificial radionuclides' activity levels are below the decision thresholds (*Table VI.15*).

Cereals

No gamma-emitting radionuclides were detected in the wheat sample taken in Pont-Saint-Esprit in 2010. The activity levels of the artificial (gamma-emitting and transuranium (plutonium, americium and strontium-90)) radionuclides are below the decision thresholds of the analytical techniques used.

Fruit and vegetables

Fruit samples are regularly taken north and south of the Marcoule site, in Chusclan and Codolet. The frequency and type of these samples vary depending on the season and production (five or six samples per year). In addition, four samples of fruit and vegetables grown within a 15 km radius of the site were analyzed in 2010. The main results are shown in Table VI.16.

Table VI.15 – Mean activities in the milk samples taken near the Marcoule site (Bq/L).

Radionuclide	Laudun-l'Ardoise	Le Pontet	Roquemaure	Saint-Laurent-des-Arbres
	Goat's milk	Cow's milk	Goat's milk	Goat's milk
^{40}K	64 ± 8	46.9 ± 1.4	65 ± 6	66 ± 6
^{137}Cs	< 0.39	< 0.11	< 0.1	< 0.1
^{134}Cs	< 0.34	nm	< 0.07	< 0.08
^{131}I	< 0.6	< 0.14	< 0.11	< 0.12
^{90}Sr	0.046 ± 0.01	< 0.033	nm	nm
HTO	3.4 ± 0.6	4.3 ± 0.6	nm	nm

nm: not measured

Low strontium-90 activity levels of between 0.048 ± 0.041 Bq/kg wet and 0.19 ± 0.07 Bq/kg wet were detected in three fruit samples taken in the Chusclan and Codolet municipalities. These levels are close to those observed in zones outside the influence of any nuclear facilities.

The significant tritium activity levels measured in the fruit and vegetable samples indicate that concentration levels are due to the Marcoule nuclear facilities' atmospheric discharge.

Wine

Analysis of red wine produced in Saint-Étienne-des-Sorts, which was conducted in order to detect gamma-emitting radionuclides, revealed the presence of potassium-40 at an activity concentration of 34 ± 7 Bq/L. The main artificial radionuclides likely to be released by the Marcoule site were not detected by the measuring devices used.

Table VI.16 – Mean activities or ranges of activities measured in the fruit and vegetables produced around the Marcoule site (Bq/kg wet).

Radio-nuclide	Chusclan	Codolet	Laudun - l'Ardoise	Orange	Sauveterre	Pont-Saint-Esprit
	Fruit	Fruit	Cabbage	Apple	Lettuce	Apple
^{40}K	39 ± 6/ 140 ± 22	48 ± 7/ 130 ± 20	77 ± 9	41 ± 7	133 ± 17	42 ± 7
^{137}Cs	< 0.029	< 0.03	< 0.026	< 0.07	< 0.11	< 0.039
^{90}Sr	0.1 ± 0.07/ 0.19 ± 0.07	0.048 ± 0.041	nm	nm	nm	nm
HTO	20 ± 3.6/ 64 ± 6	4.8 ± 3.9/ 61 ± 6	nm	nm	4.8 ± 1.9	nm
OBT	nm	nm	nm	nm	0.328 ± 0.017	nm
^{14}C	6.2 ± 1.7/ 19 ± 10	2.7 ± 1/ 9 ± 2.4	nm	nm	nm	nm

nm: not measured

Continental aquatic compartment

Surface water

IRSN possesses all tritium activity measurements taken in the Rhône river's water both upstream and downstream of the Marcoule site since the 1970s (*Figure VI.35*). The trend shows that activity levels are decreasing, notably at the end of the 1990s. Tritium concentrations in the Rhône river as a result of the Marcoule site's activities, which can be measured by the ratio between the activities upstream and downstream of the site, was occasionally detected in the 1980s and 1990s. The historical mean ratio is, however, 1 (*Figure VI.36*).

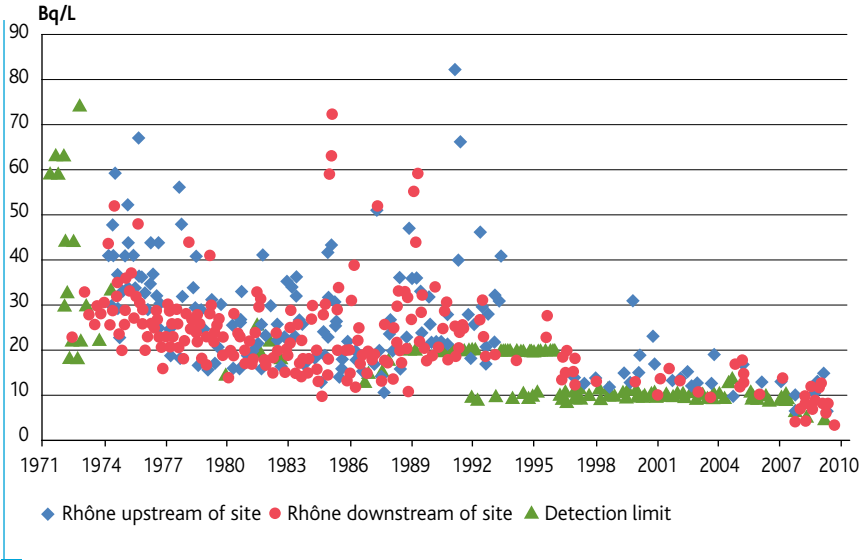

Figure VI.35 *– Tritium activity in Rhône river water samples taken upstream and downstream of the Marcoule site (Bq/L).*

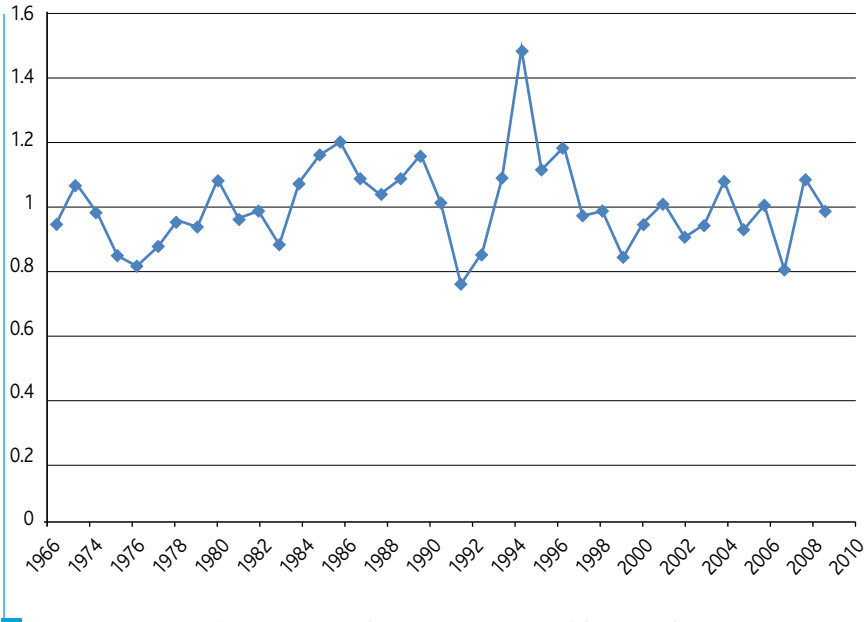

Figure VI.36 *– Ratio of tritium activities downstream/upstream of the Marcoule site.*

Sediments

Monthly or annual sediment samples are taken at ten monitoring stations along the Rhône river, from Saint-Étienne-des-Sorts upstream of the site down to the mouth of the Rhône at Port-Saint-Louis. The main results are shown in Table VI.17.

Upstream of the Marcoule site (at Saint-Étienne-des-Sorts), only cesium-137 was detected in the sediments in 2010, at an activity level of 0.81 ± 0.34 Bq/kg dry. Downstream, several artificial radionuclides (^{137}Cs, ^{60}Co, ^{54}Mn, ^{241}Am, ^{238}Pu, ^{239}Pu, $^{239+240}$Pu and ^{90}Sr) were detected in the sediments.

Cesium-137 is systematically detected in all samples, at higher levels than the other radionuclides, mainly at the Codolet (30 ± 6 Bq/kg dry) and Avignon (14.5 ± 3.2 Bq/kg dry) monitoring stations. Although concentration levels due to the site's legacy discharge cannot be excluded in the case of this radionuclide, its presence is mainly due to past atmospheric fallout.

Traces of transuranium radionuclides (mainly americium-241, plutonium-239 and plutonium-240), which are primarily linked with the Marcoule site's past discharge, are detected as far away as the mouth of the Rhône, at the Port-Saint-Louis monitoring station. The sediment samples with the highest transuranium radionuclide activities (1.05 ± 0.24 Bq/kg dry in the case of ^{241}Am, and 0.49 ± 0.13 Bq/kg dry in the case of $^{239+240}$Pu) are those taken at Codolet, the monitoring station nearest the Marcoule site's liquid discharge point. Plutonium-238 is occasionally detected at the Roquemaure and Avignon monitoring stations: the ^{238}Pu/$^{239+240}$Pu activity ratio of approximately 0.5 is typical of civilian spent fuel (that of atmospheric fallout from nuclear weapons testing in the '60s is approximately 0.025).

Some cobalt-60, mainly linked with the Marcoule site's past discharge, is detected between Orange and Avignon, at activity levels of between 0.63 ± 0.16 Bq/kg dry and 2.6 ± 0.6 Bq/kg dry. Traces of manganese-54 and strontium-90 are also occasionally detected in Roquemaure, at activity levels of 0.38 ± 0.22 Bq/kg dry and 0.84 ± 0.14 Bq/kg dry, respectively.

Table VI.17 – Mean activities measured in the Rhône sediment samples taken upstream and downstream of the Marcoule site (Bq/kg dry).

Radionuclide	Saint-Étienne-des-Sorts Upstream – 6 km	Codolet Downstream – 3 km	Orange Downstream – 10 km	Roquemaure Downstream – 13 km	Avignon Downstream – 25 km	Port-Saint-Louis-du-Rhône Downstream – 100 km
^{137}Cs	0.81 ± 0.34	30 ± 6	4.83 ± 0.28	5.85 ± 0.32	14.5 ± 3.2	9.7 ± 2.5
^{60}Co	< 0.46	< 1	0.47 ± 0.08	0.68 ± 0.07	1.39 ± 0.44	< 0.6
^{54}Mn	< 0.43	< 0.9	nm	0.43 ± 0.07	< 0.8	< 0.6
^{40}K	510 ± 70	690 ± 90	460 ± 23	457 ± 19	540 ± 80	490 ± 70
Other gamma-emitters (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{106}Ru)	< 7	< 15	< 5	< 6	< 10	< 9
^{238}Pu	< 0.06	< 0.07	< 0.14	0.061 ± 0.012	0.12 ± 0.07	< 0.07
^{239}Pu	nm	nm	< 0.43	nm	nm	nm
$^{239+240}$Pu	< 0.05	0.49 ± 0.13	nm	0.088 ± 0.017	0.33 ± 0.11	0.13 ± 0.08
^{241}Am	< 0.06	1.05 ± 0.24	< 0.33	0.078 ± 0.016	0.37 ± 0.12	0.2 ± 0.09
^{90}Sr	< 0.36	< 0.3	< 4.3	0.162 ± 0.037	< 0.42	< 0.44

nm: not measured

Ground water

The ground water flows in the Rhône river's alluvium, consisting of highly permeable sands and gravels, at a speed of approximately 1 meter/day. The alluvium forms successive terraces whose altitude decreases southwards. The impermeable substratum consists of Pliocene blue marls whose surface has been shaped through river erosion, forming channels and cuestas. This morphology considerably affects the subterranean flows, due to the layer's general thinness. As a result, although the ground water generally flows southwards towards the Codolet plain, it sometimes flows eastwards or westwards locally, notably as a result of the channels and cuestas.

The different levels have tritium concentrations, whose measured activity levels at a given point show little variation (*Figure VI.37*). The activity ranges from a few Bq/L to approximately 200 Bq/L between sampling points, however.

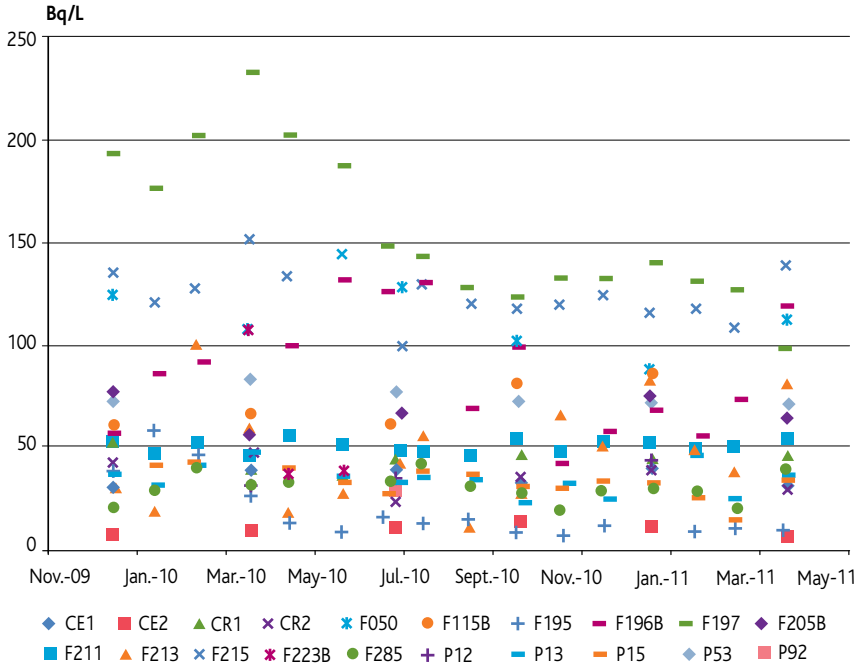

Figure VI.37 – Tritium activity in the ground water rainwater samples taken on and near the Marcoule site (Bq/L).

An increase in the total alpha activity was observed in March 2011 at the ground water sampling point named "MAR/EAU/F115B", reaching levels of over 0.5 Bq/L (*Figure VI.38*). The ground water flows from north to south in this zone and collects water with uranium concentrations from the nearby Tourettes spring. These concentrations are the residue from old incidents in the uranyl nitrate disposal zone, as the results of the analyses conducted by CEA show (*Table VI.18*).

The "MAR/EAU/F213" monitoring point south of the Marcoule site's waste processing station has residual gross beta activity (*Figure VI.39*). This residual activity is linked with the zone's total concentration levels due to several previous incidents on the site.

Continental aquatic fauna

Fish are caught monthly in the Rhône near the Marcoule site. The results of their radiological analysis are shown in Table VI.19. In addition to cesium-137, which is regularly detected at a mean activity level of 0.227 ± 0.035 Bq/kg wet, the samples occasionally have significant strontium-90 activity levels (between 0,059 ± 0.046 Bq/kg wet and 0.4 ± 0.15 Bq/kg wet) and carbon-14 activity levels (a mean activity level of 89 ± 13 Bq/kg wet). The measured tritium levels show the Rhône river's concentration levels are due to the discharge from the Marcoule site and, to a lesser degree, those of the other nuclear facilities upstream.

***Table VI.18** – Results of supplementary analyses conducted by CEA on old concentrations in the uranyl nitrate disposal zone (Bq/L).*

Radionuclide	Activity (Bq/L)	
	April 2011	May 2011
Total alpha	0.54	0.60
^{234}U	0.25	0.41
^{235}U	0.02	< 0.02
^{238}U	0.28	0.50
^{239}Pu	< 0.003	< 0.004
$^{238}Pu + ^{241}Am$	< 0.009	< 0.010

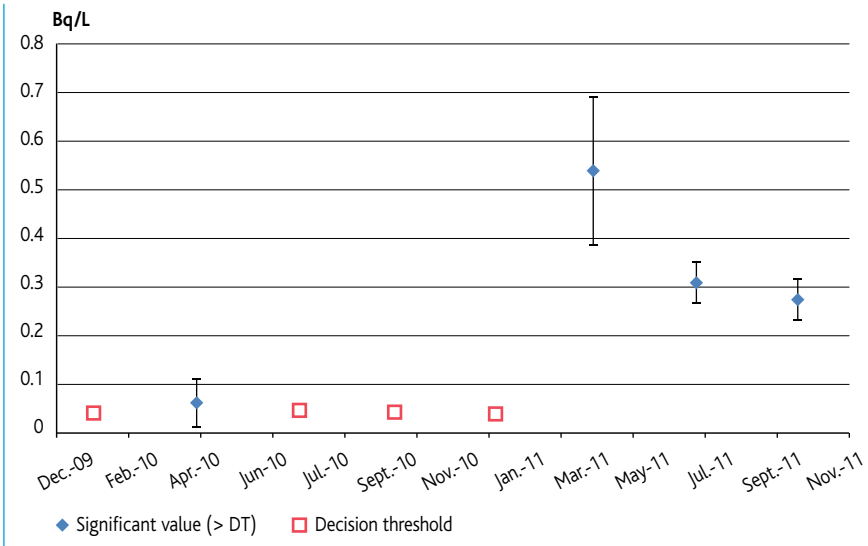

***Figure VI.38** – Gross alpha activity in the ground water samples taken at point "MAR/EAU/F115B" on the Marcoule site (Bq/L).*

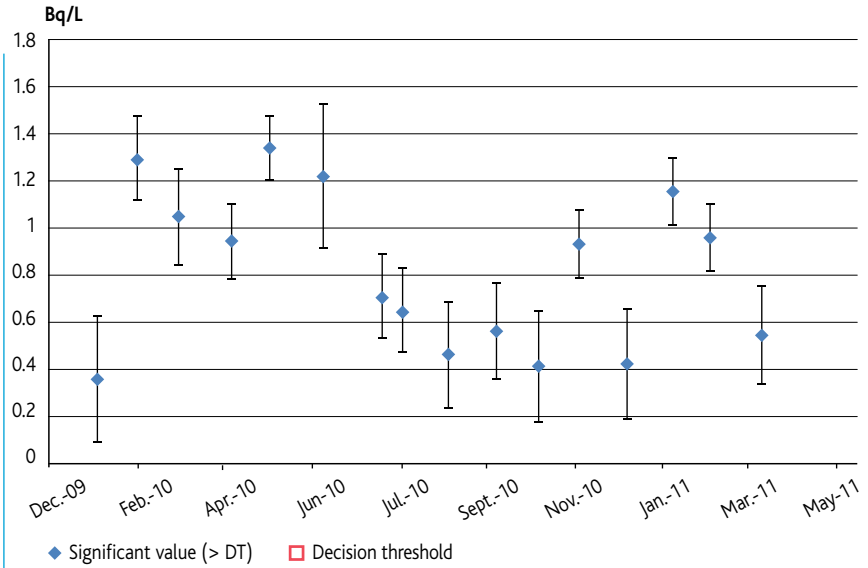

***Figure VI.39** – Gross beta activity in the ground water samples taken at point "MAR/EAU/F213" south of the Marcoule site waste processing station (Bq/L).*

***Table VI.19** – Mean activity level measured in the fish caught in the immediate vicinity of the Marcoule site (Bq/kg wet).*

Radionuclide	Fish
^{40}K	97.6 ± 4.5
^{137}Cs	0.227 ± 0.035
^{134}Cs	< 0.09
^{106}Ru	< 1.3
^{90}Sr	0.081 ± 0.013
HTO	32 ± 3.5
^{14}C	89 ± 13

Continental aquatic flora

Aquatic plant samples are taken upstream (twice yearly at Saint-Étienne-des-Sorts) and downstream of the Marcoule site (monthly at Caderousse, and twice yearly at Codolet) (*Table VI.20*).

As well as the usual presence of potassium-40, analysis also reveals the presence of traces of artificial radionuclides such as cesium-137 both upstream and downstream of the site. These traces can mainly be attributed both to past atmospheric fallout from nuclear weapons testing and to the Chernobyl accident.

The samples taken downstream of the site show traces of plutonium-238 and plutonium-239+240 activity as well of americium-241 activity, which are higher than those taken upstream, suggesting that the plants have activity concentrations resulting from the site's authorized discharge. This finding is not applicable to strontium, whose upstream and downstream activity levels are identical.

The tritium levels found in the aquatic phanerogams are higher than those usually observed in zones outside the influence of any nuclear activities. The samples taken downstream show slightly higher activity levels than those observed upstream, suggesting that they have added concentrations due to the Marcoule site's discharge as well as by the liquid discharge from the nuclear power plants upstream of the site on the Rhône river (*Chapter V – Rhône Valley NPPs*).

Iodine-131 was detected upstream of the Marcoule site in May 2010. Its presence was mainly due to chronic discharge from the nuclear medicine centers.

***Table VI.20** – Mean activities measured in the aquatic phanerogam samples taken upstream and downstream of the Marcoule site (Bq/kg dry)*.*

Radionuclide	Saint-Étienne-des-Sorts Upstream of Marcoule – 6 km		Codolet Downstream of Marcoule – 3 km		Caderousse Downstream of Marcoule – 5 km
	Pondweed		Pondweed		Phanerogam
	May 2010 sample	November 2010 sample	May 2010 sample	November 2010 sample	Annual mean
^{137}Cs	< 0.8	1.9 ± 1	1.6 ± 0.7	26.7 ± 3.7	0.66 ± 0.15
^{131}I	6 ± 3	< 8	< 3.3	< 40	nm
^{40}K	720 ± 100	480 ± 60	1100 ± 140	810 ± 110	638 ± 24
Other gamma emitters (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{58}Co, ^{60}Co, ^{54}Mn, ^{106}Ru)	< 14	< 18	< 30	< 33	< 8
^{238}Pu	< 0.007	< 0.021	< 0.022	0.181 ± 0.044	nm
$^{239+240}$Pu	0.013 ± 0.008	0.038 ± 0.017	0.101 ± 0.023	1.62 ± 0.18	nm
^{241}Am	< 0.013	0.035 ± 0.021	0.092 ± 0.038	0.048 ± 0.031	nm
^{90}Sr	1.06 ± 0.18	nm	1.23 ± 0.22	nm	1.05 ± 0.24
^{234}U	4.78 ± 0.43	7.5 ± 1.1	nm	nm	nm
^{235}U	0.31 ± 0.05	0.62 ± 0.14	nm	nm	nm
^{238}U	4.64 ± 0.42	7.2 ± 1	nm	nm	nm
HTO (Bq/kg wet)	3.4 ± 1.7	< 3.7	4.5 ± 1.3	8.4 ± 1.9	8.4 ± 3.4
OBT	nm	nm	nm	41.5 ± 2.1	nm
^{14}C	nm	nm	nm	nm	220 ± 70

** Unless specified otherwise*
nm: not measured

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***Figure VI.40** – Taking aquatic plant samples downstream of the Marcoule site.*

Saclay site

The Saclay CEA center, which is located in the Paris region and whose first facilities began operation in 1952, conducts multidisciplinary research in widely varied activities ranging from fundamental research to applied research in the fields of nuclear energy, physical sciences, life sciences, climate and the environment, technological research and education.

The center's main discharge is produced by the organic molecule concentration laboratory's experimental *Osiris* and *Orphée* reactors as well as by "CIS bio international", an independent company manufacturing radiopharmaceuticals for use in nuclear medicine.

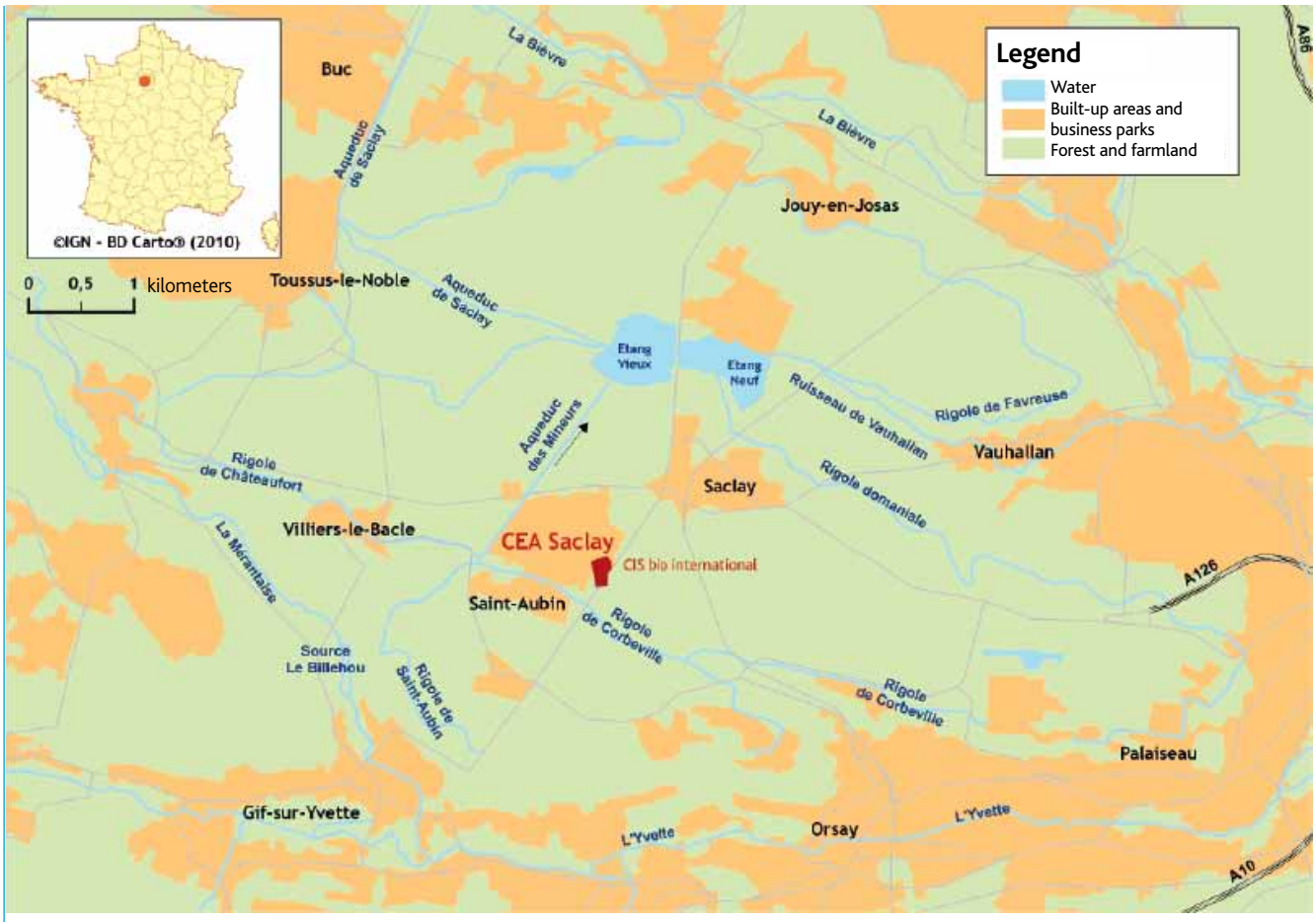


Figure VI.41 – Geographical location of the Saclay site.

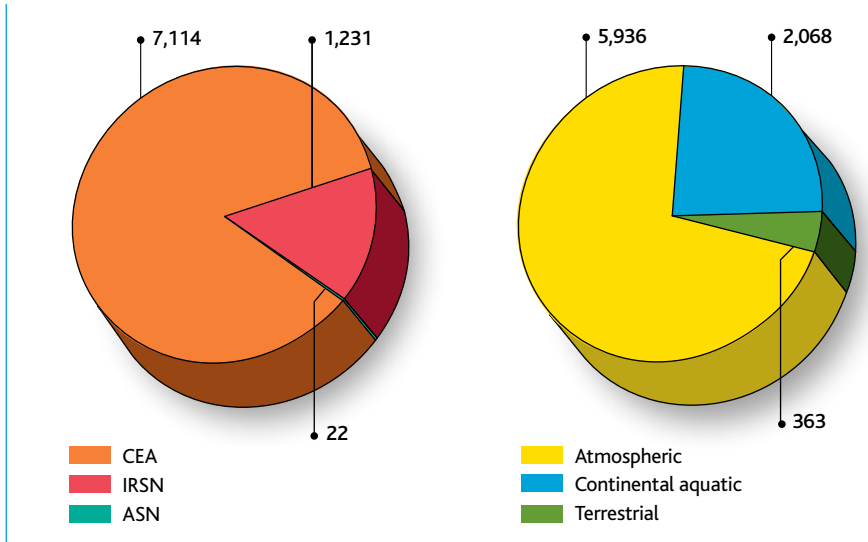


Figure VI.42 – Saclay site: sample distribution by data producer and by compartment.

Atmospheric compartment

Atmospheric aerosols

Apart from the readings taken during the period of the Fukushima accident, no other abnormal beta activity index values (*Figure VI.14*) and alpha activity index values (*Figure VI.15*) have been detected. No artificial radionuclides have been detected in the environment by means of gamma spectrometry.

In the Saclay CEA site's environment, an increase in the beta activity index was observed between the end of March and the end of April 2011 (*Table VI.21*). This phenomenon is mainly due to the presence of artificial radionuclides linked with the atmospheric fallout from the Fukushima nuclear power plant accident.

Table VI.21 – Activity levels in the atmospheric aerosol samples taken in the Saclay site's environment (mBq/m³).

Radionuclide type	Radionuclide	Mean activity or detection limit (mBq/m³)
Gross activity indices	Alpha activity	0.021 ± 0.001
	Beta activity	0.24 ± 0.01 0.65 ± 0.02*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

Gases sampled by bubblers

Atmospheric tritium activity levels are measured by means of bubblers at four monitoring stations near the site: Saclay, Saint-Aubin, Villiers-le-Bâcle and Orsigny. In 2010, the tritium activity concentration measured at these four stations was usually below the decision threshold (< 0.4 Bq/m³). The maximum measured value was 1.155 ± 0.082 Bq/m³ (*Figure VI.43*). When tritium is detected around the Saclay center, it comes from the molecule concentration research laboratories.

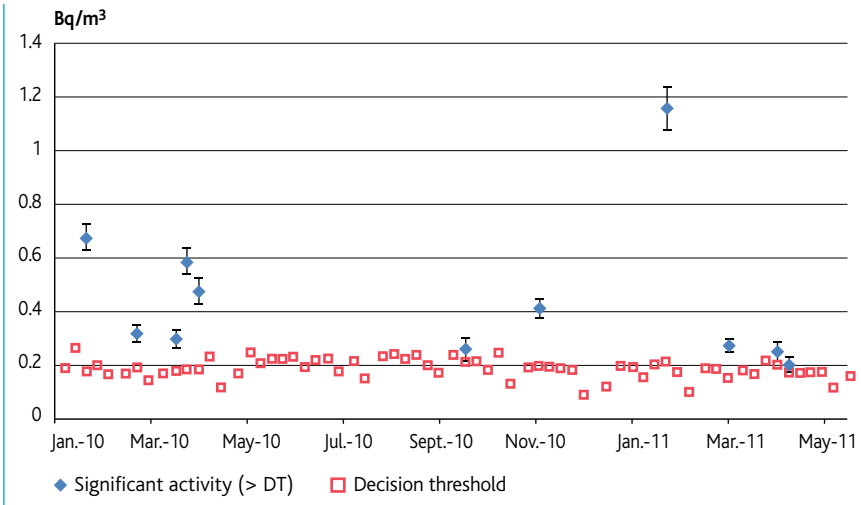


Figure VI.43 – Atmospheric tritium (HTO) activity measured in samples taken near the Saclay site (Bq/m³).

Other gases

The monitoring of gaseous iodine-131 activity revealed the presence of this radionuclide during the period of the Fukushima nuclear power plant accident (*Table VI.9*). Except during this period, no significant activity levels have been measured. Although iodine-131 is present in CIS bio international's gas discharge, it is rarely present in discharge from Saclay CEA center's facilities.

Rainwater

Analysis of the rainwater samples taken near the Saclay site occasionally shows the presence of tritium linked with the center's gas discharge (*Figure VI.44*).

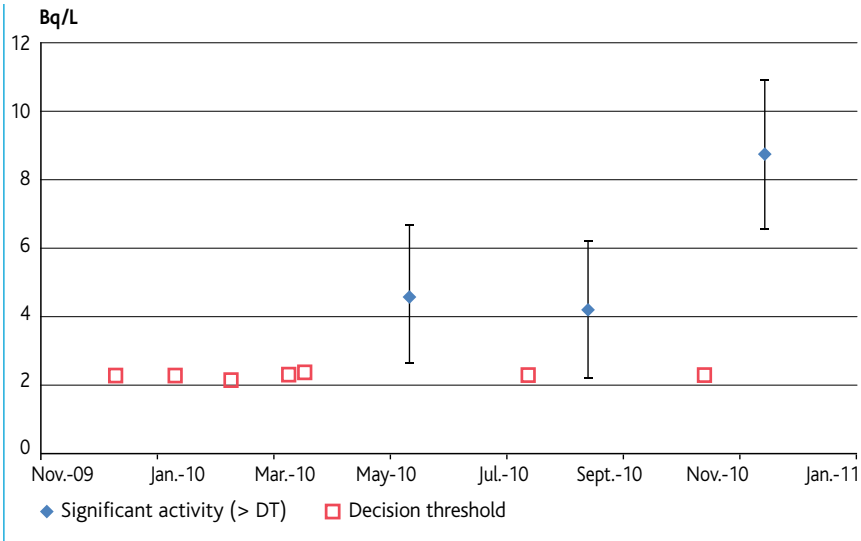


Figure VI.44 – Tritium activity in rainwater samples taken near the Saclay site (Bq/L).

Terrestrial compartment

The effects of the Saclay site's activity level upon its nearby terrestrial environment are monitored by means of regular soil, terrestrial plant (grass, fruit and vegetable), milk and cereal samples.

Terrestrial flora

Monthly grass samples are taken at four sampling points within a 2 km radius of the Saclay site. This monitoring is supplemented by the taking of twice-yearly samples in Saclay itself.

The analytical results of the grass samples indicates the presence of tritium, which can be attributed to discharge from the Saclay center (*Table VI.22*), and strontium-90, which can be attributed to past atmospheric fallout from nuclear weapons testing.

Normally, the activities of the other radionuclides are below the decision thresholds associated with the measuring devices used. Following the Fukushima nuclear power plant accident in March 2011, however, traces of iodine-131 were detected in the four samples taken on April 15, 2011, with activity levels between 0.37 ± 0.13 and 0.49 ± 0.11 Bq/kg wet. Cesium-134 and cesium-137 was also detected in Saint-Aubin and Villiers-le-Bâcle on the same day.

For more information
Chapter III – The Fukushima Accident

Soils

The cesium-137 specific activity measured in the topsoil samples taken in 2010 within the zone potentially affected by the Saclay center's discharge was 5.1 ± 0.8 Bq/kg dry, which is a similar value to that observed throughout France. These concentrations can be attributed both to past atmospheric fallout from nuclear weapons testing and to the Chernobyl accident.

Agricultural production and foodstuffs

Milk

Analysis of the monthly cow's milk samples taken at farms near the Saclay center does not reveal any abnormal artificial activity (*Table VI.23*). A single significant free tritium value, which was close to the decision thresholds (3.5 ± 1.9 Bq/L), was observed among the six milk samples taken in Jouy-en-Josas between January 2010 and May 2011.

In addition, the milk sample taken at the farm in Saint-Rémy-lès-Chevreuse on April 1, 2011 contained traces of iodine-131; its measured activity concentration of 0.08 ± 0.022 Bq/L can be attributed to the Fukushima nuclear power plant accident in Japan a few weeks previously.

Cereals

No artificial gamma-emitting radionuclides were measured in the wheat samples taken in 2010 in Saclay.

Fruit and vegetables

The radioactivity observed in the plants grown near the Saclay center is mainly due to natural potassium-40 (*Table VI.24*).

The zucchini and raspberries picked in Jouy-en-Josas contain tritium levels showing added concentration levels due to the Saclay center's discharge.

Low strontium-90 activity levels have been observed in the strawberries and wild rhubarb grown in Jouy-en-Josas; they are close to the levels generally found in France and can be attributed to past atmospheric fallout from nuclear weapons testing.

Table VI.23 – Mean activities in the milk samples taken near the Saclay site (Bq/L).

Radionuclide	Jouy-en-Josas	Saint-Rémy-lès-Chevreuse
^{40}K	52.2 ± 1.4	51.1 ± 1.4
^{137}Cs	< 0.09	nm
^{131}I*	< 0.017	< 0.017
^{90}Sr	< 0.018	< 0.019
HTO	2.6 ± 0.5	< 4
OBT	< 25	< 34

** Excluding a significant value measured following the Fukushima accident in March 2011.*
nm: not measured

Table VI.22 – Mean activities measured in the grass samples taken around the Saclay site (Bq/kg dry).*

Radionuclide	Saclay		Orsigny	Villiers-le-Bâcle	Saint-Aubin
^{40}K	530 ± 60	744 ± 30	792 ± 30	683 ± 29	849 ± 33
^{137}Cs**	< 0.8	< 0.41	< 0.31	nm	nm
^{90}Sr	nm	0.53 ± 0.06	0.56 ± 0.08	0.47 ± 0.06	0.56 ± 0.06
HTO (Bq/kg wet)	28.4 ± 2.6	< 2.5	6.7 ± 2.6	< 3.4	3.9 ± 2.1

** Unless specified otherwise*
*** Excludes significant values measured around the Saclay site following the Fukushima accident*
nm: not measured

In addition, iodine-131 was detected in the cabbage samples taken on April 4, 2011 in Saclay, with an activity of 0.29 ± 0.12 Bq/kg wet. This activity should be viewed in relation to the accident at the Fukushima nuclear power plant in Japan in March 2011.

For more information

Chapter III – The Fukushima Accident

Table VI.24 – Activities measured in the fruit and vegetables produced near the Saclay site (Bq/kg dry).

Radionuclide	Saclay	Jouy-en-Josas						
	Cabbage	Cauliflower	Zucchini	Strawberry	Raspberry	Pumpkin	Wild rhubarb	Tomato
^{40}K	131 ± 15	100 ± 15	58 ± 8	56 ± 10	50 ± 7	141 ± 16	124 ± 15	74 ± 10
^{90}Sr	< 0.05	< 0.26	< 0.09	0.11 ± 0.036	nm	< 0.23	0.047 ± 0.013	< 0.09
HTO	nm	nm	25 ± 6	nm	5.2 ± 1.7	nm	nm	nm
OBT	nm	nm	< 10	nm	nm	nm	nm	nm

nm: not measured

Continental aquatic compartment

Surface water

IRSN has observed strontium-90 concentrations of approximately 4 mBq/L in surface water in the Mineurs aqueduct (outlet) near the site and in the nearby Étang Neuf and Étang Vieux pools. This activity should be viewed in relation to the center's authorized strontium-90 discharge.

The tritium detected by IRSN in the Mineurs aqueduct since 1989 shows that its activity is regularly decreasing, which is consistent with the reduction in the center's authorized liquid discharge (*Figure VI.45*).

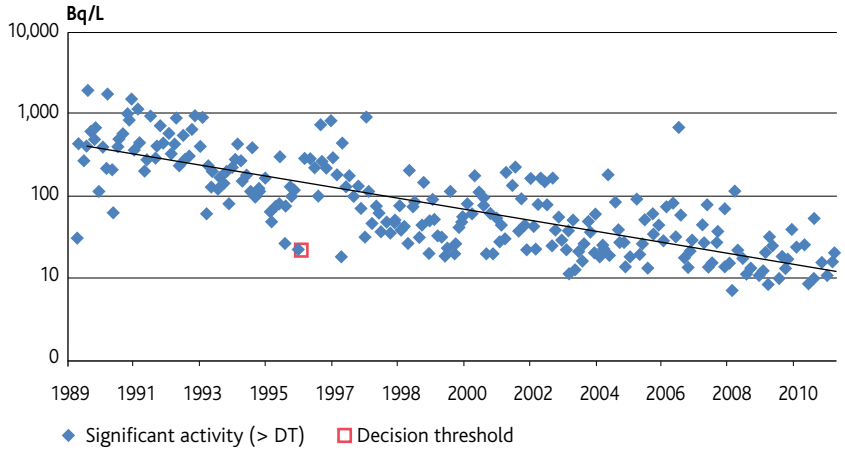


Figure VI.45 – Tritium activity in water samples from the Mineurs aqueduct (Bq/L).

© A. Chézière/CEA

Figure VI.46 – Taking a water sample from the Étang Vieux pool near the Saclay site, for radiological and physicochemical analysis.

Sediments

Twice-yearly or annual sediment samples are taken at seven monitoring stations near the Saclay center. This monitoring includes the taking of sediment samples in the Mineurs aqueduct, through which the Saclay center's liquid discharge flows; and in the Étang Vieux pool, the discharge's receiving environment. Table VI.25 shows the main results obtained in 2010.

In the case of the artificial radionuclides, analysis of the Mineurs aqueduct's and the Étang Vieux pool's sediments has revealed residual concentrations by cesium-137, cobalt-60, plutonium and americium-241. This can be attributed to the site's past liquid discharge. The annual mean specific activity of these radionuclides has considerably decreased since then. For example, cesium-137 activity has been reduced by a factor of 100 since 1990.

This concentration level is no longer observed in the Étang Neuf pool or the other watercourses further away (Ru de Vauhallan brook, La Bièvre stream and Ru de Saint-Marc brook).

Table VI.25 – Mean activities measured in the sediment samples taken downstream of the Saclay site's liquid waste discharge pipe and in the neighboring watercourses (Bq/kg dry).

Radionuclide	Saclay				Vauhallan	Verrières-le-Buisson	Toussus-le-Noble
	Mineurs aqueduct	Mineurs aqueduct	Étang Vieux pool	Étang Neuf pool	Vauhallan stream	La Bièvre	Saclay aqueduct
^{40}K	404 ± 37	523 ± 37	480 ± 80	605 ± 42	384 ± 27	340 ± 50	460 ± 80
^{137}Cs	55.6 ± 4.2	1.77 ± 0.34	74 ± 12	0.31 ± 0.18	0.53 ± 0.17	0.52 ± 0.21	7.9 ± 1.2
^{60}Co	2.79 ± 0.47	< 0.32	1.9 ± 0.49	< 0.2	< 0.16	< 0.21	< 0.17
^{90}Sr	< 0.5	< 4.8	< 4.6	< 3.6	< 2.9	< 2.9	< 3.3
^{241}Am	0.24 ± 0.09	< 0.6	< 0.8	< 0.8	< 0.7	< 0.44	< 0.7
^{238}Pu	< 0.11	0.13 ± 0.05	0.36 ± 0.18	< 0.15	< 0.33	< 0.33	< 0.26
$^{239+240}$Pu	1.57 ± 0.33	0.25 ± 0.09	2.6 ± 0.7	< 0.2	< 0.33	< 0.28	< 0.39
^{235}U	nm	2.9 ± 1	< 3.5	< 3.4	nm	< 2.1	< 3

nm: not measured

© IRSN

Figure VI.47 – Taking sediment samples in the Étang Vieux pool near the Saclay CEA center.

Ground water

There are two aquifer levels with added tritium concentrations:

- **The deep aquifer** of Fontainebleau sands, which is 60 meters thick and lies on a relatively impermeable layer of marls rich in oyster fossils. The layer flows from north to south with outlets downstream of the site, consisting of springs on the southern and western slopes of the Saclay plateau.
- **The superficial aquifer** consisting of millstone clays, on which perched layers are resting, is situated in relatively impermeable sandy loam layers of varying depths fed by rainfall and with no stable direction of flow.

The tritium activities measured by all of the piezometers vary between the decision threshold and 180 Bq/L in the case of well F44. The tritium activity in well F44 can firstly be explained by water infiltrations from the Villiers pool, and secondly by its closeness to basic nuclear installation # 72, where the center's solid waste is stored (*Figure VI.48*).

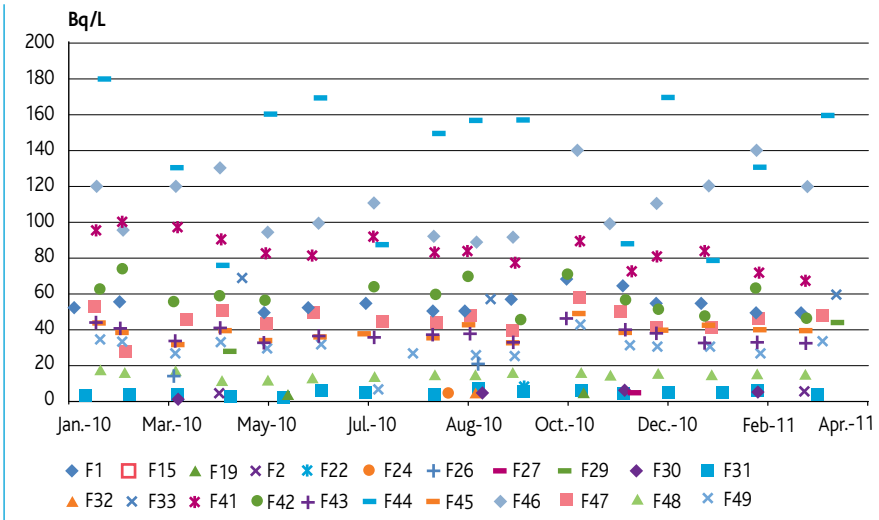


Figure VI.48 – Tritium activity in the Fontainebleau sand ground water samples taken on and near the Saclay site (Bq/L).

Continental aquatic fauna

In 2010, pike were caught in Saclay's Étang Neuf pool for radiological analysis. The main results are shown in *Table VI.26*.

The free tritium activity in these fish, which was slightly above the decision thresholds, can be attributed to the Saclay research center's activities.

Table VI.26 – Activities measured in the pike samples caught in the Étang Neuf pool (Bq/kg wet).

Radionuclide	Activity
^{40}K	140 ± 21
^{137}Cs	0.56 ± 0.16
^{60}Co	< 0.11
^{90}Sr	< 0.29
HTO	6.9 ± 3.5
OBT	< 36

Continental aquatic flora

The annual reed samples taken in the Mineurs aqueduct downstream of Saclay's liquid waste discharge pipe contain residual concentrations from the research center's past discharge: they contain traces of americium and plutonium and cesium-137 isotopes, as well as a slight concentration of tritium (*Table VI.27*).

Table VI.27 – Activities measured in the reed samples taken downstream of the Saclay site's liquid waste discharge pipe (Bq/kg dry).*

Radionuclide	Mineurs aqueduct	Étang Vieux pool	Étang Neuf pool
^{40}K	950 ± 150	800 ± 140	940 ± 160
^{137}Cs	10 ± 3	< 0.8	< 0.9
^{60}Co	< 2.1	< 1.1	< 1.1
Other gamma-emitting radionuclides (^{106}Ru, ^{110m}Ag, ^{124}Sb, ^{125}Sb, ^{131}I, ^{134}Cs, ^{54}Mn, ^{58}Co)	< 36	nm	nm
^{90}Sr	nm	< 1.1	< 1.5
^{238}Pu	0.022 ± 0.011	nm	nm
$^{239+240}$Pu	0.118 ± 0.026	nm	nm
^{241}Am	0.108 ± 0.027	nm	nm
HTO (Bq/kg wet)	14.3 ± 2.1	4.7 ± 2.5	2.8 ± 2.6
OBT	nm	< 410	< 480

** Unless specified otherwise*
nm: not measured

Valduc CEA center

The Valduc center, which was created in 1957 and is situated 45 km northwest of Dijon in eastern France, specializes exclusively in conducting technological research and development on the materials used in France's nuclear deterrent weapons. As well as conducting research on the production of the weapons' nuclear components, the center's specialists are also responsible for maintaining and dismantling the nuclear warheads. Due to its specialized nuclear weapons activities, this site mainly discharges, under regulatory control, gaseous tritium (nearly 300 TBq in 2009).

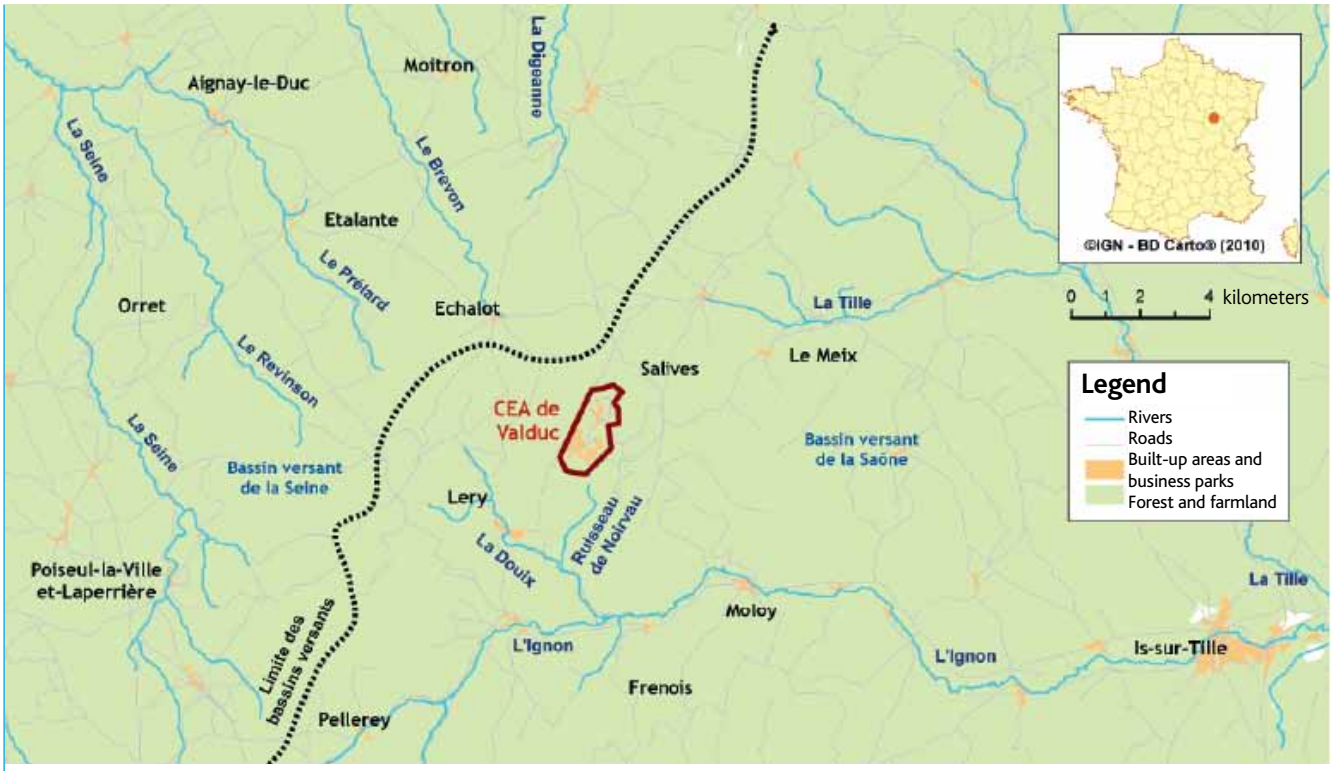


Figure VI.49 – Geographical location of the Valduc CEA site.

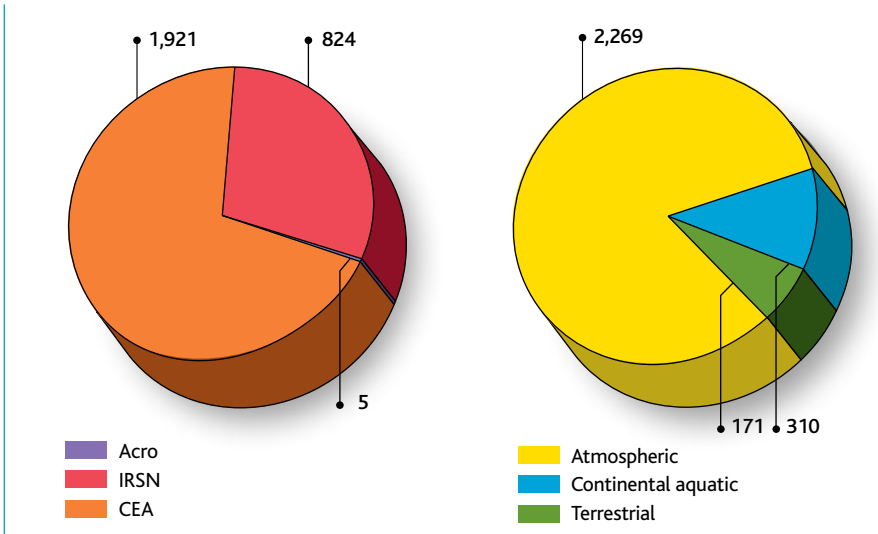


Figure VI.50 – Valduc CEA site: sample distribution by data producer and by compartment.

Atmospheric compartment

Atmospheric aerosols

Apart from the readings taken during the period of the Fukushima accident, no other abnormal alpha activity (*Figure VI.52*) and beta activity values have been observed. With the exception of natural radionuclides (^{7}Be and ^{210}Pb), gamma spectrometry has not detected any artificial radionuclides present in the environment.

In the Valduc CEA site's environment, an increase in the beta activity index was observed between the end of March and the end of April 2011 (*Table VI.28 and Figure VI.51*). These readings can be attributed to air masses passing over France after being contaminated by the Fukushima nuclear power plant accident.

For more information

Chapter III – The Fukushima Accident

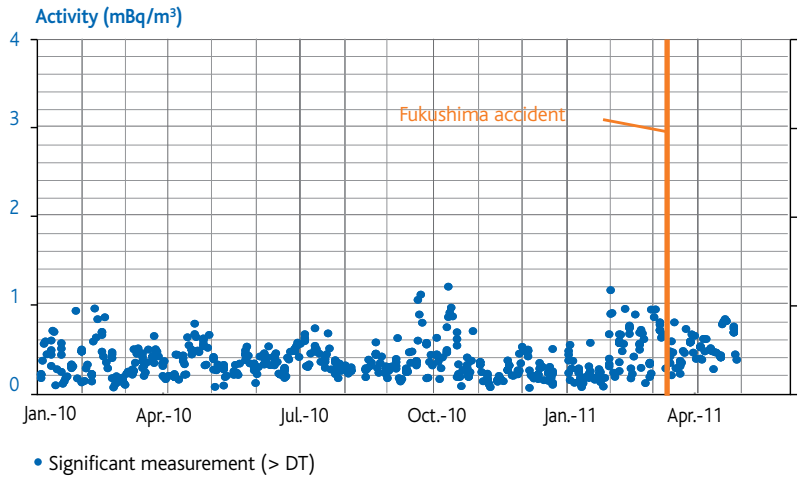


Figure VI.51 *– Time plot of the gross beta activity of aerosols near the Valduc CEA site (mBq/m³).*

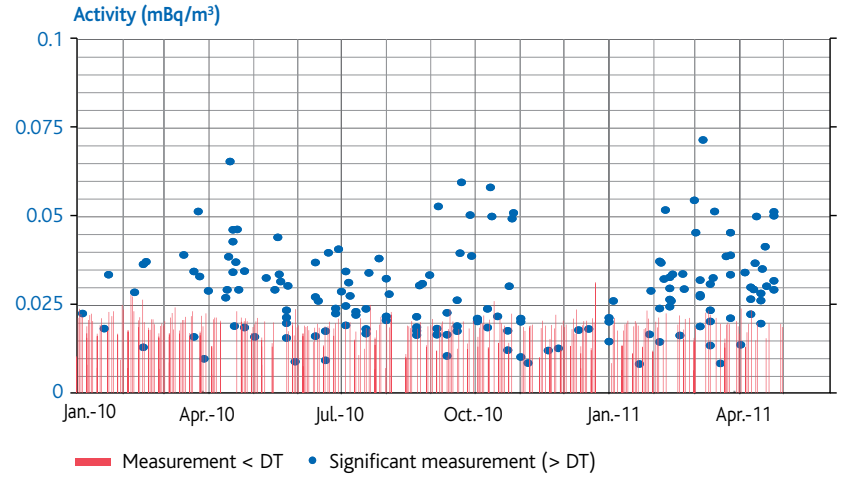


Figure VI.52 *– Time plot of the gross alpha activity of aerosols near the Valduc CEA site (mBq/m³).*

Table VI.28 *– Activities in the aerosol samples taken in the Valduc CEA site's environment (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Gross activity	Alpha activity	0.038 ± 0.001
	Beta activity	0.23 ± 0.01 0.50 ± 0.02*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

Gases sampled by bubblers

A bubbler continuously samples the air at the sampling station in Salives, under the Valduc center's prevailing winds. The atmospheric tritium is mainly detected in significant quantities in the form of water vapor. This activity, which varies between the decision threshold and 4.15 Bq/m³, shows that the environment has permanent added concentrations due to the site's atmospheric discharge. The tritiated water vapor's activity tends to be cyclical over time, with the highest values appearing in the summer (*Figure VI.53*).

Rainwater

Rainwater samples are taken at four points near the site. The tritium's mean activity concentration is approximately 23 Bq/L, reflecting the site's activity levels. During the observation period, 4% of the values were above 100 Bq/L, with a maximum value of 353 Bq/L observed at Échalot (*Figure VI.54*).

Terrestrial compartment

The Valduc CEA center's monitoring is based on regular grass and milk samples taken in the site's immediate vicinity, combined with annual meat and cereal samples.

Terrestrial flora

Around the Valduc center, four monthly grass samples are taken from April to October. These are supplemented by six annual samples. Their analysis for the presence of tritium reveals that the grass has added concentration levels due to the center's atmospheric discharge, as shown by the results displayed in Table VI.29. The measured free tritium levels vary greatly over time and reflect the tritium's activity levels in the air when the samples are taken. These levels mainly depend on the activities discharged by the nuclear research center and the weather conditions at the time.

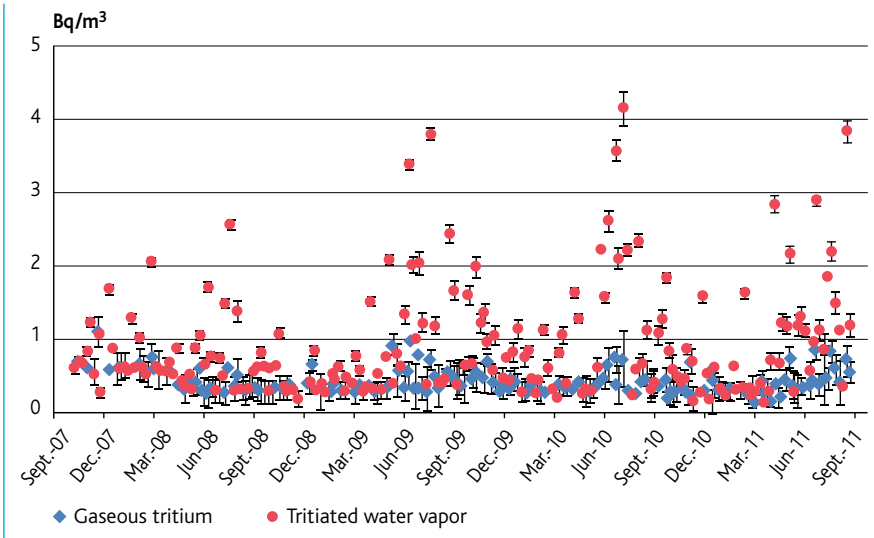


Figure VI.53 – Atmospheric tritium activity measured near the Valduc site (Bq/m³).

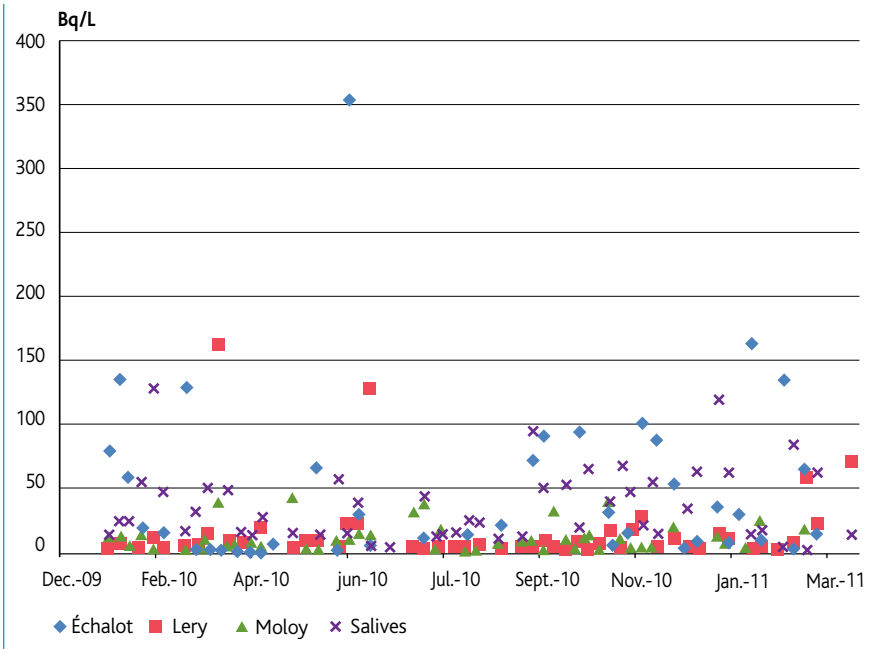


Figure VI.54 – Tritium activity measured in rainwater near the Valduc site (Bq/L).

Table VI.29 – Activity levels measured in the grass samples taken around the Valduc site.

Sampling location	Range of HTO activities (Bq/kg wet)	Mean HTO activity (Bq/kg wet)	Mean OBT activity (Bq/kg dry)
Échalot	9.9 ± 2.4 / 47.3 ± 4.3	23.1 ± 1	8.8 ± 0.7
Lamargelle	5.9 ± 2.1 / 79 ± 6	20.8 ± 1	nm
Le Meix	nm	nm	27.3 ± 1.2
Lery	nm	nm	21.3 ± 1
Minot	nm	nm	16.7 ± 0.9
Moloy	5 ± 2.3 / 55.2 ± 5	17.1 ± 0.9	nm
Pellerey	nm	nm	12.8 ± 0.7
Salives	6.1 ± 2.3 / 32.4 ± 3.6	15 ± 0.9	34.6 ± 1.4

nm: not measured

Agricultural production and foodstuffs

Milk

The monitoring of cow's milk produced around the Valduc center consists in analyzing monthly samples taken in Salives and annual samples taken in Lamargelle.

This analysis reveals that the milk has an added concentration of tritium discharged by the CEA center, notably in Salives where the measured activity levels vary between 20.5 ± 2.9 Bq/L and 42 ± 3.8 Bq/L. The activity concentration of the milk samples taken in April 2010 in Lamargelle was 6.5 ± 2.1 Bq/L.

The other radionuclides' activity levels are below decision thresholds, apart from natural potassium-40, whose activity levels are similar to those measured throughout France (their mean is 49.4 ± 1.8 Bq/L).

Meat

Analysis of beef from cattle reared in nearby Chanceaux has not revealed any radiological anomalies. Organically bound tritium (OBT) was measured with a specific activity of 0.52 ± 0.16 Bq/kg wet.

Cereals

In 2010, wheat samples were taken from Salives' annual harvest. With the exception of potassium-40, the gamma-emitting radionuclides' specific activity levels were below the decision thresholds of the measuring devices used. These samples show an added concentration of OBT reflecting the Valduc center's atmospheric discharge (measured specific activity: 55.2 ± 2.8 Bq/kg dry).

Continental aquatic activity

Surface water

Two aquifers flow below the Valduc site. Below the site, the upper layer is fed through rain infiltration and drained through many barely productive springs, most of which are temporary and situated on the edge of the plateau. The fissured lower aquifer, whose outlets include the Douix spring (which flows at a rate of several tens of liters per second), contains a layer fed by rain infiltration and by the upper layer. The two aquifers are connected by rifts in the Combe au Tilleul area.

IRSN measures the tritium activity in this ground water by taking samples at the outlets, which mainly consist of the Coquille, Galopine, Prégelan and Prélard springs and the public water fountains in the surrounding villages. The added tritium concentration measured at these points varies between 10 and 59 Bq/L.

The watercourses that flow northwards and eastwards under the CEA site's prevailing winds are the Brévon and the Digeanne, both of which flow into the Seine river. The tritium activity levels of the water in these rivers is approximately 20 Bq/L, which is due to the Valduc center's atmospheric discharge and the ground water that has added concentrations of tritium. South of the site, the Douix à Léry stream's water, which enters the upper reaches of the Seine, are marked with tritium for the same reasons. In addition, the tritium activity measured in the Ignon river (25 Bq/L) is reduced due to the dilution of the stream's water. The Ignon river is also fed by the Douix stream (27 Bq/L), which is in turn fed by the Noirveau stream (190 Bq/L). These watercourses are the main vectors of surface drainage. West of the site, sheltered from the prevailing winds, the tritium activity is considerably lower in the Prélard (7 Bq/L), Revinson (4 Bq/L) and Seine (4 Bq/L) rivers.

Figure VI.55 – Taking a water sample at the La Coquille spring in Etalante.

Institut Laue-Langevin international research center and Grenoble CEA center

The Grenoble CEA and Institut Laue-Langevin (ILL) research centers are located very close together in the Grenoble agglomeration in eastern France.

The Grenoble CEA center, which was created in 1956, is one of CEA's civilian sites. Since January 2001, it has been engaged in a project to clean up and dismantle its six basic nuclear installations. Their dismantling is due for completion at the end of 2012, and the final installation is scheduled for administrative decommissioning in 2013. This center's activities now concentrate on microelectronics and nanoelectronics, new energy technologies and biotechnologies.

Institut Laue-Langevin (ILL) is an international research center offering researchers one of the most intense neutron sources in the world. The center has 40 state-of-the-art spectrometers providing information on the material's structure and dynamics (solid, liquid, gas, etc.), and its research covers a variety of fields: particle physics, nuclear physics, chemistry, biosciences, material sciences, etc.

Since 2010, ILL has been responsible for the environmental monitoring conducted at both sites.

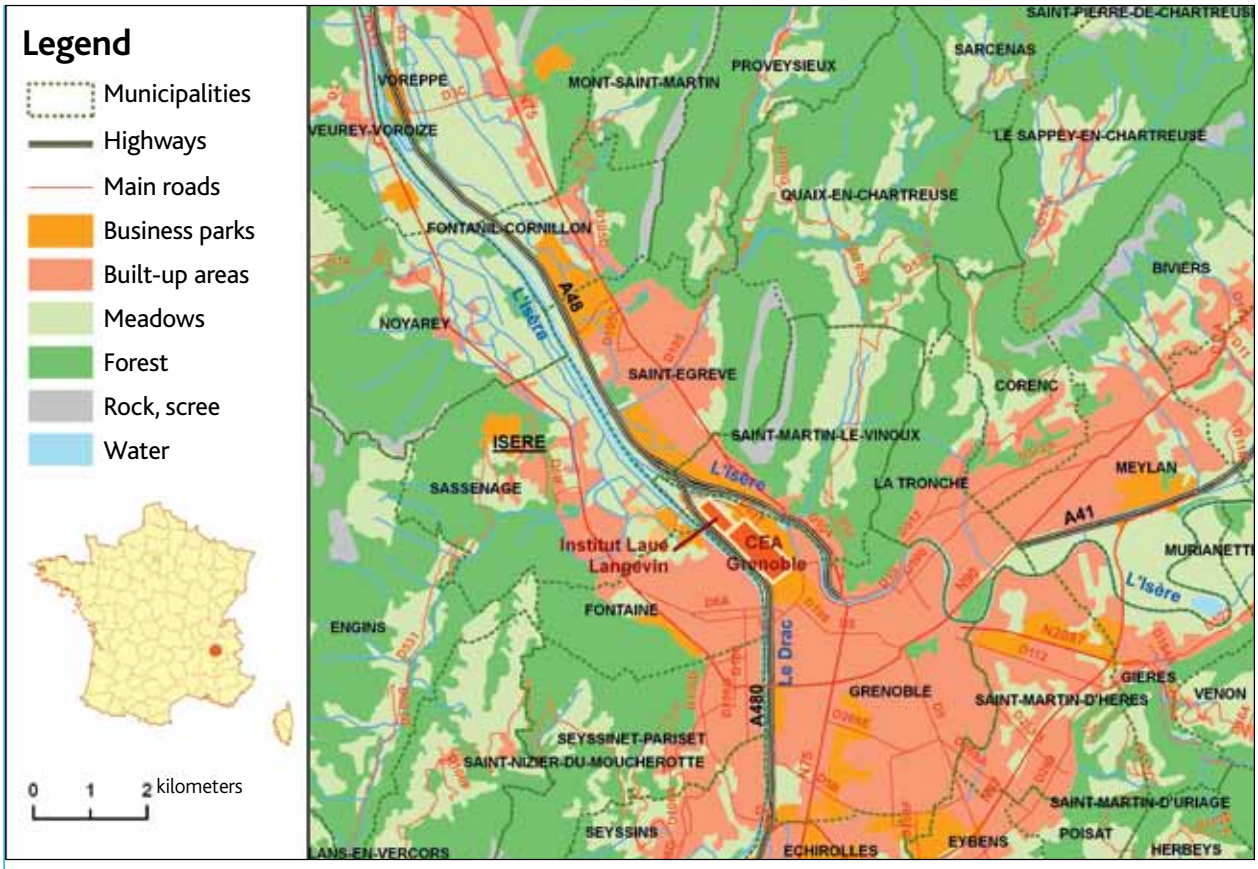


Figure VI.56 – Geographical location of ILL and the Grenoble CEA center.

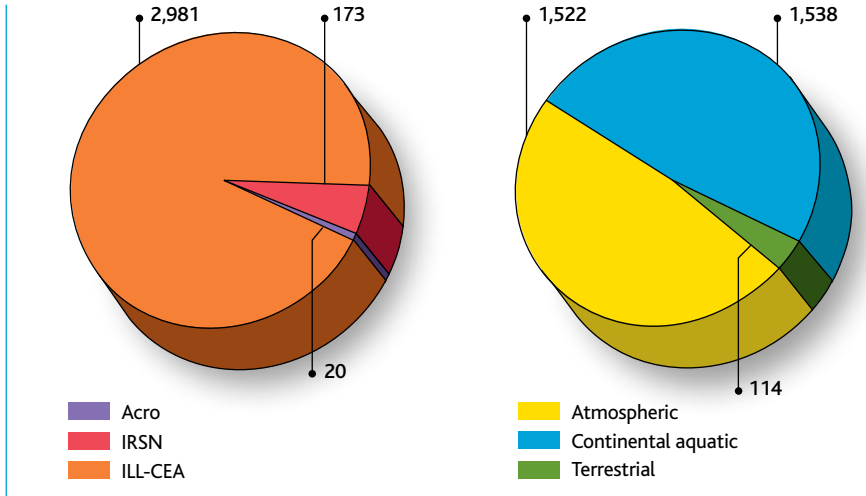


Figure VI.57 – ILL and the Grenoble CEA center: sample distribution by data producer and by compartment.

Atmospheric compartment

Atmospheric aerosols

Apart from the readings taken during the period of the Fukushima accident, the monitoring of beta activity indices has not measured any abnormal values. No artificial gamma-emitting radionuclide activity levels above the decision thresholds of the measuring devices used could be detected.

In the Grenoble CEA site's and ILL's environment, significant cesium-137 and iodine-131 activity levels were observed between the end of March and the beginning of May 2011 (*Table VI.30*). These findings can be attributed to air masses passing over France after being contaminated by the Fukushima nuclear power plant accident. An increase in the gross beta activity between the end of March and the end of April 2011 has also been observed (*Figure VI.58*). This can be attributed to the presence of artificial radionuclides linked with the Fukushima accident.

For more information
Chapter III – The Fukushima Accident

Gases sampled by bubblers

Two bubblers continuously sample the air, one at a station located at the point where the Drac and Isère rivers meet northwest of the site, and the other southeast of the site. Both these stations are located under the prevailing winds. The atmospheric tritium is mainly detected in significant quantities in the form of water vapor. The maximum activity levels measured at the stations are approximately 1 Bq/m³ southwest of the site and 2.3 Bq/m³ at the northwest station (*Figure VI.59*).

Other gases

The monitoring of gaseous iodine-131 activity has revealed the presence of this radionuclide during the Fukushima nuclear power plant accident (*Table VI.31*).

For more information
Chapter III – The Fukushima Accident

Except during this period, no significant activity has been measured, as there is very little of this radionuclide in the discharge from the Grenoble CEA center's and ILL's facilities.

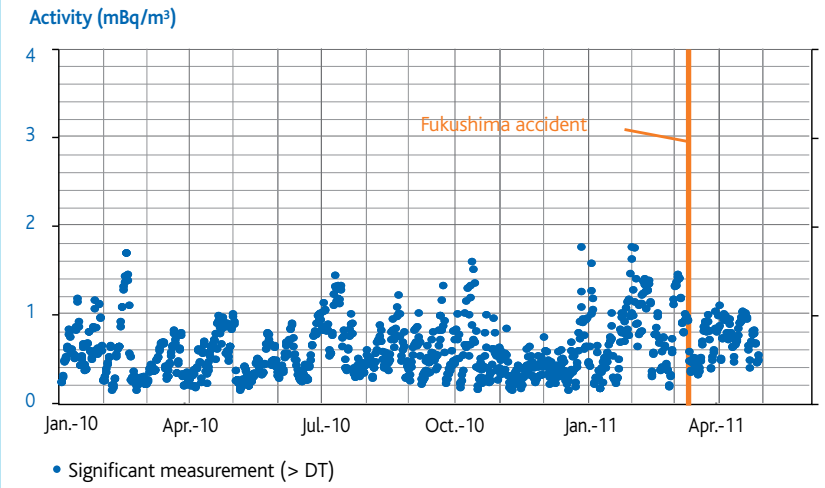


Figure VI.58 *– Time plot of the gross beta activity of aerosols near ILL and the Grenoble CEA site (mBq/m³).*

Table VI.30 *— Activity levels measured in the Grenoble CEA center's and ILL's environmental aerosols (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Gross activity	Beta activity	0.37 ± 0.01 0.64 ± 0.01*
Artificial radionuclides*	Cesium-137	0.026 ± 0.008*
	Iodine-131	0.042 ± 0.011*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

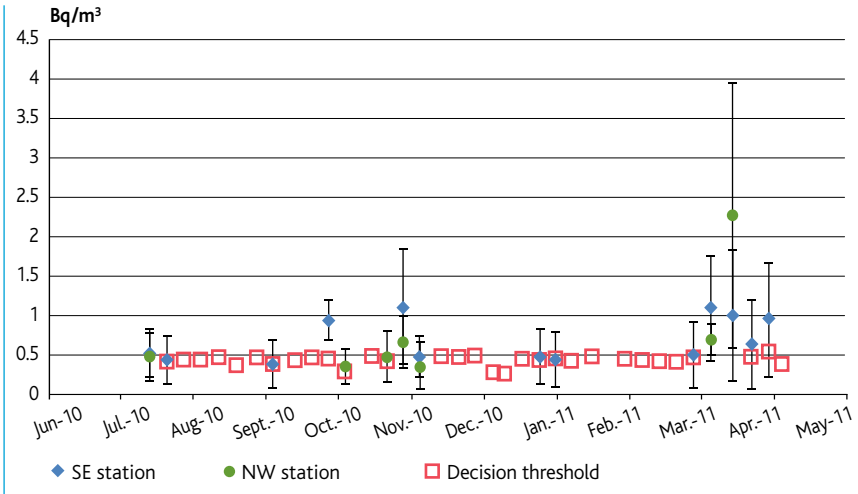


Figure VI.59 *– Atmospheric tritium activity measured near ILL (Bq/m³).*

Table VI.31 *— Gaseous iodine-131 activity measured in the ambient air near the Grenoble CEA center and ILL's reactor (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity or decision threshold (mBq/m³)
Artificial gaseous radionuclide	Iodine-131	< 0.30 0.29 ± 0.04*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

Rainwater

Tritium is regularly measured in the rainwater samples taken near the ILL site (*Figure VI.60*), where the atmospheric conditions are greatly influenced by the Isère river's transverse valley. The tritium's mean activity is 4.3 Bq/L. It should be noted that a higher tritium activity level was occasionally observed in March 2011, in both rainwater and air.

ILL also measured an iodine-131 activity concentration of 1.3 Bq/L, linked with the Fukushima accident, in a rainwater sample taken at the end of March 2011.

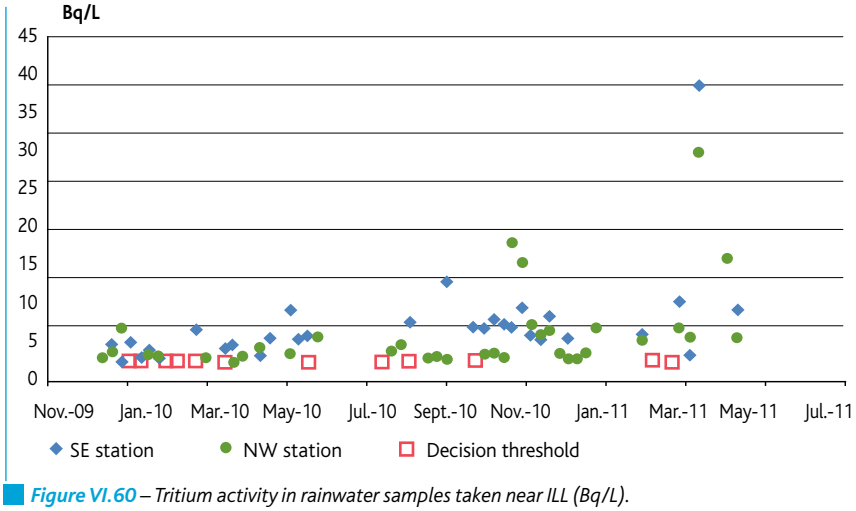


Figure VI.60 – Tritium activity in rainwater samples taken near ILL (Bq/L).

Terrestrial compartment

The CEA center's and ILL's environment is monitored by means of monthly or annual terrestrial plant, milk and cereal samples.

Terrestrial flora

The monthly grass samples taken from May to October 2010 near the Grenoble sites showed an added concentration of tritium, the measured activity levels varying between 0.7 ± 0.61 Bq/kg wet and 13.9 ± 1.1 Bq/kg wet for Grenoble and between 1.28 ± 0.49 Bq/kg wet and 9.5 ± 1.2 Bq/kg wet for Saint-Martin-d'Hères. This added concentration can be attributed to ILL's atmospheric discharge.

From March 23 to April 9, 2011, additional samples were taken in Varces-Allières-et-Risset and Gières. The additional samples were found to contain traces of iodine-131, with specific activities varying between 0.6 ± 0.2 Bq/kg wet and 1.6 ± 0.4 Bq/kg wet. These can be attributed to the Fukushima nuclear power plant accident in March 2011.

For more information
Chapter III – The Fukushima Accident

Agricultural production and foodstuffs

Milk

Analysis of the monthly cow's milk samples taken in a farm in Proveysieux has provided the results shown in Table VI.32. Free tritium, which can be attributed to ILL's atmospheric discharge, is regularly measured with activity levels close to the decision thresholds.

Cereals

No gamma-emitting radionuclides likely to be released by Grenoble's nuclear facilities have been detected in the wheat samples taken in Buisse.

The free tritium activity of the maize harvested in Voreppe is 4 ± 0.6 Bq/kg wet, which is close to the decision thresholds. This can be attributed to ILL's atmospheric discharge.

Leafy vegetables

In 2010, annual samples of Swiss chards and lettuce grown near the Grenoble CEA center and ILL were taken.

Analysis of the Swiss chards has not revealed any abnormal artificial activity. The measured radioactivity is mainly due to natural potassium-40, whose activity is 96 ± 12 Bq/kg wet.

Low free tritium activity levels linked with ILL's discharge have been measured in the lettuce sample (its specific activity is 4.1 ± 1.7 Bq/kg wet). This sample's carbon-14 activity level is 220 ± 50 Bq/kg of carbon, the value usually observed in zones outside the influence of any anthropic discharge (230 Bq/kg of carbon), to within uncertainty.

Table VI.32 – Mean activity levels measured in milk samples taken from cows reared near the Grenoble CEA site (Bq/L).*

Radionuclide	Activity (Bq/L)
^{40}K	48.1 ± 1.2
^{137}Cs	< 0.05
HTO	2.32 ± 0.31

** Unless specified otherwise*

Continental aquatic compartment

Surface water

ILL's liquid radioactive waste and storm water are discharged, after checking, into the Isère river 1 km upstream of the point where it joins the Drac, which flows into the left side of the Isère. The cooling water is discharged into the Drac 1 km upstream of the point where it joins the Isère. The waste water produced by ILL is discharged into the municipal drain for processing by Grenoble's municipal water treatment plant.

Analysis of the data shows that ILL does not have a significant influence on the radionuclide levels measured in the Isère or the Drac, as the tritium activity levels measured upstream and downstream of the facility are roughly equal at approximately 2.5 Bq/L (*Figure VI.61*).

Sediments

Sediment samples are taken in the Isère river at two points: annually, immediately downstream of ILL, and three times a year at the Saint-Égrève dam downstream from the Grenoble CEA center. The main results are shown in Table VI.33.

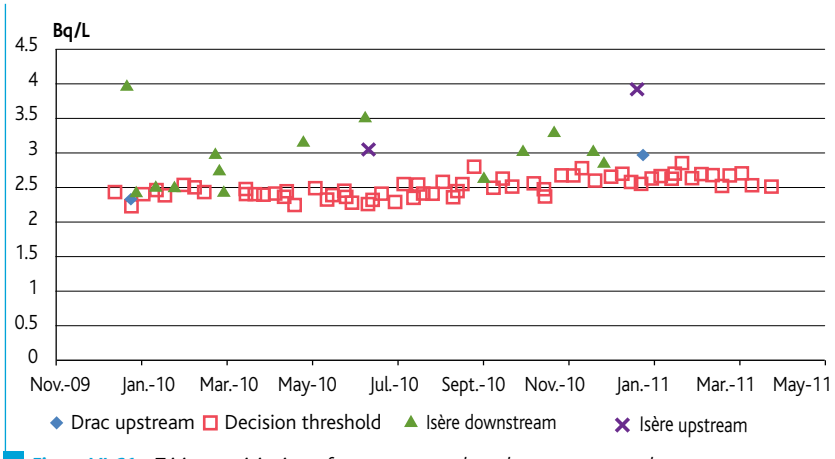


Figure VI.61 – Tritium activity in surface water samples taken upstream and downstream of ILL (Bq/L).

Table VI.33 – Activity levels measured in the sediment samples taken in the Isère river downstream of ILL in Grenoble (Bq/kg dry).

Radionuclide	Grenoble	Sassenage At Saint-Égrève dam
^{137}Cs	7.8 ± 1.7	5.9 ± 0.8
Other gamma-emitting radionuclides (^{124}Sb, ^{125}Sb, ^{110m}Ag, ^{134}Cs, ^{54}Mn, ^{58}Co, ^{60}Co, ^{106}Ru)	nm	< 11
^{241}Am	nm	0.087 ± 0.032
^{238}Pu	nm	< 0.06
$^{239+240}$Pu	nm	0.16 ± 0.06

Cesium-137 is found in all of the samples, at levels comparable to those measured in the Rhône river, outside the influence of nuclear facilities' discharge. Its presence in the Isère downstream from Grenoble's nuclear facilities is therefore mainly due to past atmospheric fallout (the Chernobyl accident and nuclear weapons testing). Traces of artificial transuranium radionuclides (^{241}Am and $^{239+240}$Pu) due to fallout from nuclear weapons testing are also regularly detected.

Ground water

ILL is located on the Grenoble alluvial plain, which is completely flat. Its flatness is due to the flow of the Isère glacier, with the Drac's ice flowing through the Isère's transverse valley. The ground water is generally close to the surface.

ILL monitors the layer's radioactivity using three piezometer networks whose median tritium concentration is approximately 2.5 Bq/L, with a maximum value of 5.2 Bq/L measured in November 2010 (*Figure VI.62*). These values should be viewed in relation to those measured in the Isère, which are of a similar size.

Continental aquatic fauna

In 2010, low cesium-137 activity levels were measured in the annual fish samples taken in the Isère river near Grenoble's nuclear sites (0.063 ± 0.013 Bq/kg wet). The other gamma-emitting radionuclides likely to be discharged by these facilities remained below the decision thresholds of the measuring devices used.

Continental aquatic flora

In 2010, ILL began taking annual reed samples in the Isère river, 11 km downstream of the facility. Of all the radionuclides likely to be discharged by Grenoble's nuclear facilities, only carbon-14 is detected with a specific activity of 320 ± 140 Bq/kg of carbon. Given the associated uncertainty, this measurement is difficult to interpret even though it is higher than the current background radiation in terrestrial environments (230 Bq/kg of carbon).

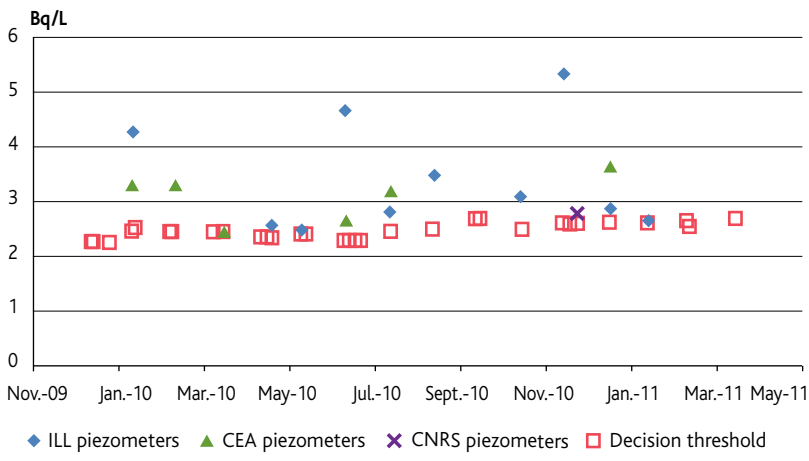


Figure VI.62 – Tritium activity in ground water near the ILL site (Bq/L).

VI.2 NUCLEAR NAVAL BASES

Four of France's military ports house naval nuclear bases. These nuclear facilities are all in or near major urban areas (Toulon, Brest and Cherbourg). In addition, these ports open onto bays with fragile ecosystems. Like all facilities, the French navy has its own laboratories specializing in radiological monitoring that take ground, atmospheric and marine samples in the port area and analyze them.

Note: the results of the marine aquatic compartment (sea water, sediments, and marine fauna and flora) are presented in Chapter IV (*"Coast"*).

Brest and Île-Longue military ports

Brest military port, in northwestern France, is the base of the French Atlantic Squadron and Strategic Oceanic Force (FOST) and France's nuclear-powered attack submarines. Ever since France's nuclear-powered ballistic missile submarines (SNLE) came into existence in 1970, they have also been based at Île Longue submarine base. Whenever an nuclear submarin returns to the base after a patrol, it is withdrawn from operation for several weeks of maintenance. The main mission of Île Longue, however, consists in fitting each submarin with its sixteen intercontinental missiles (each of which can carry six nuclear warheads) when it has just been built in Cherbourg or after a two-yearly major refit in Brest.

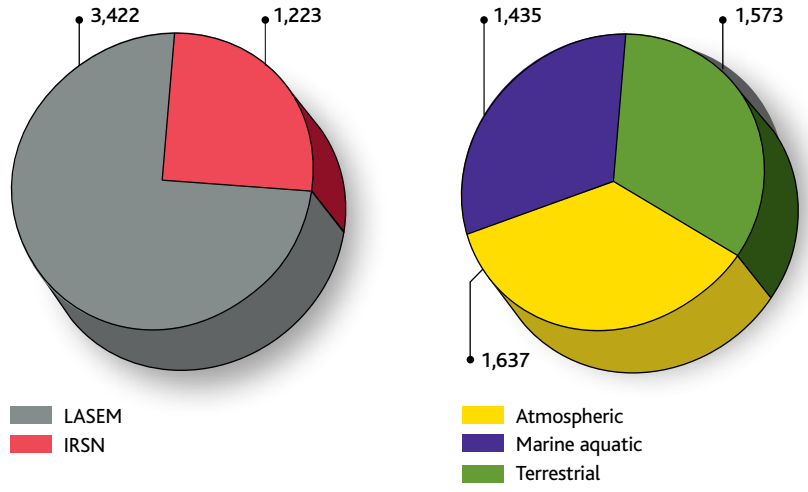


Figure VI.63 – Brest military port: sample distribution by data producer and by compartment.

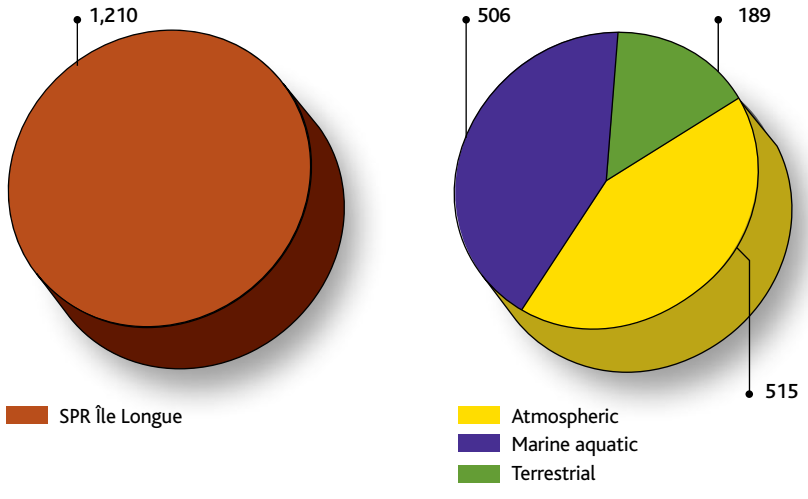


Figure VI.64 – Île Longue military base: sample distribution by data producer and by compartment.

Atmospheric compartment

Atmospheric aerosols

Apart from the readings taken during the period of the Fukushima accident, the monitoring of beta activity levels (*Figure VI.65*) has not revealed any abnormal values. The gamma spectrometry measurements have shown that, with the exception of natural radionuclides (^{7}Be, ^{210}Pb, ^{228}Ac and ^{235}U), no artificial radionuclides were present in the environment.

In the Brest military port's environment, significant cesium-134, cesium-137 and iodine-131 activity levels were observed between the end of March and the beginning of May 2011 (*Table VI.34*). These findings can be attributed to air masses passing over France after being contaminated by the Fukushima nuclear power plant accident. An increase in the gross beta activity between the end of March and the end of April 2011 was also observed (*Tables VI.34 and VI.35, and Figure VI.65*). This can be attributed to the presence of artificial radionuclides linked with the Fukushima accident.

For more information
Chapter III – The Fukushima Accident

Rainwater

Traces of lead-212 and lead-214 alone are occasionally measured in the rainwater samples taken near the Brest military port. The iodine-131 measured in the rainwater in March 2011 can be viewed in relation to releases linked with the Fukushima accident.

For more information
Chapter III – The Fukushima Accident

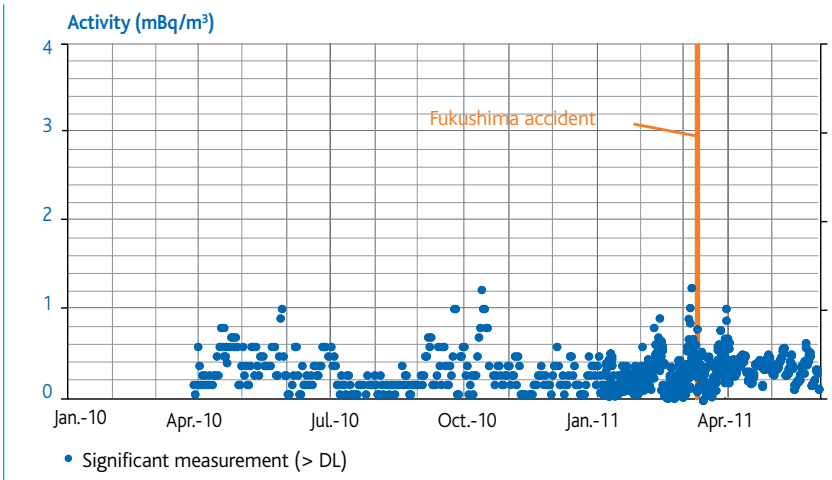


Figure VI.65 *— Time plot of gross beta activity of atmospheric aerosol samples taken near Brest, Île Longue and Cherbourg military ports (mBq/m³).*

Table VI.34 *— Activity levels measured in Brest military port's environmental aerosols (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Gross activity	Gross beta activity	0.20 ± 0.01 0.45 ± 0.01*
Artificial radionuclides during the period of the Fukushima nuclear power plant accident	Cesium-134	0.006 ± 0.001*
	Cesium-137	0.005 ± 0.001*
	Iodine-131	0.067 ± 0.006*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

Table VI.35 *– Beta activity indices of the Île Longue military base's environmental aerosols (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Gross activity	Gross beta activity	0.18 ± 0.01 0.60 ± 0.01*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

Terrestrial compartment

The military ports of Brest and Île Longue are monitored by means of regular soil, terrestrial plant and agricultural production samples (milk, meat, fruit and vegetables) taken in the immediate vicinity of these sites.

Terrestrial flora

Monthly grass and common gorse samples are taken near Brest military port, in Brest, Guipavas, Plougastel-Daoulas, Roscanvel and Crozon.

Traces of iodine-131 and cesium-134 and cesium-137 due to the Fukushima nuclear plant accident on March 11, 2011 were periodically measured in the grasses between the end of March and the beginning of April 2011 in Brest military port's environmental monitoring stations. These radionuclides have also been measured at the beginning of April 2011 in the common gorse samples taken at Guipavas Airport, Pointe des Espagnols in Roscanvel and Le Fret in Crozon. Only iodine-131 has been measured in the common gorse samples taken in the Quatre Pompes submarine base in Brest. The iodine-131 activities measured in the different samples vary between 0.14 ± 0.1 Bq/kg dry and 14.5 ± 1.4 Bq/kg dry.

For more information
Chapter III – The Fukushima Accident

Except during the Fukushima accident period, no artificial gamma-emitting radionuclides that could be attributed to these military bases' activities has been measured in the grass and common gorse samples.

Soils

Annual soil samples are taken in the area surrounding these sites. Apart from the presence of natural radionuclides, these soil samples' analytical results have indicated the presence of cesium-137, at activity levels comparable to those found throughout France. This can be attributed to past atmospheric fallout from nuclear weapons testing and the Chernobyl accident (*Table VI.36*).

Table VI.36 – Activities measured in soil samples taken around the Brest military base (Bq/kg dry).

Radionuclide	Guipavas Airport	Brest French Naval Laboratory lawn	Roscanvel Pointe des Espagnols	Crozon Le Fret	Crozon Pointe de Renard
^{137}Cs	4.28 ± 0.3	6.23 ± 0.3	28.4 ± 0.8	0.3 ± 0.13	5.84 ± 0.28
^{134}Cs	nm	< 0.47	< 0.6	< 0.19	nm
^{131}I	nm	< 1	< 0.9	< 1	nm
^{60}Co	< 0.17	< 0.22	< 0.24	< 0.2	< 0.13
^{110m}Ag	< 0.18	< 0.23	< 0.26	< 0.21	< 0.13
^{40}K	647 ± 19	865 ± 19	469 ± 12	495 ± 23	475 ± 17
^{228}Ac	56 ± 7	38.7 ± 3.6	54 ± 4.8	nm	62 ± 8
^{212}Pb	53.1 ± 1.9	41.1 ± 1.2	55.2 ± 1.6	nm	60.9 ± 2.2
^{214}Pb	48.7 ± 2.1	34.9 ± 1.4	44.8 ± 1.5	nm	33.2 ± 1.5
^{234}Th	49 ± 22	32 ± 11	36 ± 12	nm	41 ± 17
^{235}U	nm	4.2 ± 0.5	5.4 ± 0.6	nm	4.64 ± 0.28

nm: not measured

Agricultural production and foodstuffs

Milk

Monthly cow's milk samples are taken at three farms in Daoulas, Guipavas and Crozon. This monitoring was supplemented by a one-off goat's milk sample taken on April 5, 2011 to assess the effects of the Fukushima nuclear power plant accident on March 11, 2011 upon metropolitan France. The milk's measured radioactivity is mainly due to natural potassium-40, whose mean activity concentration is 42.3 ± 0.3 Bq/L in cow's milk and 47.4 ± 2.1 Bq/L in goat's milk.

The presence of iodine-131 in the three cow's milk samples taken at the beginning of April 2011, which had activity concentrations of between 0.10 ± 0.03 and 0.34 ± 0.04 Bq/L, is linked with the Fukushima nuclear power plant accident. Similarly, low iodine-131 and cesium-137 activity levels have been measured in the cow's milk from Plougastel-Daoulas, with activity concentrations of 0.78 ± 0.05 and 0.036 ± 0.026 Bq/L, respectively.

No artificial gamma-emitting radionuclides have been measured outside this period.

Meat

The annual radioactivity analysis of rabbits reared in Plougastel-Daoulas has shown that there are no artificial radionuclides in the flesh, skeletons or viscera.

Fruit and vegetables

Normally, no artificial gamma-emitting radionuclides are measured in the fruit and vegetables grown around Brest military port. The measured radioactivity is mainly due to natural potassium-40, whose activity levels are shown in Table VI.37. The lettuce sample taken on April 26, 2011 in Guipavas had a low cesium-137 specific activity of 0.039 ± 0.036 Bq/kg wet, which could be attributed to the Fukushima nuclear power plant accident that occurred the previous month.

Table VI.37 – Mean potassium-40 activities measured in the fruit and vegetables produced near the Brest military base (Bq/kg dry).

Species	Activity
Apple	46.9 ± 2.2
Lettuce	114.2 ± 2.4
Leek	98 ± 1.9
Cabbage	71.5 ± 2.8
Turnip	121.5 ± 4.4
Parsley	271 ± 12

Cherbourg military port

Cherbourg military port, on France's northern coast, houses the French defense procurement agency (DGA) and is mainly responsible for building or dismantling the nuclear-powered attack and ballistic missile submarines built by the French shipbuilding directorate (DCN). It also provides the French naval forces and visiting foreign ships with logistics support.

Atmospheric compartment

Atmospheric aerosols

Apart from natural radionuclides, no artificial radionuclides have been measured in Cherbourg military port's environment (*Table VI.38*). Monitoring of the beta activity index (*Figure VI.65*) has not revealed any abnormal values.

Aquatic compartment

Ground water

Traces of actinium-228 (*Figure VI.67*), thallium-208, bismuth-214, lead-212 and lead-214 produced in the natural thorium and uranium-238 decay chains are occasionally measured in the ground water.

Tritium is measured in the ground water with activity levels of approximately 5.5 Bq/L; these vary between the decision threshold and 10.4 Bq/L during the period under study (*Figure VI.68*).

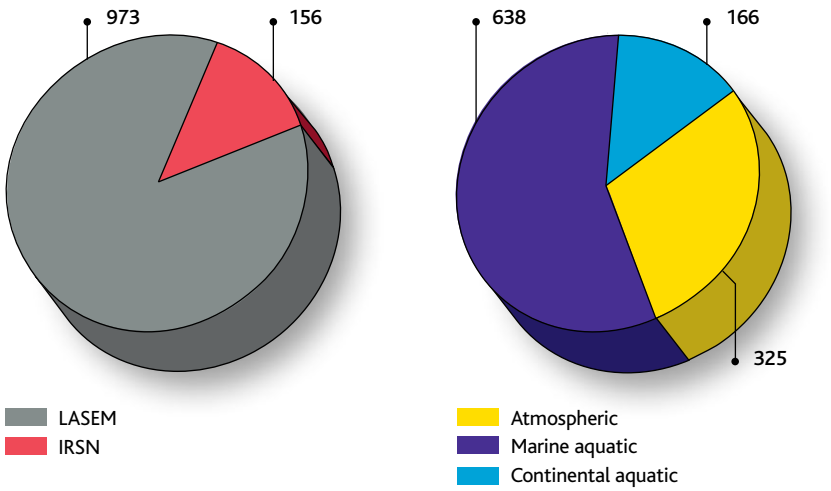


Figure VI.66 – Cherbourg military port: sample distribution by data producer and by compartment.

Table VI.38 – Natural radionuclide activities measured in Cherbourg military port's environmental aerosols (mBq/m³).

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Natural radionuclides	Beryllium-7	2.03 ± 0.03
	Potassium-40	0.053 ± 0.003
	Actinium-228	0.0024 ± 0.0003
	Uranium-235	< 0.0036

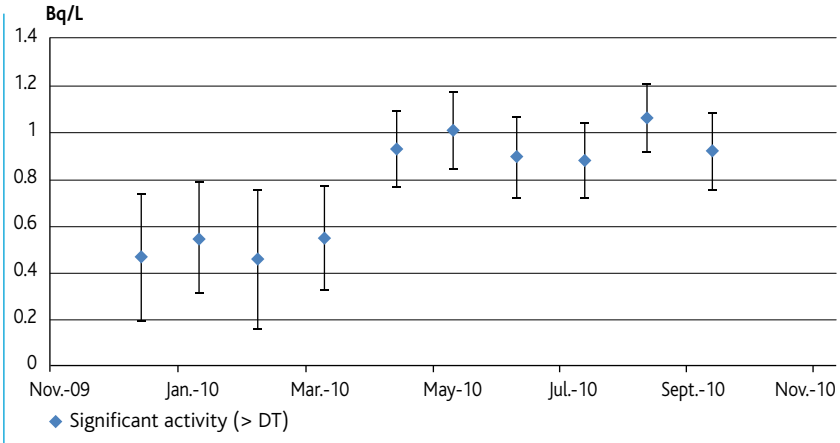


Figure VI.67 – Actinium-228 activity measured in ground water in the Homet zone near Cherbourg harbor (Bq/L).

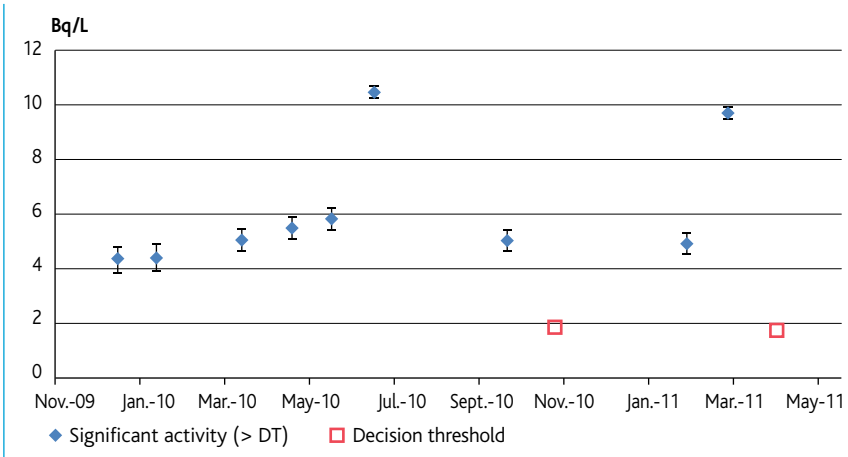


Figure VI.68 – Tritium activity measured in ground water in the Homet zone near Cherbourg harbor (Bq/L).

Toulon military port

Toulon military port, on France's southern coast, is the main French naval base, together with Brest. It mainly services most of France's naval action force, including its nuclear-powered attack submarines. Furthermore, 37 surface ships are based at Toulon; these include the aircraft carrier "Charles-de-Gaulle" (France's largest nuclear-powered surface vessel).

Atmospheric compartment

Atmospheric aerosols

In Toulon military port's environment, an increase in the beta activity index was measured between the end of March and the end of April 2011 (*Table VI.39*), which can be attributed to the presence of artificial radionuclides released in the Fukushima nuclear power plant accident.

Apart from this finding, no other abnormal beta activity index values have been observed.

Rainwater

Iodine-131 was measured in the rainwater samples taken in March and April 2011. This measurement can be linked with the Fukushima accident. No significant activity levels have been measured outside this period.

Terrestrial compartment

Terrestrial flora

Regular samples of shrubs (mastics and cypresses) and aromatic herbs are taken around Toulon military port. Analysis of these samples has not revealed any abnormal activity resulting from the Toulon site's nuclear activities.

Only a few traces of iodine-131 have been measured in a mastic sample taken on April 4, 2011 with an activity of 4 ± 1.9 Bq/kg dry; these can be attributed to the Fukushima nuclear power plant accident in Japan on March 11, 2011.

For more information
Chapter III – The Fukushima Accident

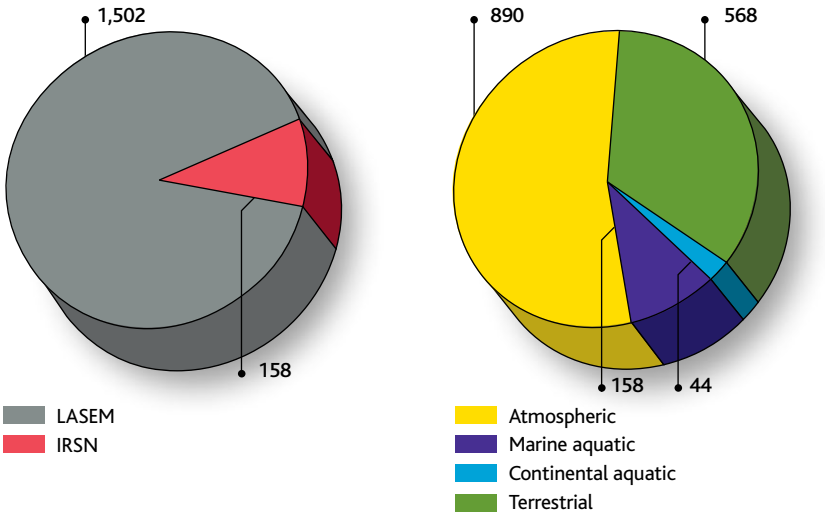


Figure VI.69 *– Toulon military base: sample distribution by data producer and by compartment.*

Table VI.39 *– Beta activity indices of Toulon military port's environmental aerosols (mBq/m³).*

Radionuclide type	Radionuclide	Mean activity (mBq/m³)
Gross activity	Gross beta activity	0.18 ± 0.01 0.33 ± 0.01*

** Measurements taken during the period of the Fukushima nuclear power plant accident between March 22 and May 6, 2011.*

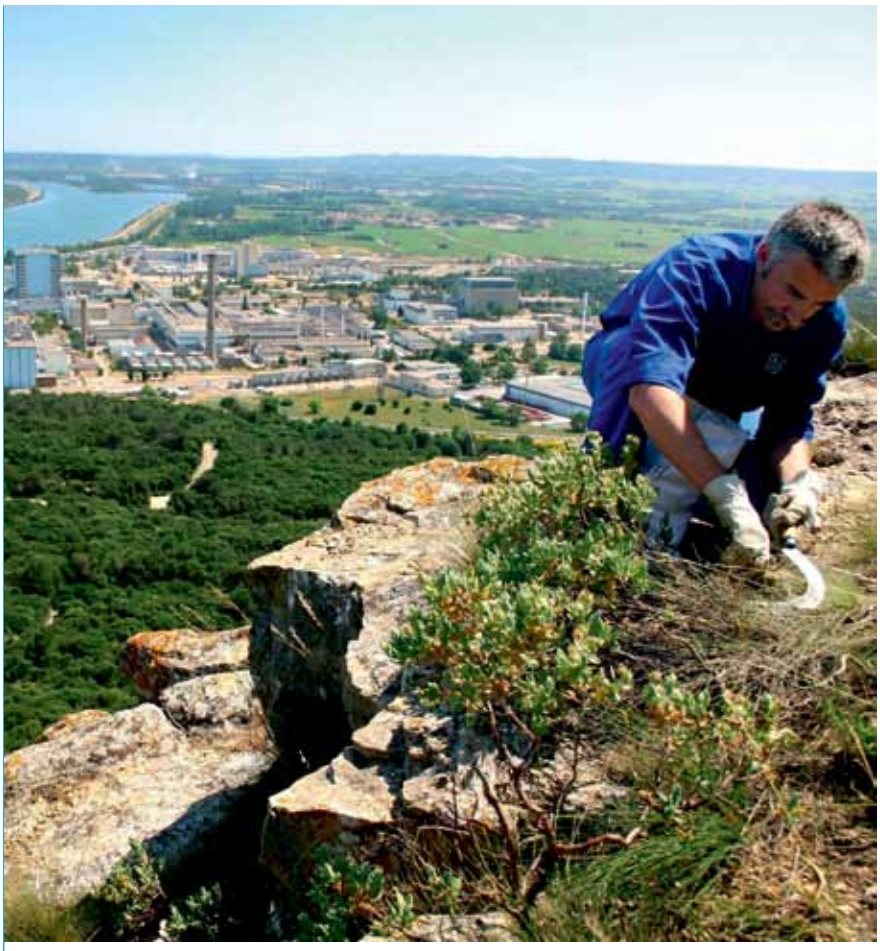
Agricultural production and foodstuffs

Fruit and vegetables

No artificial gamma-emitting radionuclides have been measured in the fruit and vegetables grown around Toulon military port. The measured radioactivity is mainly due to natural potassium-40, whose activity levels are shown in Table VI.40.

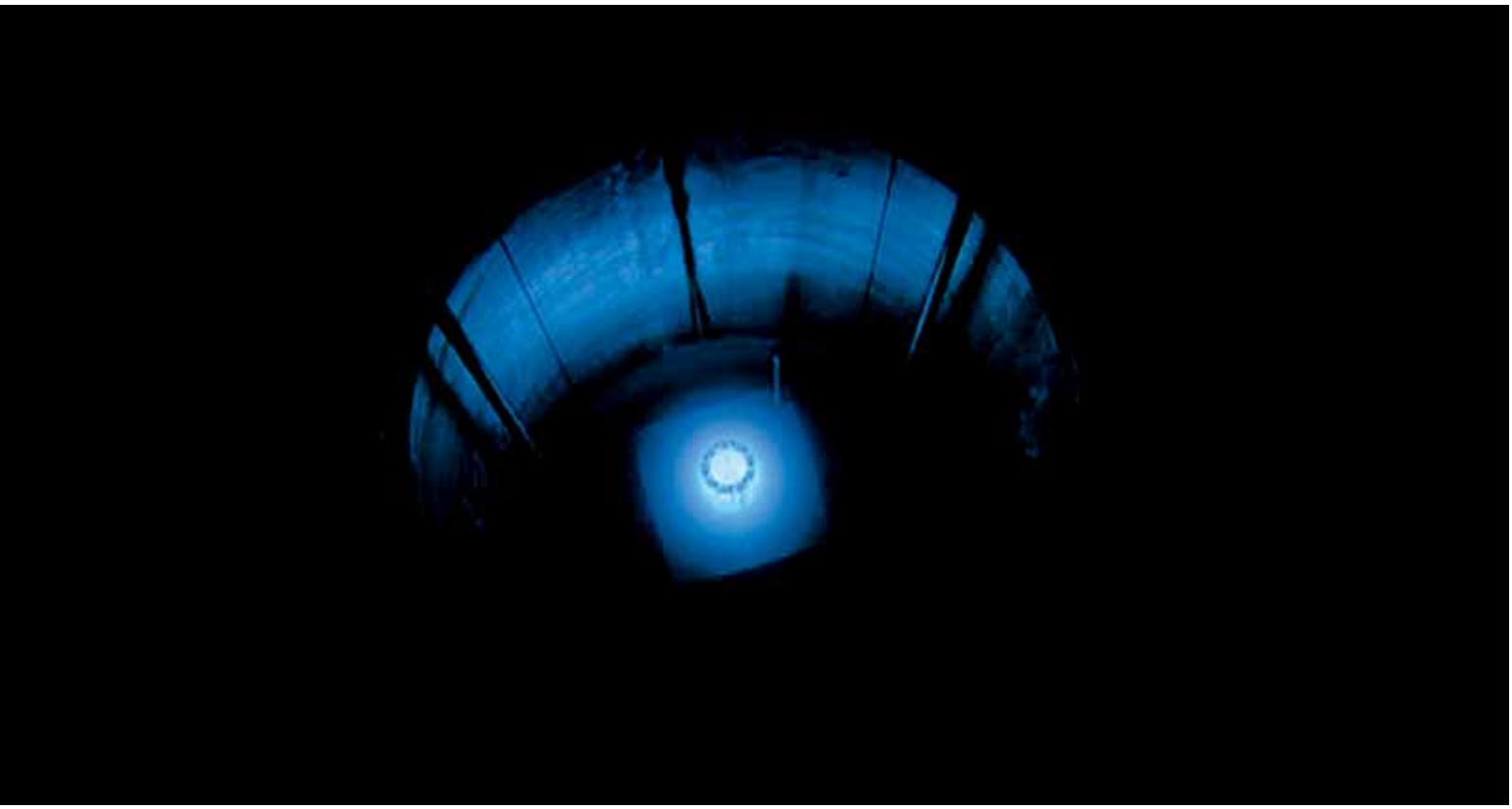
Table VI.40 *– Mean potassium-40 activities measured in the fruit and vegetables produced near the Toulon military base (Bq/kg dry).*

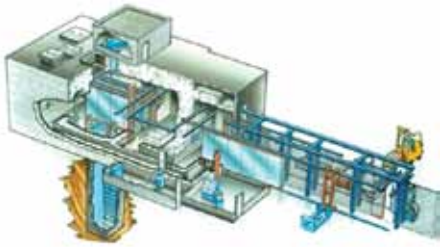
Species	Activity
Grape	154 ± 5
Tomato	80 ± 2.4
Lettuce	77.1 ± 1.8
Zucchini	136.1 ± 4.1
Potato	184 ± 6



© Areva NC

Figure VI.70 – Taking plant samples in the Marcoule site's environment.





VII

MONITORING OF FACILITIES THAT USE NATURAL OR ARTIFICIAL SOURCES OF RADIOACTIVITY

In addition to the principal nuclear fuel cycle (*Chapter V*) and research (*Chapter VI*) operators, a number of industrial sectors use raw materials containing naturally occurring radionuclides or employ ionizing radiation sources for a range of applications. Some of these facilities are classified as basic nuclear installations (INB) or environmentally regulated facilities (ICPE), and are therefore subject to regulatory environmental radioactivity monitoring.

Industrial facilities operating with raw materials that contain naturally occurring radionuclides

A number of modern and traditional industrial activities generate large volumes of low-level radioactive waste: **radium-bearing waste**. As its name indicates, this type of waste contains trace amounts of radium and radium progenies from the uranium decay chain, which occur as trace elements in the Earth's crust. Some radium-bearing waste occurs as a result of clean-up activities at contaminated sites formerly involved in the radium industry, which flourished during the pre-war period. More recent sources of such waste include the processing of very low-level radioactive mineral ores such as monazite, which contains rare earths and their oxides in variable proportions. The terms **rare earths** and **lanthanides** refer to a group of around fifteen chemical elements with similar structures and properties.

Monazite ore is particularly rich in rare earths, notably cerium, terbium and europium. Rare earths are used in an extensive range of applications including ceramic and glass-making, magnets, petrochemical catalysts, metalworking, cathode ray tubes and liquid crystal displays. Cerium is required for the manufacture of particle filters for diesel-engined vehicles. Monazite ore is also naturally rich in thorium and radium. In France, Rhodia has used this ore at its plant in La Rochelle, and it has also been used industrially at other locations, where thorium-contaminated process waste sometimes remains. Examples include sites in Serquigny, Thann and Pargny-sur-Saulx in northern and eastern France (*see Chapter III.3*).

The level of radioactivity in such radium-bearing waste tends to range from a few tens to a few thousands of becquerels (Bq) per gram. The principal radionuclides are long-lived alpha emitters. Radium-bearing waste is classified as low-level long-lived waste (LLW-LL). This category of waste will be subject to special conditioning and disposal requirements, currently being researched by ANDRA.

This chapter focuses on the case of the Rhodia Electronics & Catalysis (previously Rhodia Terres Rares) plant, which used monazite until 1994. The site has been subject to regular environmental radioactivity monitoring, including atmospheric and groundwater monitoring.

Industrial ionization facilities

Several industrial ionization facilities exist in France. These use gamma radiation to sterilize medical equipment or treat foodstuffs.

Irradiating food products destroys micro-organisms with no need to heat them. This process can be used to extend product shelf lives by preventing bulbs and tubers from germinating, eliminating parasitic insects in cereals and fresh fruit and vegetables, and pasteurizing and eliminating bacteria in fish and meat. Gamma radiation sterilization is used to eradicate harmful insects, for example. Multiple applications involving sterilization of objects such as medical devices and surgical instruments also exist. Gamma ray treatments are also used in the ethnological and archeological fields, to preserve and restore artworks and other artefacts.

The Ionisos group currently operates a network of ionization centers, respectively located in Pouzauges, Sablé-sur-Sarthe and Dagneux, and the Isotron group operates a facility in Marseille (*Figure VII.1*).

Figure VII.1 -Geographical location of the facilities covered in this chapter.

VII.1 RHODIA ELECTRONICS & CATALYSIS PLANT IN LA ROCHELLE

The Rhodia plant in La Rochelle on France's Atlantic coast is a "high-threshold Seveso" facility located on the Chef de Baie industrial estate to the west of the town center. The site accommodates production facilities as well as significant research and development resources.

© Rhodia

Figure VII.2 - Rhodia plant in La Rochelle.

From 1946 to 1994, the plant used monazite, a raw material that containes rare earths and trace natural radioactivity. In 1998, Rhodia acquired the chemicals business of Rhône-Poulenc. Monazite has not been processed directly in La Rochelle since 1994. Rhodia now receives concentrates from China, where they have been processed to largely strip them of their naturally occurring radionuclides. However, activities at the La Rochelle site over a sixty-year period generated a significant quantity of radium-bearing waste.

Rhodia stores approximately 20,000 metric tons of untreated thorium hydroxide and 11,000 metric tons of thorium nitrate, essentially at its La Rochelle facility. The thorium 232 activity of these products is around 720 Bq/g and 1,650 Bq/g, respectively. Since monazite processing in La Rochelle ended in 1994, Rhodia no longer produces these products. These materials may be of use as a power source for the nuclear industry if "fast-neutron" reactors are developed in the future. Rhodia also has suspensions containing potentially recoverable rare earths.

Until 1974, the plant discharged liquid and solid waste into the sea off Port-Neuf beach (La Rochelle bay). Prior to 1991, the plant shipped part of its solid waste to ANDRA's CSM waste disposal facility, and thereafter to temporary storage facilities at the CEA center in Cadarache. Rhodia owns approximately 13,300 metric tons of waste, in the form of:

- **radium-bearing waste** ("RRA") almost 200 tons of which are stored in La Rochelle (with a total average specific activity of around 1,600 Bq/g);
- **general solid waste** ("RSB") consisting of spoil contaminated with ore leaching residues and miscellaneous waste (including packaging and scrap metal), of which 8,000 tonnes are stored in La Rochelle (with a total average specific activity of around 75 Bq/g).

This waste is included in the provisional inventory of waste that will be stored at ANDRA's planned LLW-LL repository.

The radiological impact of waste containing naturally occurring radioactive materials derives from the presence of naturally occuring radionuclides. Certain radionuclides have radioactive half-lives of several million years, and will therefore have time to migrate into the soil, surface water and ground water. Transfers to the atmosphere are also possible in the shorter term. This migration to the natural environment may result in environmental contamination and radiological impacts on the population. As an environmentally regulated facility (ICPE), the Rhodia plant in La Rochelle is therefore subject to regulatory monitoring of radioactivity in the air (measured by passive dosimetry), in the water in the liquid waste treatment pond (1 sampling point) and in ground water (13 sampling points).

© ANDRA

Figure VII.3 - Radium-bearing low-level long-lived waste stored at the Rhodia plant in La Rochelle.

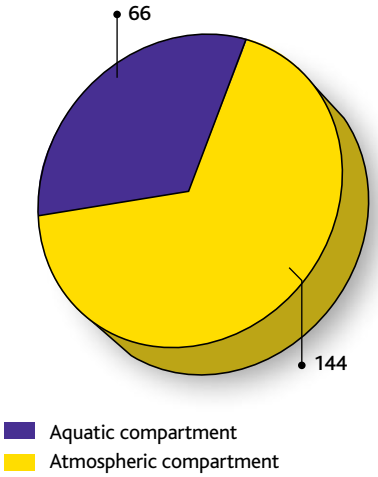


Figure VII.4 - Rhodia Electronics & Catalysis plant in La Rochelle - Number of measurements per compartment

Atmospheric compartment

Radioactivity is also monitored at the site perimeter using various sampling devices and measuring instruments. This monitoring concerns external exposure (gamma radiation measurements) and internal exposure by inhalation (measurement of the potential alpha energy generated by short half-lived decay products of radon-220 and radon-222, and measurement of the concentration of long half-lived alpha emitters carried in dust).

The results obtained from 22 passive gamma dosimeters installed along the site perimeter are sent to the National Environmental Radioactivity Measurement Network (RNM). The measured values range between 110 nSv/h and 417 nSv/h, with a mean value in the region of 230 nSv/h. These results must be compared with IRSN's mean values for the town of La Rochelle (78 nSv/h) and for the Poitou-Charentes region (119 nSv/h). Certain results are significantly abouve the regional background level, reflecting the signature left by the plant's activities, particularly waste storage. Rhodia erected buildings in which to store untreated thorium hydroxide, in order to decrease the dose rates associated with this storage activity.

For more information
Chapter IV – Atmospheric compartment

Aquatic compartment

Each year, two sampling campaigns are conducted using referenced piezometers. The data is analyzed in order to monitor the following parameters: ^{232}Th or total thorium, ^{238}U or total uranium, ^{226}Ra, ^{228}Ra, lead, dissolved manganese, dissolved mercury, dissolved nickel and ammonium. All liquid waste from the plant's chemical network is carried to the treatment station, where it is treated and made compliant with applicable standards before being discharged into the sea in La Rochelle bay. Checks are performed at point B to determine the waste's radiological and physical-chemical properties.

The La Rochelle facility extracts water from the industrial water table via a borehole (known as the Puits de Vaugouin) located near the plant. The ground water is monitored using piezometers in various locations on the Rhodia site.

Most of the measurement results for radium 226 (a decay product of uranium-238) at the water monitoring points at this site range between the decision threshold (0.0044 Bq/L) and 0.06 Bq/L. These activity levels are representative of or similar to the natural background level. Only the radium-226 readings measured by piezometers A, B and D (ground water) exceed 0.1 Bq/L, revealing a signature related to the facility's activities. The highest value (0.25 +/- 0.075 Bq/L) was measured in April 2010.

The activity levels for radium 228 (a decay product of thorium-232) measured in the water samples range between the decision threshold (0.014 Bq/L) and the maximum value of 0.48 Bq/L. The vast majority of results are below the decision thresholds. The other activity measurements are moderate, although the peak values measured at points B, D and F2 reflect the signature of the site's activities. The highest radium 228 activity value measured in the water treatment pool (point B) in 2010 was 0.13 +/- 0.03 Bq/L.

Uranium content values are below or close to the guide value of 30 µg/l of uranium recommended by the WHO for water intended for human consumption. The activity levels measured in the water treatment pool (point B) in 2010 were below or close to the decision thresholds and not indicative of any impact by the site's activities.

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Radiological impact of sediment dredging in the port of La Rochelle

In 2009, the municipal council in La Rochelle initiated a project to expand the town's Minimes marina. This entailed dredging approximately 1,000,000 m^3 of sediment to be deposited in the Antioche trench. La Rochelle council commissioned IRSN to provide technical support by assessing the radiological impact of the planned work on workers and the population. A core drilling campaign was conducted between July 20 and August 7, 2009. A total of 111 samples of the sediments to be dredged were collected at 31 sampling stations, followed by two samples at two reference stations located in Fier d'Ars (an area not subject to industrial impacts) and five samples of beach sand. These samples were collected and analyzed in accordance with an IRSN-approved protocol. The results were submitted to IRSN, enabling the Institute to perform the requested assignment.

This exhaustive assessment revealed that the choice of reference stations was appropriate, that the activity levels measured in beach sand reflected the activity of any radionuclides present in the (small) sandy fraction of the sediments to be dredged (approx. 5 Bq.dry for the thorium-232 and uranium-238 chains). The activity levels measured in this sediment were not significantly different from those measured in sediment at the reference stations (approximately 30 Bq.kg-1 dry for the thorium-232 and uranium-238 chains), although a few specimens revealed sporadic, moderate industrial effects (attributable to waste from the Rhodia plant located 3 km away, which produces rare earths from thorium-bearing monazite).

The radiological impacts on workers assigned to the sediment dredging operations and on the general population were estimated based on the activity measurements made on the sediment samples. The maximum effective dose calculated for workers assigned to sediment dredging operations is 0.012 mSv. The maximum effective dose calculated for the population group of adult professional fishermen who consume large amounts of fish or seafood is 0.035 mSv.year^{-1}. Although based on pessimistic assumptions, the calculated doses are low, and well within the limit of 1 mSv.year^{-1}.

VII.2 INDUSTRIAL IONIZATION FACILITIES

Industrial ionization facilities use gamma radiation (mainly from cobalt-60 sources) to sterilize medical devices and treat food products.

In such facilities, the irradiation process takes place in a chamber containing very highly radioactive cobalt-60 sources. The products to be irradiated are placed on trays on a conveyor belt, which carries them into and out of the irradiation chamber through a "labyrinth" (*Figure VII.5*). The irradiation chamber contains a pool in which the cobalt-60 sources are stored while not being used for irradiation phases. The water in this pool acts as a screen, blocking radiation from the sources. Products are irradiated with the sources raised out of the water.

The cobalt 60 sources consist of rods supported by one or more source holders. The source holders are raised and lowered by a system of mechanically operated winches and cables.

Ionizers pose very little risk to the general population and the environment. The main potential risk relates to the exposure of employees to ionizing radiation. This risk is managed by installing radiation protection - thick walls in the irradiation chamber for when the ionizer is in operation and the water in the storage pool at other times - and implementing safety measures to control employee access to the irradiation chamber and manage source movements.

Although classified as basic nuclear installations, ionizer facilities are subject to regulatory environmental radioactivity monitoring to prevent contamination.

Facilities operated by the Ionisos group

Ionisos provides radiation treatment services using either a cobalt-60 source (for gamma radiation) or an electron accelerator.

The Ionisos group operates mainly in the following three markets:

- **sterilization:** sterilization of single-use medical devices; sterilization and decontamination of packaging, raw materials and end products for pharmaceutical and cosmetics, sterilization and decontamination of laboratory equipment;
- **radiation chemistry:** packaging film cross-linking, glass tinting and modification of plastic components to alter their properties;
- **ionization for food processing applications:** germination-inhibiting treatment, disinfection and debacterization of dried and frozen products as well as fresh produce.

Ionisos operates four facilities in France:

- An electron particle accelerator in Chaumesnil, southeast of Paris;
- Three gamma irradiation centers, respectively located in Dagneux near Lyon, Pouzauges in western France and in Sablé-sur-Sarthe in eastern Brittany. These facilities, classified as basic nuclear installations, are subject to environmental monitoring.

The only radioactive waste produced at these facilities is very low-level waste (VLLW) resulting from the various operations performed on the water in the pool in which the cobalt-60 source is stored. This waste is packed in hermetically sealed containers and stored in dedicated enclosed storerooms pending dispatch to ANDRA's very low-level waste disposal facility in Morvilliers in eastern France. Only a small quantity (< 1 m^3) of VLLW is produced each year. This waste does not interact with waterways and ground water. The ground water system is nevertheless subject to monthly radioactivity checks to ensure that the water is uncontaminated.

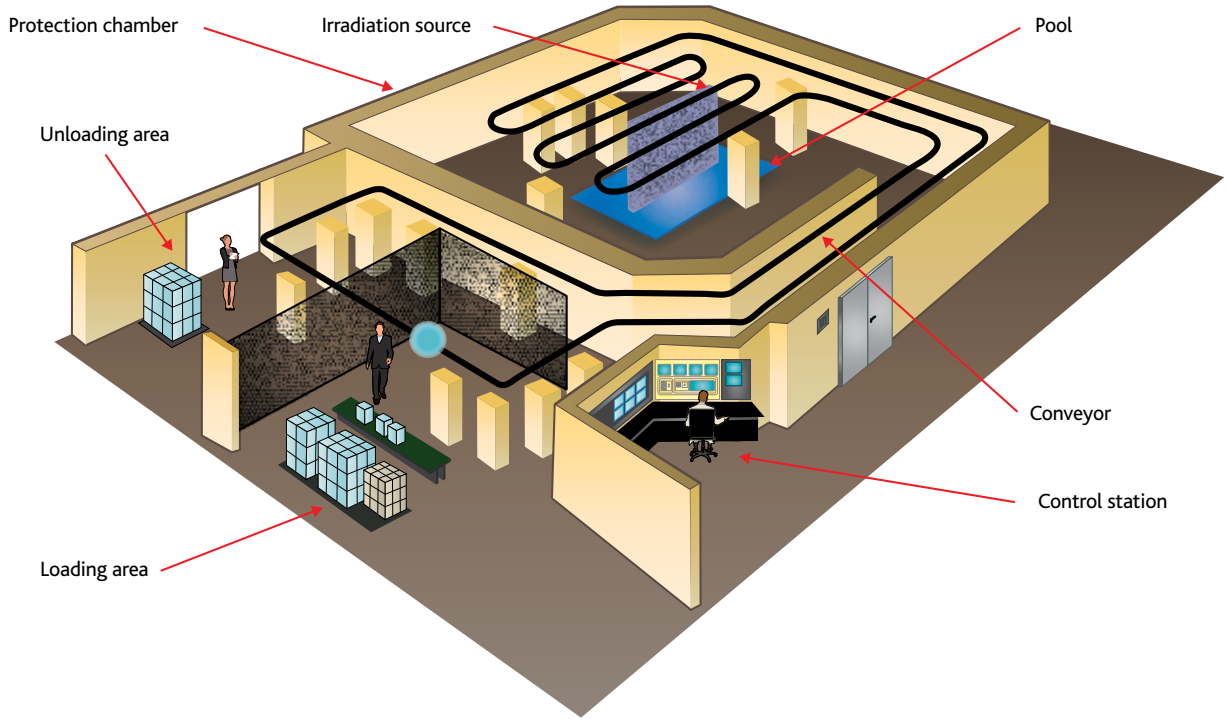

Figure VII.5 - Overview of an industrial ionizer.

Ionisos irradiation facility in Dagneux

Basic nuclear installation No. 68 (*Figure VII.6*) is located in Dagneux, 25 km east of Lyon in south-east France. This INB houses three irradiation units:

- Irradiation units D1 and D2, which are no longer in service;
- Irradiation unit D3, which was built in 1972 and remains in operation.

Ground water is monitored to track the gross beta activity index. In addition to this monitoring, gamma spectrometer measurements on these monthly samples are made, to quantify any gamma-emitting radionuclides released from the site (only cesium -137 and cobalt-60 measurements are submitted to the national environmental radioactivity measurement network (RNM).

Gross beta activity levels range between the decision threshold (<0.03 Bq/L) and 0.074 +/- 0.041 Bq/L (i.e. the highest value measured in December 2010). The gross beta activity readings do not indicate that the ground water has been particularly affected by the site's activities, and are far below the baseline value of 1 Bq/L stipulated in the public health code applicable to water intended for human consumption. Similarly, the results of the gamma spectrometry measurements did not reveal any detectable cesium-137 or cobalt-60 activity (the measured values were below the decision thresholds of the instruments used, averaging <0.09 Bq/L).

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Figure VII.6 *- Ionisos irradiation unit in Dagneux.*

Ionisos irradiation facility in Sablé-sur-Sarthe

Basic nuclear installation No. 154 *(Figure VII.7)* is located in Sablé-sur-Sarthe, near the towns of Laval, Angers and Le Mans. This INB, which began operating in 1992, is equipped with a pallet irradiation unit.

The gamma radiation treatment process (using a cobalt-60 source) treats pallets in two independent trains arranged on either side of a flat source. The center has the capacity to treat 50,000 pallets per year. The plant operates using a fully automated system. Products are carried on an automated overhead conveyor and treated directly on full pallets or in big-bags with no human intervention.

Ground water is monitored to track the gross alpha and gross beta activity index. In addition to this monitoring, six-monthly radium 226 and gamma spectrometry measurements are performed on these samples, to determine the quantity of gamma-emitting radionuclides potentially released by the facility.

The average gross beta activity level is 0.36 Bq/L, which is not indicative of any particular impact of the site's activities on ground water. Similarly, the gross alpha activity readings, ranging between 0.061 and 0.070 Bq/L, are below the baseline value of 0.1 Bq/L stipulated in the public health code applicable to water intended for human consumption. The measurement results for radium-226 at the water monitoring point at this site range between the decision threshold (< 0.016 Bq/L) and a maximum value of 0.026</cf> Bq/L. These activity levels are representative of or similar to the natural background level. Similarly, the results of the gamma spectrometry measurements did not reveal any detectable cesium-137 or cobalt-60 activity (the measured values were below the decision thresholds of the instruments used, averaging <0.06 Bq/L).

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Figure VII.7 *- Ionisos irradiation unit in Sablé-sur-Sarthe.*

Ionisos irradiation facility in Pouzauges

Basic nuclear installation No. 146 (*Figure VII.8*) is located in Pouzauges , 38 km south of Cholet in western France. This INB is equipped with a pallet irradiation unit. Products are loaded into baskets suspended from an automated overhead conveyor system.

Six-monthly ground water samples are collected using a piezometer. The results of the gamma spectrometry measurements did not reveal any detectable cobalt-60 activity in 2010 or 2011 (the measured values were below the decision thresholds in the region of 0.2 Bq/L).

Isotron facility in Marseille

Isotron France SAS is a sterilization services provider based in Marseille. The company offers a range of services to manufacturers, including sterilization of medical devices and packaging, debacterization, insect eradication and microbial decontamination.

Isotron is registered as a data provider with the RNM network, owing to its operation of INB No. 147 in Marseille. The company has begun submitting data relating to the six-monthly samples collected in January and June 2011 at two ground water extraction points (P1 and P2). The results of these measurements had not been submitted to RNM by the date limit for processing data relating to the reference period covered by this assessment.

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Figure VII.8 *- Ionisos irradiation unit in Pouzauges.*

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VIII

FRENCH POPULATION EXPOSURE TO IONIZING RADIATION

VIII.1 AVERAGE EXPOSURE OF THE POPULATION IN FRANCE

All sources of natural and artificial radioactivity contribute to exposure levels. This exposure of the French population is assessed by IRSN (*Figure VIII.1*). French citizens receive an average total annual dose of approximately 3.7 mSv. This value, which varies according to geographical location and lifestyle, should be treated as a macroscopic indicator; it is not applicable to any particular group of people.

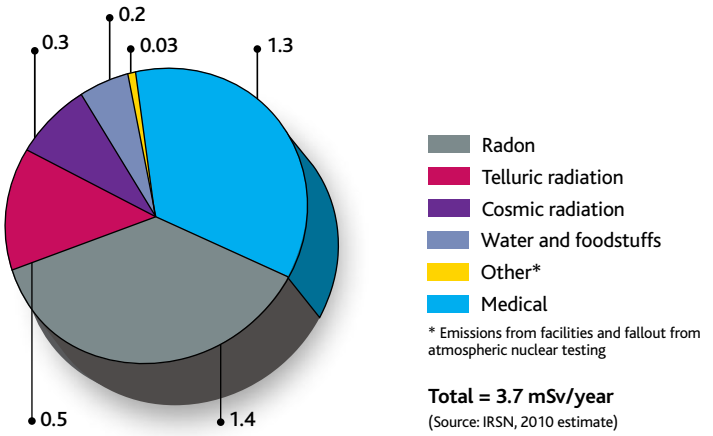

Figure VIII.1 - Average exposure to ionizing radiation of the population in France

Exposure due to natural radioactivity

The French population is exposed to natural radioactivity from several sources:

- **radon**, (*see IRSN Focus*), a gaseous decay product of uranium, may build up in homes, making a significant contribution to the mean dose (approx. 1.4 mSv per year per person). Exposure levels vary by a factor of 15 between the most and least exposed departments;
- **naturally occurring radionuclides present in the ground** emit terrestrial radiation resulting in an average external exposure (to ^{238}U, ^{235}U, ^{232}Th, ^{40}K, etc.) in the region of 0.5 mSv per year per person. In France, this exposure is subject to a variability factor of 5;
- **cosmic radiation** causes external exposure, which varies with altitude. The average dose is 0.28 mSv per year per person. At sea level, this value is around 0.27 mSv per year per person, rising to 0.38 mSv in the departments situated at the highest mean altitude;
- **exposure by ingestion of naturally occurring radionuclides present in food and water** represents 0.23 mSv per year per person, of which 0.18 mSv is attributable to potassium-40. This exposure depends on food intake and soil type.

Exposure to natural radioactivity accounts for an average of 65% of total annual exposure.

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Radon

*Radon is a naturally occurring radioactive gas. It results from the disintegration of uranium and radium found in the Earth's crust (*Figure VIII.2*). Originating primarily in granitic and volcanic subsoil and certain construction materials, radon is found everywhere on the Earth's surface.*
Lung cancer is the reason for vigilance with regard to radon, which sometimes builds up in homes and other enclosed spaces. Radon and its solid decay products enter the lungs along with inhaled air. These decay products emit alpha radiation which can cause cancer.

Migration to the atmosphere depends on two factors:

- ***Weather conditions** are among the factors that can cause radon concentrations to vary over time at a particular location. Depending on soil composition, weather conditions (wind, sun, rain, cold, etc.) will affect the migration of radon from the soil into the atmosphere.*
- ***Soil and rock properties:** radon concentrations vary across a region, depending on the natural uranium content of the subsurface. Granitic ground tends to*

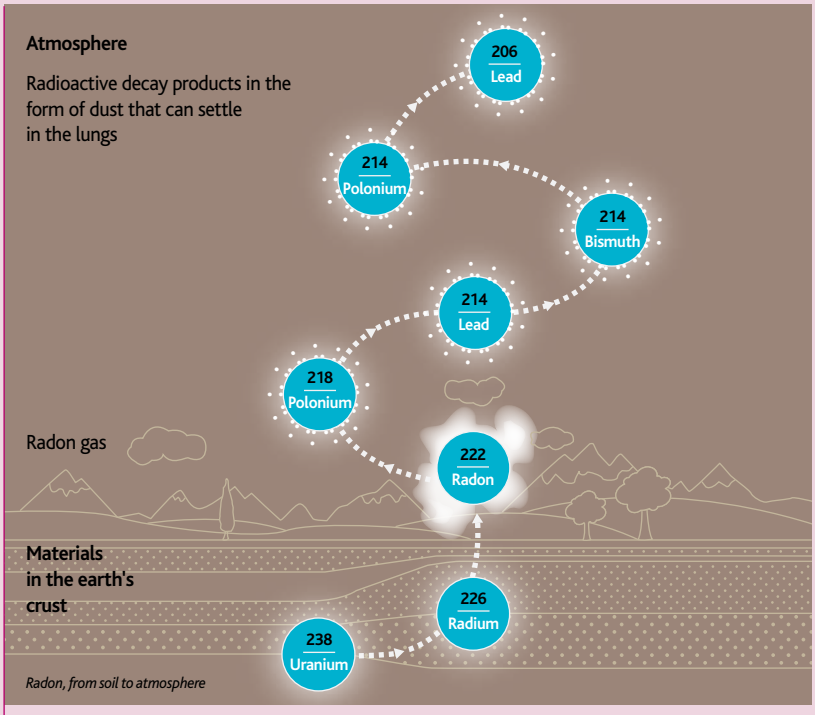

Figure VIII.2 - Radon - from the soil into the atmosphere

Exposure due to artificial radioactivity

The principal source of exposure to artificial radioactivity relates to the use of medical sources, particularly radiation-based diagnostic techniques (X-ray imaging, mammograms, scanner photography, etc.); such sources account for an average of 1.3 mSv per year per person. This dose is obviously not received uniformly by the population. Individual figures vary from less than 0.1 mSv to values well in excess of 1mSv per year per person, depending on the medical procedures to which patients are subject.

Industrial activities and nuclear facilities in normal operation account for only a very small fraction of the French population's total radiation exposure. The calculated doses for the most heavily exposed local populations do not exceed a few tens of µSv per year per person(1 µSv = 0.001 mSv), principally ingested in food products (>90%).

At national level, the average effective dose attributable to **residual consequences of the Chernobyl accident and atmospheric nuclear testing** is estimated to be between 0.01 mSv and 0.03 mSv per year per person (source: IRSN). The Institute's assessment of the dosimetry impact of **consequences of the Fukushima accident** on the French population are described in VIII.6.

release more radon than sedimentary land, due to the higher concentration of naturally occurring uranium.

Measurement campaigns and subsequent statistical interpretations have been carried out to estimate so-called "domestic" radon exposure (i.e. exposure to radon in homes) (see IRSN atlas). The average measured radon activity level in France has been estimated at 63 Bq/m³, with approximately half the results less than 50 Bq/m³, 9% greater than 200 Bq/m³ and 2.3% above 400 Bq/m³ (source: IRSN).

Radon is also present in all natural surface water and ground water, at variable activity concentrations. Radon originates in two ways:

- *the first, less significant formation process is radioactive decay of dissolved radium-226;*
- *the second process involves the dissolution of radon present in rock in which water sits or circulates, enabling it to travel to the water table or the surface. The radon concentration of water depends on the radon content of the rock from which it migrates, the geochemical conditions, and how long the water remains in the rock.*

In open air, radon dissolved in water is readily volatile. As a result, gaseous radon rapidly migrates into the atmosphere. The activity concentrations of radon in water vary considerably, ranging from a few becquerels per liter to several thousand. The highest activity concentrations are normally found where the water reservoir is formed by uranium-rich rocks.

Understanding the nature of the geological formations in a region makes it possible to map the areas in which high concentrations of radon in buildings are most likely to occur. Such a map provides a useful technical foundation to guide the implementation of a radon risk management strategy, combined with data resulting from measurement campaigns conducted to detect radon in buildings. To this end, the French Nuclear Safety Authority tasked IRSN with defining and implementing a method for mapping the radon potential of the ground throughout metropolitan France. These maps (example: Figure VIII.3*) cannot be used to predict radon concentrations inside buildings, and are therefore no substitute for onsite measurements.*

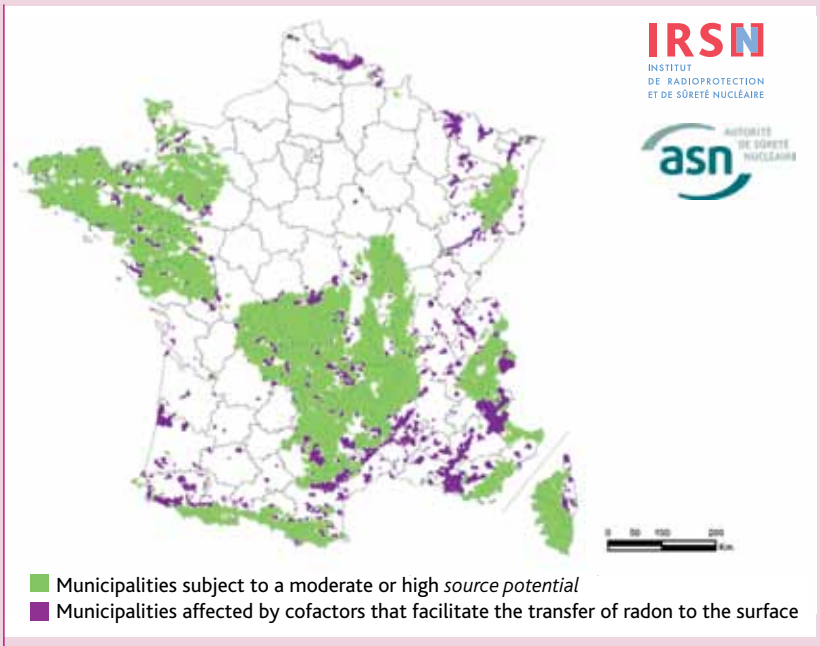

***Figure VIII.3** - Map of municipalities with at least some areas subject to moderate and/or high radon potential, due to the "source potential" of the underlying geological formations (shown in green) or as a result of aggravating factors such as faults, underground mine workings and hydrothermal vents (shown in purple).*

VIII.2 ASSESSING THE BIOLOGICAL EFFECTS OF RADIOACTIVITY ON LIVING ORGANISMS

The effects on individuals resulting from exposure to radionuclides are not measured directly. They are quantified using the effective dose for the entire body. The standard measurement unit for this dose is the sievert (Sv), or more often its subunits: the millisievert (1 mSv = 0.001 Sv) and the microsievert (1 µSv = 0.000001 Sv). With some radionuclides, the dose can also be calculated for a specific organ when the organ is more sensitive to the effects of radiation than the whole body (such as iodine for example, for which the target organ is the thyroid gland).

A distinction is made between **external and internal exposure**, depending on how the radiation comes into contact with the organism. External exposure is when an individual is exposed to sources of radiation that remain outside the body (for example, exposure to radionuclides in the air or in soil deposits); the received dose depends on exposure time. In the case of **internal exposure**, the radionuclide enters the organism - normally through ingestion or inhalation. The resulting internal radiation then continues after the radionuclide has entered the body, gradually decreasing based on the radioactive half-life of the incorporated radionuclide and the rate at which it is eliminated.

In the case of internal exposure caused by a radionuclide with a long half-life, the **commited dose is calculated**. This dose indicates, at the time of exposure, all the different "future" doses the individual will be exposed to over the entire time period required to completely eliminate the radionuclide. In cases where the radionuclide will remain in the body, the calculated period will be the lifetime of the individual, ranging from 50 years (for an adult) to 70 years (for an infant under 1 year old).

VIII.3 DOSES RECEIVED BY THE POPULATION AS A RESULT OF NUCLEAR ACTIVITIES

No overall monitoring method able to exhaustively determine the doses received by the population as a result of nuclear activities currently exists (ASN, 2011). Radioactive liquid waste from basic nuclear installations is accurately inventoried, however. In addition, the area around these facilties is subject to environmental radioactivity monitoring. Based on the collected data, the dosimetric impact of this discharge on populations living in the immediate vicinity of the facilities can then be calculated using models that simulate transfers to the environment. The dosimetric impacts vary, depending on the type of facility and the lifestyles of the studied population groups, from a few microsieverts per year to a few dozen microsieverts.

Dosimetric estimates determined using transfer models

The total effective dose attributable to the predicted liquid and atmospheric emissions from a facility is assessed taking into account exposure pathways and dose coefficients for each radionuclide and each exposure pathway.

This calculation entails simulating the transfers to humans of radioactivity present in liquid and gaseous waste. It also includes assumptions relating to the lifestyles of the relevant populations (concerning their dietary habits, for example). Figure VIII.4 shows the potential routes whereby radioactivity discharged by a nuclear installation may be transferred to humans.

From a practical perspective, when calculating the impact of a facility's discharge on humans, the dose is calculated by adding together the external exposure from artificial radioactivity in the atmosphere (plumes), in soil deposits or in bathing water, on one hand, and the internal exposure caused by inhaling contaminated air and eating contaminated food products.

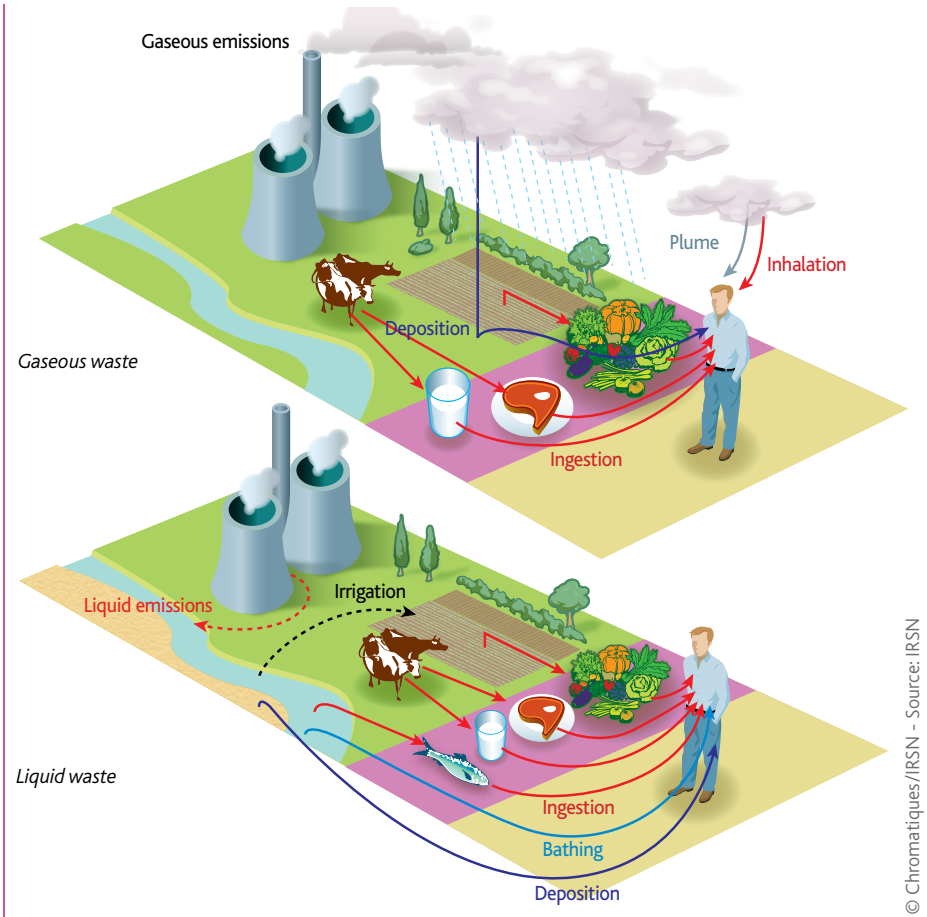

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***Figure VIII.4** - Routes for the transfer to humans of radionuclides discharged in gaseous and liquid emissions from nuclear facilities*

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Simulation-based evaluation of the radiological impact of nuclear activities

Operators are required to assess the dosimetric impact of their activities. This obligation derives, depending on the circumstances, from either Section L.1333-8 of the French public health code or the applicable regulations relating to discharge from basic nuclear installations. The result must be assessed considering the maximum permissible annual dose for the general public (1 mSv/year) defined in Section R.1333-8 of the public health code. This regulatory limit corresponds to the sum of the effective doses received by the public as a result of nuclear activities.

In practice, it should be noted that only trace levels of artificial radioactivity are detectable in the vicinity of nuclear facilities, and that in routine monitoring programs, most measurements are below the decision thresholds or reflect natural background radioactivity. As a result, these measurements cannot be used to estimate doses. Nuclear facility discharge measurements must therefore be introduced into models that describe the transfer of radioactivity to humans. Each operator uses its own models. ASN would like these methods to be standardized wherever possible, and in 2009 began exploring ways to achieve this in partnership with IRSN.

Table VIII.1 contains an assessment of the doses attributable to INBs. This table shows a few examples of effective doses received by the most exposed reference population groups.

***Table VIII.1** - Examples of radiological impacts of nuclear sites since 2005, taken from calculations performed by operators using discharge data for the most exposed reference groups (operator data, in mSv).*

Operator/Site	Most exposed reference group (population/distance from site in km)[a]	Estimated received doses, in mSv					
		2005	2006	2007	2008	2009	2010
Areva/La Hague	Digulleville (child/2.6)	$1x10^{-2}$	$1x10^{-2}$	$1x10^{-2}$	$8x10^{-3}$	$8x10^{-3}$	$1x10^{-2}$
GANIL/Caen	IUT (adult/0.6)	$2x10^{-3}$	$3x10^{-3}$	$< 6x10^{-3}$	$< 9x10^{-3}$ [b]	$3x10^{-3}$	$< 3x10^{-3}$
EDF/Cattenom	Garche north, Warpich (2009,2010) (adult/2.15) (2009, 2010: infant/1.5)	$1.6x10^{-3}$	$2.1x10^{-3}$	$2x10^{-3}$	$2.4x10^{-3}$	$2.5x10^{-3}$	$3.3x10^{-3}$
Areva/FBFC	Riffard farm [adult/0.2]	*	*	*	$6x10^{-4}$	$8x10^{-4}$	$1x10^{-3}$
EDF/Civaux	Ervaux south [adult/0.7]	*	*	*	$8x10^{-4}$	$7x10^{-4}$	$9.7x10^{-4}$
EDF/Penly	Saint-Martin Plage,Vassonville (2009,2010) [adult/1.05] [2009,2010: fisherman/0.7]	$9x10^{-4}$	$4.5x10^{-4}$	$5.4x10^{-4}$	$3x10^{-3}$	$9x10^{-4}$	$9.7x10^{-4}$
EDF/Tricastin	Clos du Bonneau, Le Trop Long (2009, 2010) [adult/1.25] [2009, 2010: infant/1.25]	$7x10^{-5}$	$6x10^{-5}$	$6.1x10^{-5}$	$4x10^{-4}$	$7x10^{-4}$	$9.4x10^{-4}$
Areva/Tricastin (Areva NC, Comurhex, Eurodif, Socatri, Set)	Les Prés Guérinés [adult (2005: child)/3; 3.1; 2.16; 1.3; 1.5]	$2x10^{-3}$	$1x10^{-3}$	$1x10^{-3}$	$5x10^{-4}$	$5x10^{-4}$	*

a: Until 2008, only "adult" values were calculated for facilities operated by EDF. Since 2009, the dose for the most exposed of the two age-based reference groups (adult or infant) for each site is stated.

b: Value measured at the site perimeter by passive dosimeters. Several dosimeters revealed traces of radioactivity even after the facility was shut down. The value is therefore greatly overestimated, according to the operator.

Focus cont.

Table VIII.1 (cont.) *- Examples of radiological impacts of nuclear sites since 2005, taken from calculations performed by operators using emissions data for the most exposed reference groups (operator data, in mSv).*

CEA/Saclay	Christ-de-Saclay [adult/1]	$1x10^{-3}$	$1x10^{-3}$	$8x10^{-4}$	$7x10^{-4}$	$5x10^{-4}$	$6x10^{-4}$
EDF/Belleville-sur-Loire	Neuvy-sur-Loire [adult/1.3]	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$	$6x10^{-4}$	$7x10^{-4}$	$6x10^{-4}$
Andra/Manche	Hameau de La Fosse [adult/2.5]	$8x10^{-4}$	$8x10^{-4}$	$7x10^{-4}$	$7x10^{-4}$	$6x10^{-4}$	$4x10^{-4}$
EDF/Bugey	St-Étienne d'Hières south [adult/0.45]	*	*	*	$5x10^{-4}$	$5x10^{-4}$	$3.6x10^{-4}$
EDF/Chinon	Le Neman [adult/1.25]	$2.1x10^{-4}$	$2.5x10^{-4}$	$1.3x10^{-4}$	$4x10^{-4}$	$4x10^{-4}$	$4x10^{-4}$
EDF/ Fessenheim	EDF complex (Koechlin) [adult, 2010: infant)/1.2]	*	*	*	$7.5x10^{-5}$	$8x10^{-5}$	$1x10^{-4}$
ILL/Grenoble	Fontaine (gaseous emissions) and Saint-Egrève (liquid emissions) [infant/1 (Fontaine); 1.4 (Saint-Egrève)]	*	*	*	*	$1x10^{-4}$	$1x10^{-4}$
EDF/Creys-Malville	Chancillon farm [adult, 2010: infant)/0.85]	*	*	$1x10^{-5}$	$2x10^{-5}$	$8x10^{-6}$	$6x10^{-5}$
CEA/Fontenay-aux-Roses	Fontenay-aux-Roses [child/1.5]	$2x10^{-5}$	$1x10^{-5}$	$9x10^{-6}$	$9x10^{-6}$	$5x10^{-6}$	$4x10^{-6}$
Andra/CSA	CD24 road bridge [child/2.1]	$6x10^{-6}$	$5x10^{-6}$	$3x10^{-6}$	$2x10^{-6}$	$5x10^{-6}$	$2x10^{-6}$

** Information not provided by the operator*

The doses attributable to basic nuclear installations for a particular year are estimated based on the actual discharge from each facility during the studied year. This evaluation includes discharge via the identified routes (e.g. stacks and discharge pipes leading to rivers or the sea). It also includes diffuse emissions and any sources of radiological exposure to ionizing radiation present at the facility. These components together make up the "source term".

Doses are estimated with respect to one or more clearly identified reference groups. These are uniform groups of individuals subject to relatively uniform exposure, who are representative of members of the population particularly exposed to a specified facility's source term, based on realistic scenarios.

This population category (adult, child or infant) varies from site to site and from year to year, as does the group's distance from the site.

Lastly, dose estimates reflect a range of modeling parameters, including, for example, meteorological data (e.g. locally observed wind roses). Taken together, these parameters, which are specific to a given site, largely account for the differences observed between one site and another, and between one year and another.

The radiological impact associated with each of the featured nuclear sites is much less than 1% of the public exposure limit of 1 mSv per year. ASN therefore considers that in France, environmental discharge from the nuclear industry has an extremely limited radiological impact.

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Figure VIII.5

Dosimetric assessments for measured environmental activity levels

To ensure compliance with the assumptions adopted in the impact assessment, operators are required to implement environmental radioactivity monitoring programs (covering water, air, soil, milk, grass, farm produce, etc.). For many artificial radionuclides discharged by nuclear facilities, the activity levels measured in the environment are too low to be measured above the decision thresholds in the various environmental compartments.

In the case of naturally occurring radionuclides and remanent radionuclides from earlier deposits, an increase in activity attributable to current nuclear facilities is only rarely perceptible; this applies, for example, to ^{90}Sr, ^{137}Cs and most ^{14}C, as well as plutonium and americium isotopes.

Example simplified assessment based on results from foodstuffs

When radionuclides are measured in food products, the doses resulting from eating the food are generally not attributable (at all, or to any significant extent) to current discharge from nuclear facilities. Assessments based on measurements cannot be treated as impact calculations, due to the lack of significant measurements (i.e. measurements above decision thresholds).

By way of illustration, note that 70% of the 18,600 measurements relating to the biological compartment that were included in these calculations were below the decision thresholds. Of the 30% of significant values, only 10% related to edible products, and half of these results concerned ^{40}K, a naturally occurring radionuclide systematically present and measurable in such samples.

Table VIII.2 shows a few examples with partial calculations reflecting, for various types of facility, the local data and the measured radionuclides most specific to the discharge liable to be measured in the environment.

The activity levels taken into account were the average measured values. For these values, the dose attributable to a consumption of 1 kg of each of the considered foodstuffs was calculated. A comprehensive assessment should include all foods in the diet and all radionuclides, which is not currently achievable using the data available in the RNM network.

Dose coefficients relate to the effective whole-body equivalent dose in adults. They derive from the 1996 Euratom directive. The doses thus evaluated are shown in Table VIII.2. This table shows the measured activity's origin (natural, remanent or, less frequently, anthropic signature) for the various radionuclides and their respective average activity levels (or isotope ratios).

Table VIII.2 - Radionuclide concentrations measured in food products and effective doses in adults corresponding to ingestion of 1 kg (or 1 L) of each type of food

Foodstuff	Location	Radionuclide	Average (Bq/kg (wet) or Bq/L)	Standard deviation (Bq/kg (wet) or Bq/L)	Number of measurements
Seafood	La Hague	^{14}C	50	13	14
Cow's milk	La Hague		22	6	85
Fish	La Hague		36	15	30
Meat	La Hague		39	16	4
Fruit	Marcoule		9	5	13
Seafood	La Hague	^{60}Co	0.18	0.16	18
Thyme	Cadarache	^{137}Cs	0.62	0.28	20
Fish	FBFC Romans		0.16	0.05	3
Fish	La Hague		0,14	0,05	18
Fish	Marcoule		0.45	0.18	11
Fish	All NPPs		0.16	0.14	15
Lettuce	All NPPs		0.29	0.51	8
Fruit	Marcoule	HTO	26	21	13
Cow's milk	Marcoule		6	3	9
Cow's milk	Valduc		28	3	17
Seafood	La Hague	^{129}I	0.37	0.32	59
Cow's milk	La Hague		0.03	0.02	14
Fish	La Hague		0.30	0.29	4
Seafood	La Hague	^{238}Pu	0.009	0.005	28
Seafood	La Hague	^{239}Pu	0.016	0.008	48
Seafood	La Hague	^{241}Am	0.1	-	1
Cow's milk	France	^{90}Sr	0.051	0.025	17
Cow's milk	La Hague		0.059	0.022	85
Lettuce	Malvési	^{234}U	0.04		1
Lettuce	Malvési	^{238}U	0.06		1
Fish	Pierrelatte	^{234}U	0.01		1
Fish	Pierrelatte	^{238}U	0.02		1
Lettuce	Pierrelatte	^{234}U	0.06		1
Lettuce	Pierrelatte	^{235}U	0.003		1
Lettuce	Pierrelatte	^{238}U	0.06		1
Fish	FBFC Romans	^{235}U	1.7E-4	9.7E-5	3
Fish	FBFC Romans	^{238}U	1.3E-3	1.3E-3	6

Individual effective dose (µSv/kg or µSv/l ingested)	Notes on measurements
2.9E-2	The measured values for ^{14}C are slightly higher than the background level (due to natural and remanent activity from atmospheric nuclear tests) for the La Hague facility, and at background level for the Marcoule facility.
1.3E-2	
2.1E-2	
2.2E-2	
5.5E-3	
6.0E-4	Value attributable to current discharge
8.1E-3	All ^{137}Cs measurements lie within the usual range of values unaffected by facilities (remanent activity from fallout from atmospheric testing and the Chernobyl accident).
2.0E-3	
1.8E-3	
5.9E-3	
2.1E-3	
3.8E-3	
4.7E-4	These measurements are indicative of a slightly enhanced tritium background level, compared with an expected value of approx. 1 to 3 Bq/kg (wet) without the facility's influence.
1.1E-4	
5.0E-4	
4.0E-2	Values attributable to past and current emissions from the site.
3.4E-3	
3.3E-2	
2.1E-3	Although low, these values are indicative of an anthropic signature, as the $^{239+240}Pu$ to ^{238}Pu ratio of 0.6 is significantly greater than that of fallout from nuclear tests (theoretically 0.03).
4.0E-3	
2.0E-2	Values attributable to past and current emissions from the site.
1.4E-3	All ^{90}Sr measurements lie within the usual range of values unaffected by facilities (remanent activity from historical deposits).
1.6E-3	
2.1E-3	Balanced values in the range of values generally observed at sites unaffected by nuclear facilities.
2.5E-3	
4.9E-4	Although low, these values are indicative of an anthropic signature. The ^{235}U to ^{238}U isotope ratio is greater than for these two isotopes in naturally occurring uranium (0.72%).
9.0E-4	
2.9E-3	
1.6E-4	
2.7E-3	
7.8E-6	
5.9E-5	

The dose values are low, ranging from 8×10^{-6} to 6×10^{-2} µSv per kg or per liter of ingested food products, for each of the measured radionuclides, regardless of their origin. These results naturally reflect the very slight specific activity or activity concentration levels added to the various biological compartments of the environment by nuclear facilities. In addition, a person would need to eat excessively large quantities of the food concerned before reaching the dose limit for the general public (1 mSv/year).

Concerning the areas near to nuclear power plants, it has been established, based on the results of routine monitoring programs as well as the results of supplemental studies, that almost no environmental impact attributable to emissions is detectable. For example, although it is possible to calculate theoretical ^{60}Co concentrations[2] of around 0.000 001 Bq/L of milk, the order of magnitude expected near a nuclear power plant based on actual discharge, no technical means of measuring such a low activity level exists.

2 – Assessment performed by SECRE/LME, using the Symbiose modeling platform with actual emissions data supplied by EDF

VIII.4 ASSESSMENT OF THE RADIOLOGICAL QUALITY OF DRINKING WATER IN FRANCE

With effect from January 1, 2005, health checks on the radiological quality of water intended for human consumption is mandatory in France. This monitoring regime is overseen by the Regional Health Agency (ARS), supported by approved laboratories using analytical protocols accredited by the French Accreditation Committee (COFRAC). IRSN provides technical assistance to the Nuclear Safety Authority (ASN) in this area. The Institute plays a role in approving laboratories (application processing, onsite inspections etc.) and managing changes to the regulatory framework. IRSN also performs analyses.

Circular ref. DGS/EA4/2007/232 of June 13, 2007 defined a two-stage drinking water radioactivity measurement strategy:

- An initial phase of overall analyses, the results of which are compared to guide values and a quality baseline. Where those values are compliant, the total indicative dose for an annual consumption of 730 liters of water by an adult is assumed to be less than the reference value of 0.1 mSv/year.
- For non-compliant values, a second phase of analyses is triggered in order to specifically search for an naturally occurring and, where applicable, artificial radionuclides that may be present. The total indicative dose is then calculated based on the measured activity levels and compared with the reference value.

Principal results obtained by IRSN in 2010

Between 10 and 20% of analyzed water samples require specific radionuclide searches. The radionuclides most commonly found in samples are radium-226 and uranium-234 and -238. More rarely, polonium-210 and lead-210 may be detected, and in exceptional cases, radium-228.
Overall, fewer than 5% of analyzed samples were representative of a total indicative dose greater than 0.1 mS.v/year. The highest total indicative dose calculated in 2010 was 0.91 mSv per year. This result was primarily due to the presence of lead-210 and polonium-210.

When the total indicative dose exceeds 0.1 mSv/year as a result of naturally occurring radionuclides present due to the ground's geological properties, the Regional Health Agency (supported by ASN) adopts a prudent, pragmatic approach (which may initially entail restrictions on use), taking into consideration the number of people concerned and any available means of reducing the radiological activity (for example by diluting the resource or introducing treatments), as well as any difficulties and inconvenience relating to their implementation.

In the case of uranium, the activity levels obtained for isotopes 234 and 238 provide a basis for calculating the mass concentration of uranium, which can then be used to assess the related chemical risk. The value thus obtained is compared with the WHO's guideline value of 30 µg/l.

Lastly, radon 222, a naturally occurring gaseous radionuclide, may be analyzed but is currently not covered by the applicable national regulations. These regulations are liable to change in the near future, in accordance with the European Union guideline issued in 2001 and the WHO recommendation on drinking water. However, it has been established that the principal risk associated with this radionuclide relates to its inhalation.

The results of the tap water radiological quality monitoring campaign conducted by Regional Health Agencies between 2008 and 2009 (see DGS/ASN/IRSN report published in 2011) revealed that 99.83% of the population received water that complied at all times with the regulatory total indicative dose limit of 0.1 mSv/year. In addition, a historical assessment (1977-2003) carried out by IRSN in 2010 revealed that 4% of the significant measurements relating to the presence of radon in monitored water resources exceeded a level of 1,000 Bq/L. Most of these results were obtained in areas already concerned by the issue of radon from geological deposits accumulating in the air inside buildings. Although radon in water does not raise any short-term health issues, DGS and ASN, supported by IRSN, are seeking to clarify the relevant drinking water quality regulations and enforcement methods.

For more information

Figure VIII.6

www.sante.gouv.fr/eau-et-radioactivite.html

VIII.5 DOSIMETRIC ASSESSMENT FOR FRENCH POLYNESIA

Population exposure to this residual artificial radioactivity is mainly due to ingestion and external exposure. Exposure via inhalation is negligible (direct fallout and resuspension of radioactive dust are now extremely low, and practically undetectable).

In 2010, no food product contributed more than 1 mSv/year to the dose by ingestion. A few foods eaten in large quantities may contribute more than 0.1 mSv/year to the dose. This is the case for Tahitian beef, which is also eaten on Tubuai, Mangareva and Maupiti, pork in Tahiti, copra on Rangiroa, lagoon fish on Rangiroa and Hao, and cabbage on Hiva Oa.

The total annual doses (i.e. the sum of the doses by external exposure, inhalation and ingestion) for adults and children are shown in Figures VIII.7 and VIII.8, respectively.

The results reveal that the annual ranges between the minimum and maximum values for all five archipelagos are broadly comparable for adults and children. The overall average for the past 20 years is approximately 3.5 µSv/year for children and 4.5 µSv/year for adults.

This order of magnitude comprises all three components of the "additional" dose, and can be compared with the total (natural and artificial) dose of 1,000 µSv per year on average in the South Pacific, as established by the SPREP (South Pacific Regional Environment Program) in 1983. The "additional" dose due to artificial radionuclides in French Polynesia therefore represents less than 0.5% of the total average dose for the region.

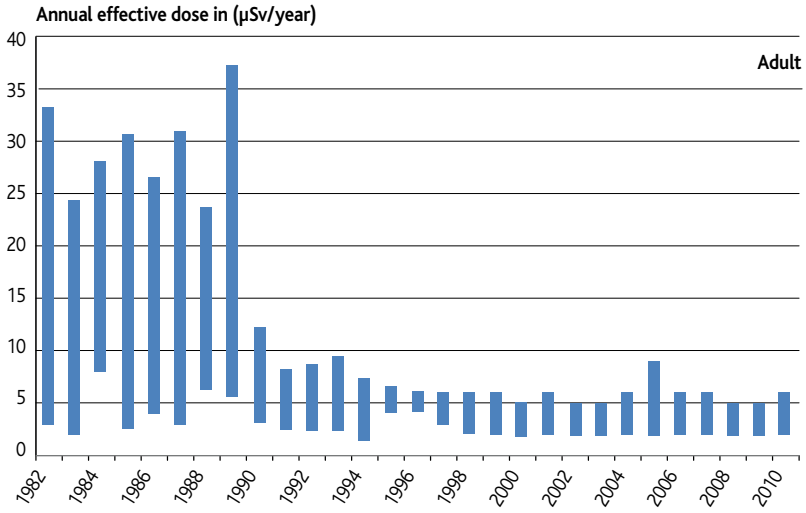

***Figure VIII.7** – Annual effective doses associated with artificial radioactivity in adults in French Polynesia since 1982 (µSv/year)*

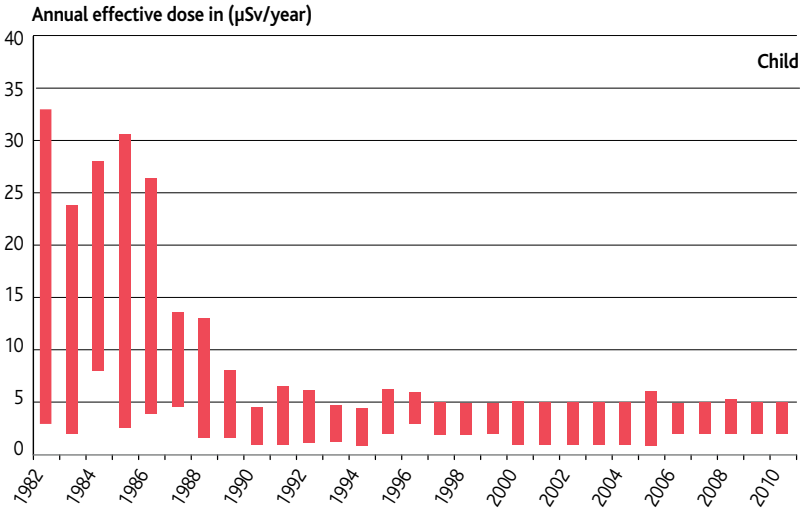

***Figure VIII.8** – Annual effective doses associated with artificial radioactivity in children under five in French Polynesia since 1982 (µSv/year)*

VIII.6 ASSESSMENT OF THE DOSIMETRY IMPACT OF THE FUKUSHIMA ACCIDENT ON THE FRENCH POPULATION

Regarding the consequences in France of the Fukushima accident, the radionuclides of concern and the principal exposure pathways were as follows:

- **Internal exposure by inhalation of iodine-131** in the contaminated air mass as it moved over France (the other artificial radionuclides, which had far lower activity levels, represented only marginal contributions);
- **Internal exposure due to eating food** containing traces of iodine-131 and cesium-134 and -137;
- **External exposure due to radioactive deposits** formed by atmospheric fallout of radionuclides emitted during the Fukushima accident.

The activity levels of airborne radionuclides were too low to result in significant external exposure attributable to the contaminated air mass.

In view of the very low radionuclide activity levels measured in the air, and the absence of significant differences in exposure between different areas of the country, the assessment is based on the average, minimum and maximum values acquired by IRSN from mid-March to mid-May 2011 for France as a whole. These assessments were based on pessimistic assumptions.

Estimated doses due to inhalation of iodine-131

The average values for all measurement results above the decision thresholds were respectively 1 mBq/m³ for gaseous iodine-131 and 0.2 mBq/m³ for iodine-131 in aerosol form. As iodine aerosols were measured at levels above the decision threshold during a period of 60 days (compared with 30 days for the gaseous form, which was measured with a higher decision threshold), the 60-day value was adopted for both forms, for the purpose of estimating the activity concentration ingested over the period: respectively 60 mBq.d/m³ for the gaseous form and 12 mBq.d/m³ for aerosols.

The radioactivity intake over the exposure period is calculated by multiplying the breathing rate by the ingested activity concentration. The dose can then be determined by multiplying the activity intake by the dose factor, stated in Sv/Bq inhaled.

The following parameters were estimated for this calculation:

- equivalent doses to the thyroid gland, a target organ for iodine-131, for a one-year-old child;
- effective dose for an adult.

Based on these assumptions:

- **the equivalent dose to the thyroid gland due to inhalation of iodine-131 was estimated at 2 µSv for a one-year-old child;**
- **the effective dose due to inhalation of iodine-131 was estimated at 0.03 µSv for an adult.**

In comparison, the doses by inhalation attributable to fallout from the Chernobyl accident in France were estimated at between 40 and 470 µSv, for the equivalent dose to the thyroid in a one-year-old child, and between 4 and 46 µSv for the effective dose in adults, depending on the location in France.

Estimated doses due to eating food containing traces of artificial radionuclides

Ingestion-related doses were calculated by multiplying the ingested radioactivity (Bq) by the ingestion dose factor (Sv/Bq ingested). The ingested activity was calculated based on the specific activity or activity concentration of the relevant foods (in Bq/kg or Bq/L), multiplied by a food intake (kg/d or L/d) and by the length of time during which traces of artificial radionuclides attributable to the Fukushima accident were detected in the food (d).

Two scenarios were considered when performing this calculation:

- **"average" scenario**, based on the average activity levels of the foods and the periods during which significant values (i.e. above the decision thresholds) were observed;
- **"worst-case" scenario**, based on the maximum contamination values and contamination assumed to last seven days, which is pessimistic inasmuch as these relative concentration "spikes" in reality only concerned each of the considered products for a brief period (less than three days and in most cases a single day). Concerning iodine-131 and cesium-134 (a radionuclide that is very rarely measured above the decision thresholds), there was no background radiation prior to the fallout from the Fukushima accident, indicating that the measured values are

Table VIII.3 - Contamination values and periods for food products determined for the purpose of calculating doses by ingestion (Bq/kg or Bq/L)

		^{131}I measured	^{134}Cs measured	^{137}Cs measured	^{137}Cs attributable to Fukushima
Leafy vegetables	Average values in Bq/kg (period: 22 days)	0.53	-	0.35	0.30
	Maximum values in Bq/kg (period: 7 days)	2.1	-	1.14	1.10
Cow's milk	Average values in Bq/L (period: 24 days)	0.24	-	0.21	0.11
	Maximum values in Bq/L (period: 7 days)	0.66	0.05	0.58	0.48
Goat's or sheep's milk	Average values in Bq/L (period: 37 days)	0.8	-	0.12	0.07
	Maximum values in Bq/L (period: 7 days)	3.1	0.1	0.58	0,53
Meat	Average values in Bq/kg (period: 40 days)	-	-	0,12	-
	Maximum values in Bq/kg (period: 7 days)	-	-	0.28	0.08

attributable entirely to that accident. In the case of cesium-137, the background values (due to remanent fallout from atmospheric nuclear testing and the Chernobyl accident) lie in known ranges, enabling background to be deducted from the measurement results and in turn making it possible to consider in isolation the impact attributable to the Fukushima accident.

Table VIII.3 shows the data thus determined for the calculation.
Concerning the food intake, the adult value was assessed for an individual belonging to the "farming" socioeconomic category, based on data for "all of France" taken from the most comprehensive INSEE survey. The food produced was assumed to be consumed immediately (with no decay during storage), and the population was assumed to exclusively consume local produce, which is a pessimistic assumption. A supplemental assessment was also produced, taking into consideration high consumption of vegetables and meat, as well as consumption of goat's milk instead of cow's milk - a fairly rare practice that was nevertheless reported for a few families in the food survey conducted by IRSN in 2004-2005 near the Tricastin nuclear facility (this consumption scenario is known as the "Tricastin intake").

The 1-2 year-old age range was considered for children. The assumed food intake featured the following consumption profile: 54 g/d of leafy vegetables, 16 g/d of meat (beef, veal, horse, lamb, rabbit, etc.) and 320 g/d of cow's milk. For children, only the equivalent dose to the thyroid gland associated with ingestion of iodine-131 was taken into consideration, as this is the most pessimistic exposure configuration.

Cesium 134 and 137 from atmospheric fallout from the Fukushima accident were included when calculating the effective dose, but, in the light of the very low measured activity levels (*see Table VIII.3*), their contribution to the dose was minimal.

The calculation results for doses[3] due to ingestion of foods containing traces of radionuclides attributable to the Fukushima accident are shown in Table VIII.4.

In comparison, the doses by ingestion attributable to fallout from the Chernobyl accident over the period from May to December 1986 were evaluated as follows[4]:
the effective dose received by an adult was between 50 and 300 µSv, depending on the location in France;
The equivalent dose to the thyroid gland in one year-old children living in eastern France was between 6.3 and 12.7 mSv on average (i.e. between 6,300 and 12,700 µSv).

External exposure to radioactive deposits

External exposure resulting from the deposition of gamma-emitting radionuclides on the ground depends on numerous parameters, including the exposure time (outdoors) and the type of surface. The resulting effective dose for adults was assessed using the Astral code, assuming a maximum deposit[5] of 600 Bq/m² for iodine-131 and ten times less, i.e. 60 Bq/m² for cesium-134 and cesium-137, and a rural lifestyle (10 h/d outdoors), which is a conservative value. This theoretical estimate of ground deposition is very pessimistic, given the value determined for iodine-131 by measurements made at IRSN's Le Vésinet facility (*see report ref. IRSN-DEI 2011-01*).

Table VIII.4 - *Estimated doses due to food intake, for the two studied configurations of food contamination values and periods (Table VIII.3)(µSv)*

	Effective dose (µSv) Adult		Equivalent dose to the thyroid gland (µSv) One-year-old child
	Insee food intake	"Tricastin" food intake	
Dose for "Average" scenario	0.06	0.14	25.1
Dose for "Maximum" scenario	0.08	0.17	43.1

3 – Ecrin database – Values are taken from Euratom Directive 96/29 (1996 for the effective dose) and ICRP Publication 67 (for doses to the thyroid gland).

4 – Renaud P. et al. Les retombées de l'accident de Tchernobyl sur le territoire français ***Fallout in France from the Chernobyl accident***. *Lavoisier, Tec & Doc, 2007.*

5 – The total ground deposit is estimated by adding together the dry and wet deposits.
Iodine-131 deposition during rainfall *was assessed based on the volume of precipitation during the period from mid-March to mid-June (either in mm or in L/m²), multiplied by the concentration in rainwater, i.e. 25 L/m² x 0.8 Bq/L = 20 Bq/m².*
Dry deposition of iodine-131 *was calculated based on a maximum volume concentration of approximately 60 mBq x d/m³ for the gaseous form, and 15 mBq x d m³. These values must be multiplied by their respective deposition rates of 0.1 to 0.05 m/s and adjusted by applying a conversion factor of 86,400 s/d, resulting in a dry deposit of 580 Bq/m².*
Total deposition of iodine-131 *is estimated to be 580 + 20 Bq/m², disregarding decay effects.*

The results of this assessment (*Table VIII.5*) suggest that the dose due to external exposure to the deposit was no more than 1.6 µSv in the first year, and subequently less than 1 µSv/year (decreasing each year thereafter). Iodine-131 contributed to this dose during the first two months, but was then eliminated by radioactive decay; cesium-134 decays less rapidly (half-life: 2.1 years); after around a decade, cesium-137 will account for most of the dose (*Figure VIII.9*).

These values represent less than 0.4% of the maximum values attributable to fallout from the Chernobyl accident (400 µSv in the first year).

Assessment of the dosimetric impact of the Fukushima accident on the French population

The dose calculations described above are pessimistic estimates for both adults and children. They provide a worst-case indication of the Fukushima accident's potential dosimetric impact on the French population.

The effective dose potentially received during the year following the accident (or a shorter period, depending on the exposure route considered) is estimated to be less than 1.8 µSv for adults. This dose attribuable to the Fukushima accident represents less than 0.1% of the annual effective dose due to natural sources of radioactivity, which are estimated to deliver an average dose of 2.400 µSv (in France, this dose ranges from 1,000 µSV to 13,000 µSv, depending on the place of residence and the related variations in natural radioactivity according to geology and altitude).

Among children, the 1-2 year-old age bracket is the most sensitive to iodine-131 exposure, primarily through food intake with a less significant inhalation component, resulting in an estimated dose-equivalent to the thyroid gland representing less than 45 µSv. In comparison, the thyroid gland is constantly exposed to naturally occurring radioactivity, particularly potassium-40, which is naturally present in all humans, delivering an average dose of 300 µSv/year to the thyroid gland in children 1-2 years of age. Note that the dose equivalents to the thyroid gland in one-year-old children living in eastern France at the time of the Chernobyl accident in 1986 are estimated to have been between 6,300 and 12,700 µSv on average.

In conclusion, the doses potentially received in France in the period following the Fukushima accident are very low. These restults confirm that at no time did the radioactivity levels from artificial radionuclides (iodine-131, cesium-134, and cesium-137) measured in the various compartments of the environment in France and its overseas departments, regions and communities pose a health risk.

For more information

Visit the IRSN website:
http://www.irsn.fr/FR/base_de_connaissances/Installations_nucleaires/La_surete_Nucleaire/Les-accidents-nucleaires/accident-fukushima-2011/impact-monde/Pages/2-impact-fukushima-france.aspx?dId=471c8be3-2e1f-4fe0-85f3-1f8aee7a5e9a&dwId=6c699d88-aa0e-4da8-8523-f24f19ecc83d

Read the report ref. IRSN-DEI 2011-01:
http://www.irsn.fr/FR/expertise/rapports_expertise/Documents/environnement/IRSN_Analyse-impact-Fukushima-France_012012.pdf

Table VIII.5 *- Maximum total effective dose from external exposure due radioactive deposits formed by fallout from the Fukushima accident (µSv)*

After...	Total effective dose equivalent (adult)
2 months	0.4
1 year	1.6
2 years	2.5
3 years	3.3

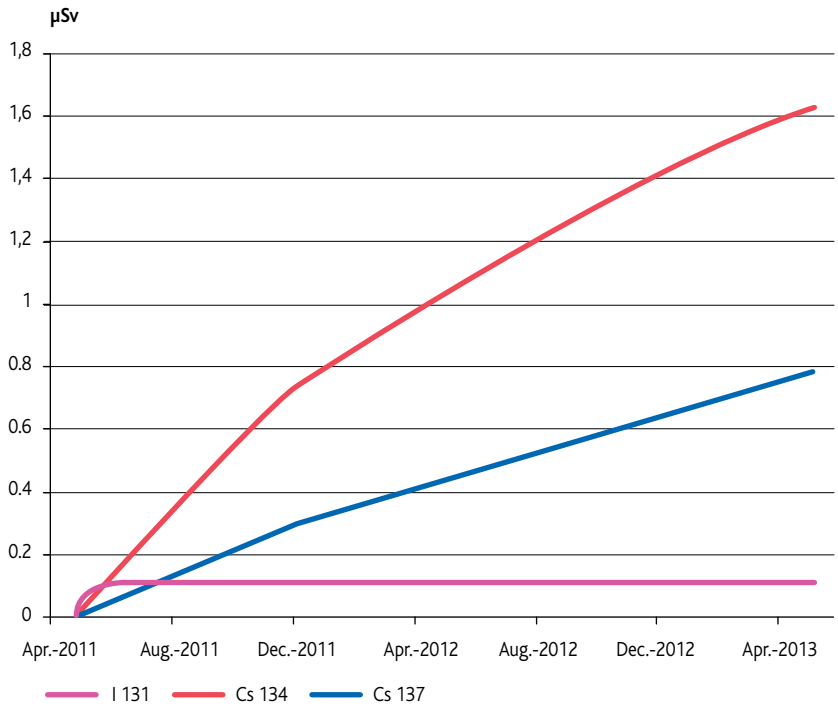

Figure VIII.9 *- Contribution of the various radionuclides to the total effective dose potentially received by an adult due to external irradiation by the deposit, for a theoretical maximum deposit of 600 Bq/m² of iodine-131, 60 Bq/m² of cesium-134 and 60 Bq/m² of cesium-137*

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Figure VIII.10 *- Using a telescopic boom to collect a water sample in the Gaffière river downstream from the Tricastin nuclear plant.*


L'atome
EDF
Repères
JRSN
N°12
Édition
Meuse/Haute-Marne
ANDRA
L'environnement du futur Cigéo se conjugue au présent
NEUTRONS FOR SCIENCE
Institut Laue-Langevin
CONTROL
asn
Extraits du Rapport de l'ASN sur l'état de la sûreté nucléaire et de la radioprotection en France en 2010
réseau national
Réseau national de mesures de la radioactivité de l'environnement
www.mesure-radioactivite.fr
Transparence
Sécurité Nucléaire
Surveillance radiologique de l'environnement à Toulon
PRESENTATION
Transfert des radioéléments
LES REJETS RADIOACTIFS ET L'HOMME
DE LA RECHERCHE À L'INDUSTRIE

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IX

RADIOACTIVITY MONITORING INFORMATION SOURCES AND DATA DISTRIBUTION NETWORKS

Providing the public with information regarding environmental radioactivity is fundamental to ensuring transparency regarding nuclear activities. The Nuclear Safety and Transparency Act, promulgated on June 13, 2006, states: "transparency in nuclear matters covers all measures implemented to uphold the public's right to reliable, accessible information" (Article 1). ASN, IRSN and other stakeholders in the French nuclear sector provide information in multiple forms, both to comply with legal obligations and to address public expectations.

The website launched by the French national measurement network (RNM) on February 2, 2010 is a major step forward in the area of public information services. The website, which is the leading reference for matters relating to environmental radioactivity monitoring, provides centralized access to the environmental monitoring results of all data providers.

IRSN has also developed an Internet site devoted to radioactivity in the environment. In a two-pronged approach, the site provides access not only to environmental radioactivity monitoring results obtained by IRSN (over one million statistics covering a time scale of more than 45 years) but also to a very well-stocked document library (including topic sheets, reports, assessments, etc.) that can be read on multiple levels to suit visitors' specific requirements.

The Internet site operated by the French Nuclear Safety Authority, ASN, also provides a wealth of information about the life of nuclear facilities and, more generally, news relating to nuclear safety and radiation protection in France.

In addition to complying with regulatory obligations relating to information transparency (including publishing annual reports as required by the Nuclear Safety and Transparency Act), the principal nuclear operators implement voluntary information policies via multiple media (websites, leaflets aimed at the general public, information leaflets presenting environmental monitoring results, etc.).

Environmental radiological monitoring data is shared internationally. In application of the Euratom treaty and as part of the work of the Ospar commission (Northeast Atlantic marine environment protection commission), IRSN releases the monitoring results obtained in the course of its activities on an annual basis. This data is subsequently used in studies and publications available to the public through a variety of media.

IX.1. PUBLIC INFORMATION WEBSITES AND OTHER MEDIA

Internet portal operated by the RNM environmental radioactivity monitoring network

The RNM database, which contains all environmental radioactivity measurements made by monitoring partners, is accessed via an information system that provides all stored information to experts and the general public, mainly through a map-based Internet portal.

This website, managed by IRSN, enables web users to access all the data via a single point of entry. It also offers navigation options to suit everyone, whatever their habitual search practices or needs (geographical search, subject search, advanced search, etc.). It is designed to provide rapid, easy access to comprehensive information relating to the RNM network (covering regulations, operation and laboratory approvals). The site features an educational section that explains the nature of radioactivity and how it is measured, describes the related biological effects, etc. The aim is to equip site visitors to understand the measurement results available on the site.

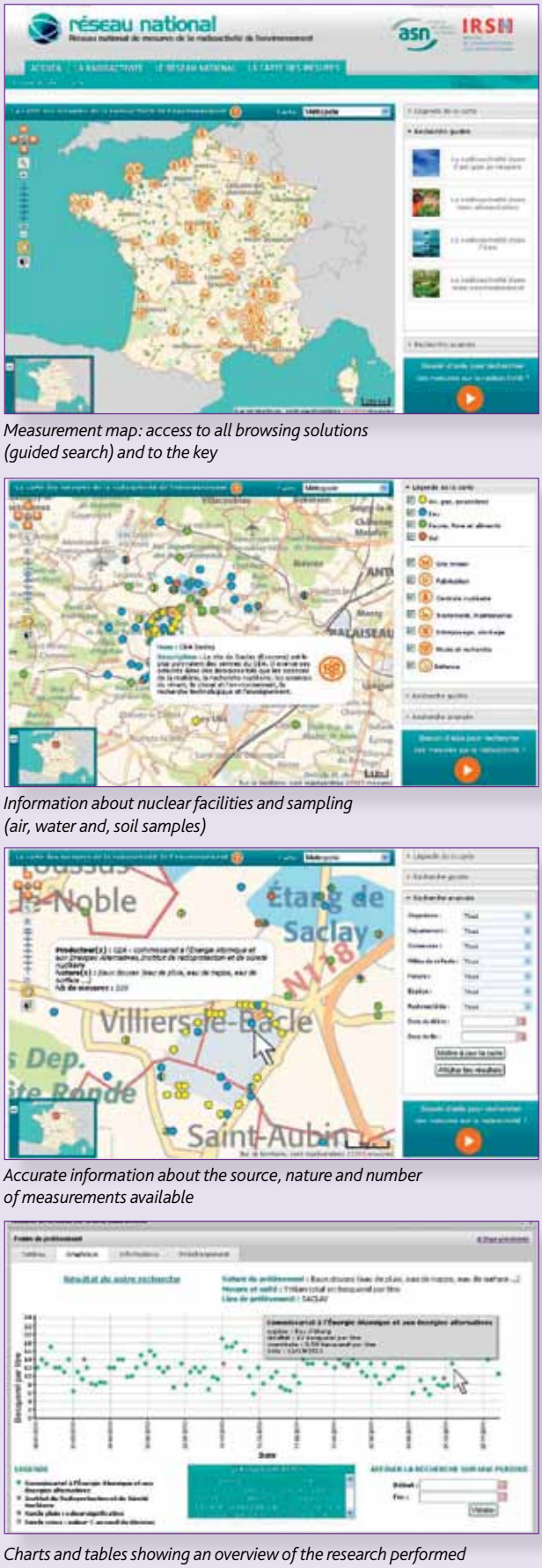
Each category of user (novice, experienced or specialist) has access tailored to their needs. The different user types can access all the information in the database in conditions appropriate to their needs, by drilling down from the most general information to the most detailed. In practical terms, users can use various integrated search tools that provide access to data via several routes:

- **Map-based searches** combine browsing tools and a dynamic key to provide rapid access to search results;
- **Topic-based searches** use thematic queries to enable non-specialist users to access results with ongoing, customized learning support;
- **Multi-criteria searches** enable professional users to perform advanced searches, view search results on the map and display the detailed results.

The map tool can be used to select a region and provide related information (such as the locations of major nuclear facilities and sampling points). The results of such queries may be viewed either in table form or as a chart showing how radioactivity levels change over time (*Figure IX.1*). Where multiple data providers make measurements at the same sampling point, the corresponding results are shown on the same chart, using a color code with a different color for each data provider.

The reporting screen features a set of tabs that enable visitors to access additional information related to results (such as information about radioactivity in the selected compartment, or values typically measured in the environment) or download data in spreadsheet (csv) format.

Other sections of the site help visitors to understand the stated measurement results (in particular aspects such as uncertainties, detection limits and decision thresholds), measurement units, etc. Lastly, the home page contains links enabling visitors to access the respective websites of the national measurement network stakeholders and the principal



Measurement map: access to all browsing solutions (guided search) and to the key

Information about nuclear facilities and sampling (air, water and, soil samples)

Accurate information about the source, nature and number of measurements available

Charts and tables showing an overview of the research performed as well as key data relating to the results

***Figure IX.1** - Searching for measurement results via the map module on the nuclear measurement network's website.*

providers of measurement data in France. **During an average month, more than 17,500 new measurement results are added. As a result, the national network provides the most comprehensive view possible of all the environmental radioactivity measurements made by the various organisations involved.**

IRSN "environmental issues" website

IRSN has made a sustained effort in recent years to disseminate more widely the resultats of its environmental radioactivity research and national environmental monitoring activities, in particular by publishing a wide range of information on its Internet site.

This has involved communicating in multiple areas, ranging from event-related information via a special publication on the home page of the institutional website www.irsn.fr to the dedicated "Environment" website used by IRSN to provide the public with access to all of the results obtained in the course of its environmental radioactivity monitoring mission.

As a major radiological monitoring stakeholder, IRSN also supplies content to the national measurement network's portal, which began operating on January 1, 2010.

In March 2009, the Institute opened a new portal site devoted to environmental radioactivity: http://environnement.irsn.fr. Visitors to this site have access to environmental radioactivity measurement results obtained by IRSN, as well as a document base *(Figure IX.2)*:

Interactive map

An interactive map provides easy access to results from IRSN's monitoring activities relating to the various environmental compartments (i.e. atmospheric, aquatic, biological and mineral) at a particular location, both in the vicinity of nuclear sites and elsewhere in France. Every day, the mean values obtained during the previous day at each station in the Téléray network are published. Measurements for the other networks are updated monthly. To date, more than one million statistics are available.

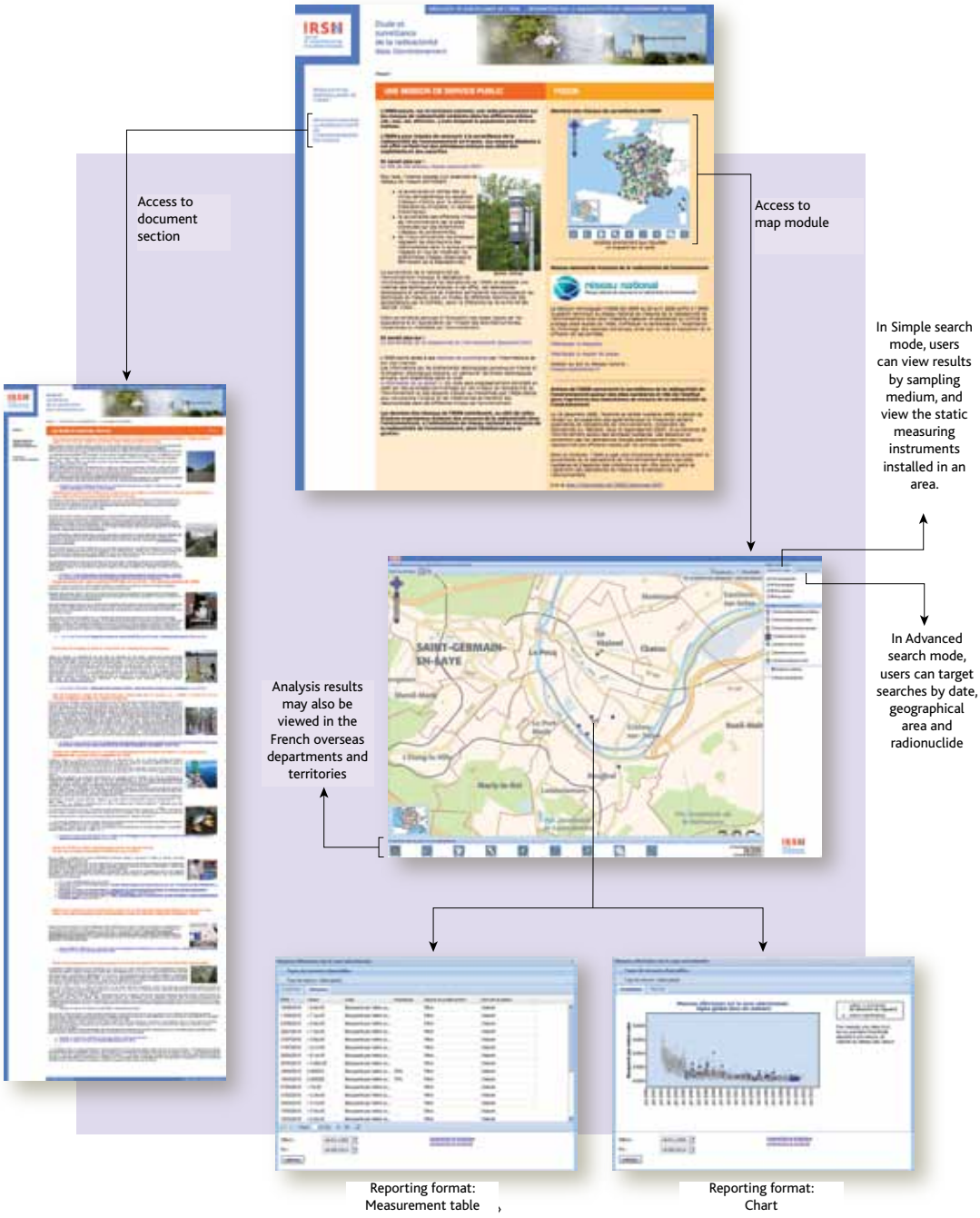


Figure IX.2 - IRSN "Environment" portal - documentation and interactive map

Efforts are being made to provide access to older data, thereby placing changing environmental radioactivity in a historical perspective, with graphical representations to make trends easier to identify. The historical data accessible on this site varies, depending on the date that the sampling stations and facilities began operating. For certain filter-based aerosol collection stations data covering a period of more than 40 years (concerning aerosol filters in particular) is available.

Document section

The site also features a database of documents relating to environmental radioactivity in France, containing a wide range of publications - from brief summaries to full IRSN reports - enabling visitors to find information of a nature appropriate to their particular requirements.

In addition to annual assessment reports relating to environmental radioactivity monitoring in metropolitan France and French Polynesia, this section contains a range of topic-based content:

- **radioactive atmospheric fallout** (from atmospheric testing of nuclear weapons and the Chernobyl accident) that affected the covered area in the past;
- **IRSN studies and expert assessments** relating to the radiological state of the environment.

This document section is regularly enriched with new IRSN summaries and expert assessment reports on the radiological state of the environment and related trends.

Internet sites of the principal data providers and interested parties

All environmental radioactivity measurement stakeholders operate websites enabling the public to obtain additional information about their activities, their inspection and monitoring programs and individual expert assessments. Certain websites also provide access to the annual public information report required under the terms of the Nuclear Safety and Transparency Act . This report includes a section relating to the nature and results of measurements of radioactive and non-radioactive waste from nuclear facilities in the environment.

EDF • FOCUS

EDF nuclear power plant environmental monitoring portal

EDF has developed a corporate website devoted to nuclear energy. This portal, accessible at http://energies.edf.com/accueil-fr/la-production-d-electricite-edf/- nucleaire-120205.html, provides access to information on nuclear power plant operation and the related issues in terms of environmental impacts. As well as a set of learning tools, the site contains a number of overview reports (on environmental monitoring, in particular), that provide the general public with comprehensive, contextualized information.

*The Internet portal developed by EDF also features a map of nuclear power plant locations (*Figure IX.3 – Map accessible at the following address: *http://energie.edf.com/nucleaire/carte-des-centrales-nucleaires-45738.html). The map provides access to a detailed fact sheet for each plant (including a presentation, events, life of the facility and publications), and to a dedicated module describing the monitoring plan at each nuclear power plant.*

Figure IX.4 shows an example with the Saint-Alban nuclear power plant (the map is available at the address http://energie.edf.com/html/energies/environnement/19/index.html). Visitors to the site can access a simplified map of the monitoring performed in the immediate vicinity of the power plant, showing information about the samples collected and measurements made. Visitors may then view a map of monitoring points in a wider area, in a radius of 5 to 10 km from the facility.

***Figure IX.3** - Overview of the interactive nuclear power plant map on the EDF website*

***Figure IX.4** - Interface providing access to the overall NPP monitoring system*
Example showing the environmental monitoring performed by EDF around the Saint-Alban facility

Selection of websites run by the leading operators (enterprises and research organizations)

French National Radioactive Waste Management agency (ANDRA)
http://www.andra.fr/

ANDRA's website features a detailed presentation of the environmental monitoring activities at each of its disposal facilities:

- **CSM waste disposal facility**
  http://www.andra.fr/andra-manche/pages/fr/menu7/le-centre-de-stockage/la-surveillance-de-l-environnement-1074.html
- **CSA waste disposal facility in the Aube department**
  http://www.andra.fr/andra-aube/pages/fr/menu4/le-centre-de-stockage-fma/la-surveillance-de-l-environnement-1091.html
- **Morvilliers VLL waste disposal facility**
  http://www.andra.fr/andra-aube/pages/fr/menu4/le-centre-de-stockage-tfa/la-surveillance-de-l-environnement-1101.html

Areva
http://www.areva.com/

Areva's website describes the environmental monitoring activities at each of its industrial facilities:

- **La Hague site**
  http://www.areva.com/FR/activites-1253/la-surveillance-de-l-environnement-de-l-usine-areva-la-hague.html
- **Comurhex-Pierrelatte**
  http://www.areva.com/FR/activites-867/la-surveillance-de-l-environnement-du-tricastin--areva-pierrelatte.html
- **Comurhex-Malvési**
  http://www.areva.com/FR/activites-870/la-surveillance-de-l-environnement-de-comurhex-malvesi.html
- **Eurodif**
  http://www.areva.com/FR/activites-876/la-surveillance-de-l-environnement-du-tricastin--eurodif-production.html
- **FBFC Romans-sur-Isère**
  http://www.areva.com/FR/activites-1040/la-surveillance-de-l-environnement-fbfc-romans.html
- **Tricastin fuel enrichment company**
  http://www.areva.com/FR/activites-3499/la-surveillance-de-l-environnement-de-la-societe-d-enrichissement-du-tricastin.html
- **Socatri**
  http://www.areva.com/FR/activites-879/la-surveillance-de-l-environnement-du-tricastin-socatri.html

French Navy
http://www.defense.gouv.fr/marine

An information leaflet describes the monitoring program and presents an overview of the results: http://www.defense.gouv.fr/content/download/148510/1486043/file/PLAQUETTES%20des%20ports%202011.pdf

French Alternative Energies and Atomic Energy Commission (CEA)
http://www.cea.fr/

The CEA site also features a presentation of the environmental monitoring activities in and around its sites, as well as direct access to all of its nuclear safety and transparency annual reports:

- **Cadarache**
  http://www-cadarache.cea.fr/carte/surveillance/index.php
- **Saclay**
  http://www-centre-saclay.cea.fr/fr/Surveillance-environnementale
- **Grenoble**
  http://www.cea.fr/le_cea/les_centres_cea/grenoble
- **Marcoule**
  http://www-marcoule.cea.fr (rubrique sécurité environnement)
- **Fontenay-aux-Roses**
  http://http://www-dsv.cea.fr (rubrique lettre de l'environnement)

Institut Laue – Langevin
http://www.ill.eu/

- **The Institut Laue – Langevin website** has a separate page describing the environmental monitoring in the area near the Institute:
  http://www.ill.eu/fr/reacteur-securite-environnement/surveillance-de-lenvironnement/
- The site also includes a **map showing the locations of sample points** used by the facility's monitoring program.

Selection of websites run by organizations with an interest in environmental radioactivity monitoring

International organizations

- **IAEA – International Atomic Energy Agency**
  http://www.iaea.or.at
- **NEA - Nuclear Energy Agency**
  http://www.nea.fr
- **ICRP - International Commission on Radiological Protection**
  http://www.icrp.org
- **IARC – International Agency for Reseach on Cancer**
  http://www.iarc.fr
- **European Commission**
  http://ec.europa.eu/index_fr.htm
- **WHO - World Health Organization**
  http://www.who.int/fr/
- **UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation**
  http://www.unscear.org
- **CTBT – Comprehensive Nuclear-Test-Ban Treaty Organization**
  http://www.ctbto.org/

Governmental sites

- **HCTISN – French High Committee for Transparency and Information on Nuclear Safety**
  http://www.hctisn.fr
- **Ministry of Ecology, Sustainable Development, Transport and Housing**
  http://www.developpement-durable.gouv.fr
- **Ministry of Agriculture and Fisheries**
  http://www.agriculture.gouv.fr
- **Ministry of Labor, Employment and Health**
  http://www.sante.gouv.fr
- **Ministry of the Economy, Finance and Industry**
  http://www.economie.gouv.fr
- **Ministry of Defence and Veterans' Affairs**
  http://www.defense.gouv.fr
- **Portal for environmental information relating to public services**
  http://toutsurlenvironnement.fr

NGOs, associations and learned societies

- **Association for Radioactivity Monitoring in Western France (ACRO)**
  http://www.acro.eu.org/
- **Independent Radioactivity Research and Information Commission (CRIIRAD)**
  http://www.criirad.com
- **"Sortir du Nucléaire" network**
  http://www.sortirdunucleaire.org
- **Greenpeace**
  http://www.greenpeace.fr
- **Nuclear Protection Assessment Research Center (CEPN)**
  http://www.cepn.asso.fr
- **Scientific Internet portal**
  http://www.science.gouv.fr
- **French Nuclear Energy Society (SFEN)**
  http://www.sfen.org
- **French Radiation Protection Society (SFRP)**
  http://www.sfrp.asso.fr
- **SRP – Society of Radiological Protection**
  http://www.srp-uk.org
- **International Union of Radioecology (IUR)**
  http://www.answeb.net
- **WISE-Paris – World Institute of Sustainable Energy**
  http://www.wise-paris.org
- **WNA – World Nuclear Association**
  http://www.world-nuclear.org

Publications by the French Nuclear Safety Authority (ASN)

ASN operates an information policy based on a media mix designed to make information accessible to its full audience spectrum. The website at www.asn.fr is the main source of information for the general public. It relates current issues concerning nuclear safety and radiation protection in France, and sets out ASN's position in its areas of expertise. The site also provides access to a document base relating to the life of nuclear facilities via a simplified browser, as well as enhanced access to data and optimized downloads of selected new items and publications.

ASN's annual report on the state of nuclear safety and radiation protection in France is a reference document containing a mine of information regarding the activities monitored by ASN in these two areas. ASN also publishes a quarterly journal named "Contrôle", which has more than 10,000 readers in France and other countries. In 2010, ASN published an edition with a feature on environmental radioacivity monitoring (*Figure IX.5: No. 188 – July 2010*).

These publications and the other materials produced by ASN (including the *ASN newsletter* and information sheets and presentation leaflets aimed at the general public) are available to view and download from www.asn.fr. They are also available at ASN's public information and documentation centre.

Figure IX.5 *- "Contrôle" magazine no. 188 with a special feature on environmental radioactivity monitoring*

IRSN assessments of the radiological state of the environment

Since 2004, as well as providing measurement results via Internet, IRSN has published (with a print run of more than 1,200 copies) annual assessments of its programs to monitor radioactivity in the French environment *(Figure IX.6)*.
This document provides an overview of the monitoring activities carried out throughout metropolitan France, both within and outside the area affected by nuclear facilities. IRSN has been carrying out its monitoring mission for many years and is in a position to comment on current results and place them in perspective with respect to past decades. A separate chapter of the report covers any radiological events that may have occurred in the course of the past year.
IRSN also publishes annual assessments of its monitoring activities in French Polynesia, which date back to 1962.

Figure IX.6 *- IRSN assessments of the radiological state of the environment*

Reports concerning the environment around basic nuclear installations

Operators are subject to certain legal reporting obligations. These include general obligations (such as the Environment report that corporations are required to produce under the terms of the Commercial Code) as well as requirements specific to the nuclear sector.

The Nuclear Safety and Transparency Act requires all operators of nuclear facilities to produce an annual report on their situation and activities, in particular in the area of radiological monitoring of the environment in and around their installations. In parallel, the regulatory framework also requires operators to publish a monitoring annual report, in application of the general guidelines on basic nuclear installations.

Annual report on monitoring of basic nuclear installation operators

The Order of November 26, 1999 sets out the general technical requirements concerning the scope and operating procedures relating to sampling activities and emissions subject to authorization by basic nuclear installations. Under the terms of Article 26 of the aforementioned order, operators of nuclear facilities are required to produce a publicly available annual report describing the operation of their facilities and covering all inspections and monitoring activities required by this order and the license.

This report describes water sampling, waste emissions, environmental monitoring and any impacts and nuisance caused. To this end, it includes an overview of the analyses and measurements performed over the previous year, the operator's assessment of any anomalies or exceeded limits, and its appraisal of the effectiveness with which operations were managed. This report also features an estimate - based on recorded discharge - of the ionizing radiation doses received during the preceding year, as a result of the installation's presence, by the reference population groups as defined in Article R. 1333-10 of the code.

The report is submitted to the French Nuclear Safety Authority (ASN), to the Regional Directorate for the Environment, Planning and Housing (DREAL), to the Regional Health Agency (ARS), to the Waterways Police and to the Local Information Commission. Operators are required to publish this annual report.

Nuclear safety and transparency report

Article 21 of the Nuclear Safety and Transparency Act (or "TSN Act") no. 2006-686 of June 13, 2006, repealed by Order No. 2012-6 of January 5, 2012 – Art. 7, stipulates that operators of basic nuclear installations must produce an annual report describing:

- **Measures implemented** in the area of nuclear safety and radiation protection;
- Reportable incidents and accidents with nuclear safety and radiation protection implications, in application of Article 54 of the Nuclear Safety and Transparency Act (Chapter V: applicable provisions in the

Figure IX.7 - Examples of operators' reports produced in accordance with the Nuclear Safety and Transparency Act

event of an incident or accident), that may have occurred inside the installation's perimeter, as well as the measures implemented to limit their development and mitigate the consequences for human health and the environment;

- **Nature and results of measurements** relating to radioactive and non-radioactive environmental emissions from the facility;
- **Nature and quantity of radioactive waste** stored at the site, and measures adopted to limit its volume and effects on health and on the environment (particularly soil and water).

This report *(Figure IX.7)* is submitted to the basic nuclear installation's health, safety and working conditions committee, which may in turn issue recommendations. Any such recommendations are appended to the document for publication and distribution. This report is also released to the public. It is submitted to the local information commission and to the High Committee for Transparency and Information on Nuclear Safety. The type of information that must be included in the report is defined in a decree.

Each year, ASN analyzes these documents and the Authority's annual report includes its principal conclusions relating to the treatment of topics specified in the law, any strategic considerations, pedagogical aspects of transparency practices and the right to access nuclear-related information (Articles 19 and 21 of the Nuclear Safety and Transparency Act).

IX.2 INFORMATION RELEASED UNDER THE TERMS OF TREATIES OR INTERNATIONAL AGREEMENTS

Information relating to environmental radioactivity monitoring is also provided internationally, in particular through the Euratom treaty and the Commission for the Protection of the Marine Environment of the Northeast Atlantic (known as the Ospar commission).

Distribution of French data in the context of the Euratom treaty

Each year, IRSN, acting on behalf of the French Government, submits several thousand environmental measurement results concerning aerosol particles, water, milk and food intake to the European Commission in order to comply with Articles 35 and 36 of the Euratom treaty. In addition to these results, raw data from the Téléray network is submitted automatically every hour.

JRC
EUROPEAN COMMISSION

The European Commission publishes regular European overviews based on the data contributed by the various Member States. A public Internet portal (http://rem.jrc.ec.europa.eu) enables visitors to view results by logging in to the various European Commission databases.

Article 35 of the Euratom treaty stipulates that: "Each Member State shall establish the facilities necessary to carry out continuous monitoring of the level of radioactivity in the air, water and soil, and to ensure compliance with the basic standards". This Article also asserts that "The Commission shall have the right of access to such facilities; it may verify their operation and efficiency". Based on the right of access, the Commission delegates the inspection of facilities for the purpose of verifying their operation and efficiency to specialist inspectors in each Member State. In this capacity, European Commission inspectors visited the Cadarache facility in June 2011, to examine the radioactivity monitoring installations deployed by the CEA *(Focus)*. Numerous French facilities have been inspected in recent years, including EDF nuclear power plants Areva's Tricastin and La Hague facilities, disused mine workings in the Limousin area, etc.

CEA • FOCUS

Verification under the terms of Article 35 of the Euratom treaty at the Cadarache facility in June 2011

A team of three inspectors from the European Commission performed an on-site inspection at the CEA's Cadarache facility, between June 20 and June 23, 2011. This inspection was part of the verification program stipulated by Article 35 of the Euratom treaty. The main focus was ensuring compliance with the Article regarding the resources used to monitor environmental radioactivity on and around the site, the representativeness of those resources, and the means of describing and quantifying emissions from nuclear facilities.

Article 35 of the Euratom treaty requires Member States to deploy adequate resources (in terms of facilities, equipment and organisation, etc.) to enable constant monitoring of the levels of radioactivity in the atmosphere, water and soil, and to ensure compliance with basic standards intended to protect the health of workers and the population against the dangers of ionizing radiation. The purpose of this inspection was to assess the effectiveness of these resources.

In addition to the CEA, for which this was the first such audit, the French Government was directly involved in the checks. The audit was attended by representatives from ASN, DREAL, IRSN, the nuclear safety and radiation protection mission (MSNR) and the Euratom technical committee (CTE), as well as several representatives from the CEA's Cadarache facility.

© G.Lesénéchal/CEA

***Figure IX.8** - Ground water monitoring at the CEA center in Cadarache*

The purpose of the audit was to verify the operation of the regulatory emissions measurement systems and the environmental monitoring programs on and near the site. Various installations were inspected to demonstrate the center's waste management processes to the inspectors, and to show them the various environmental monitoring facilities (analytical laboratories, environmental monitoring stations, etc.). A number of themes, including maintenance, calibration and data recording, archival and transmission were also examined via individual document-based reviews.

In the light of this inspection, the Commission issued a strongly positive opinion regarding the resources and organization implemented, as well as the quality of the results obtained. This audit has enhanced the reputation of the CEA and France more generally in the area of environmental radioactivity monitoring.

Data submitted by IRSN to the Ospar Commission

For around the past 15 years, IRSN has assisted the work of the Ospar Commission, which is the current legal instrument guiding internation cooperation aimed at protecting the marine environment of the Northeast Atlantic *(Figure IX-9)*. The Commission is made up of representatives of the governments of the 15 contracting parties (Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom) and the European Commission.

Its mission is to preserve the marine ecosystems and safeguard human health in the northeast Atlantic, by preventing and eliminating pollution, protecting the marine environment against harmful effects of human activities and contributing to sustainable use of the sea.

IRSN submits to the Ospar Commission radioactivity data relating to the marine samples collected along the Atlantic-English Channel coast (from water, sediment, flora and fauna), which was used to establish a baseline or benchmark against which to regularly assess the progress achieved since 1998 in terms of reducing the environmental impact of human activities. The Institute intends to continue submitting this data on an annual basis.

OSPAR COMMISSION
Protecting and conserving the North-East Atlantic and its resources

***Figure IX.9** - The five Ospar regions:*
- *Region I: Arctic waters*
- *Region II: North Sea*
- *Region III: Celtic seas*
- *Region IV: Gulf of Gascony and Iberian coastal waters*
- *Region V: Offshore Atlantic*

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X

UNDERSTANDING RADIOACTIVITY

We live in an environment that is naturally radioactive. Radioactivity is part of the universe. Without any human intervention, it is present everywhere on Earth, in matter and even in living creatures. It comes from several sources including cosmic radiation, the atmosphere and the Earth's crust. Food also contains radioactive elements such as potassium. The human body itself contains radionuclides and is therefore considered as a source of radioactivity. Radiation is invisible but it can be measured using very sensitive, high-precision instruments.

X.1 THE ATOM AND RADIATION

In the natural world, matter is made up of molecules formed by a combination of atoms. An atom *(Figure X.1)* consists of:

- **a central nucleus** made up of particles, called nucleons, which are divided into two types: protons and neutrons. Nucleons are two thousand times heavier than electrons;
- **a peripheral cloud** of electrons moving so fast that in a fraction of a second, they perform a multitude of orbits around the nucleus.

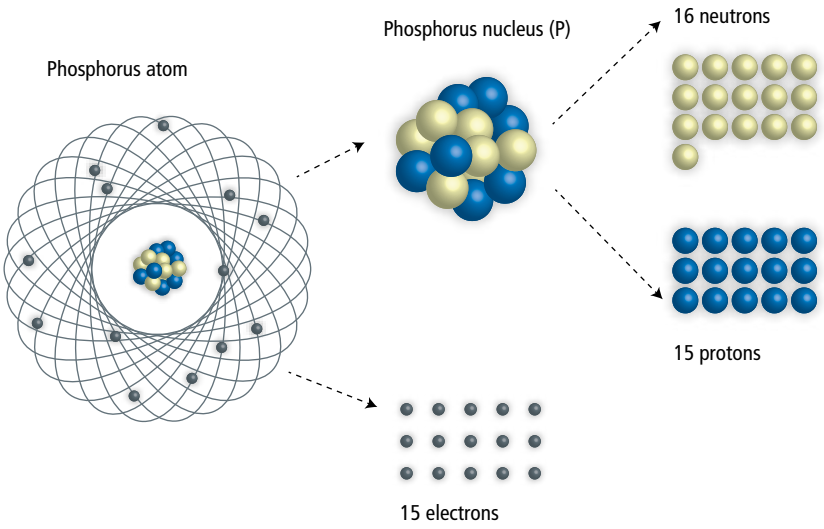


Figure X.1 - Phosphorus atom.

Certain unstable atomic nuclei have the chemical ability to spontaneously transform themselves into another form, a disintegration process referred to as decaying. When this occurs, the nuclei emit different types of rays, those with the greatest amount of energy being strong enough to tear electrons away from the atom.

Atoms that have lost a certain number of their electrons in this way then become positively charged. Nearby atoms that receive these electrons become negatively charged. Atoms that are positively or negatively charged are called ions. The rays capable of causing these reactions are referred to as "ionizing radiation", otherwise known as radioactivity.

The different types of ionizing radiation *(Figure X.2)* are:

- **cosmic radiation**, originating from galactic or solar sources, made up of particles that move at speeds close to the speed of light;
- **electromagnetic waves**, which produce the highest energy levels, i.e. gamma and X-rays:
  - > X-rays can be generated by projecting a beam of electrons onto a metal target. These electrons interact with electrons from atoms in the metal, causing their energy level to change, and thereby generating X-rays;
  - > gamma rays are emitted by radioactive atoms as they decay. It takes very thick layers of lead or concrete, for example, to stop gamma or X-rays.
- **alpha, beta plus and beta minus radiation** (particles emitted by radioactive atoms when they decay):
  - > alpha radiation, formed by a stream of helium nuclei (made up of two protons and two neutrons), can be stopped by a simple sheet of paper;
  - > beta radiation, formed by a stream of electrons, can be stopped by aluminum foil;
- **free neutrons**, which are found mainly in nuclear reactors, are emitted, for example, during fission of uranium-235 atoms. They are said to be indirectly ionizing because they generate gamma radiation or various types of particles when they are captured by nuclei or come into contact with them. These neutrons are also found at flight altitudes of long-haul and subsonic aircraft, and are responsible for 30% of the dose received by flight crews.

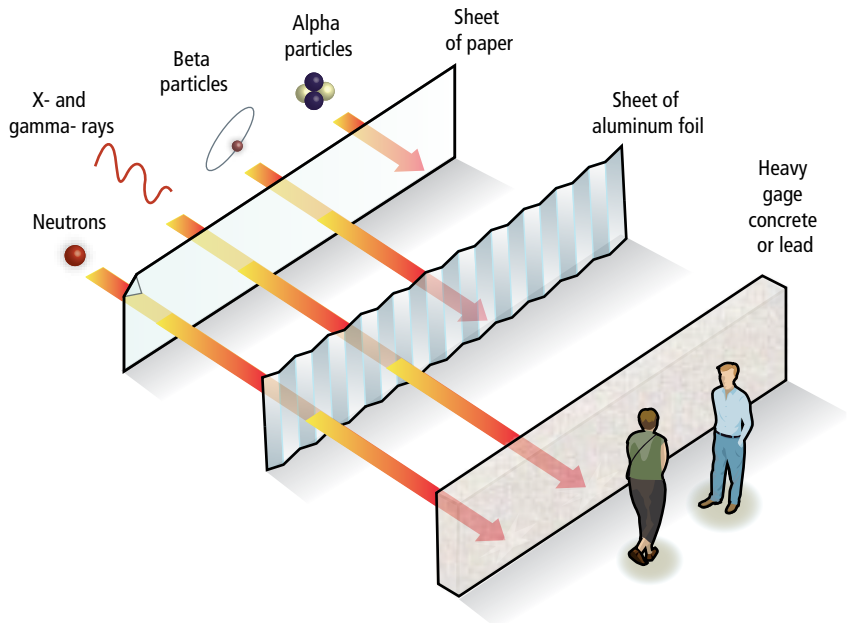


Figure X.2 - ***The various penetrating powers of alpha, beta and gamma rays and neutrons.***

Table X.1 - ***Examples of radioactive periods.***

Chemical element	Half-life
Uranium-238	4.47 billion years
Potassium-40	1.3 billion years
Uranium-235	704 billion years
Carbon-14	5,730 years
Radium-226	1,600 years
Cesium-137	30.2 years
Strontium-90	28.8 years
Tritium	12.3 years
Cobalt-60	5.27 years
Iodine-131	8.05 days
Phosphorus-30	2.55 minutes
Helium-6	0.82 second

X.2 MEASURING RADIOACTIVITY

Radiation from radioactivity cannot be directly perceived by the senses as it is invisible, silent and odorless. It was therefore impossible to detect radioactivity until humans invented the tools required to observe this phenomenon, making it possible to determine the type of radiation involved and accurately measure its intensity using various instruments.

Why does radioactivity decay?

Radioactivity decays over time. The time frame varies, however, depending on the atoms involved, and can exceed the lifespan of a human being. As an atom decays, its radioactivity gradually disappears as the atom evolves to a stable state, where it becomes non-radioactive.

Two researchers, Rutherford and Soddy, discovered that a radioactive substance loses half of its radioactivity (i.e. half of the atoms in the substance decay), over a certain period of time that is specific to that substance. This time period is called the "radioactive period" or "half-life".

Half-life varies *(Figure X.3)* from one atom to another *(Table X.1)*. Depending on the radionuclides involved, it may take anywhere from a fraction of a second to billions of years. Uranium-238 has a half-life of around 4.5 billion years. This long period explains why it can still be found on Earth in its natural state. The radioactive period of uranium-235 is around 700 million years, which explains why, when compared with uranium-238, only small amounts of uranium-235 are found on Earth (representing only 0.7% of natural uranium).

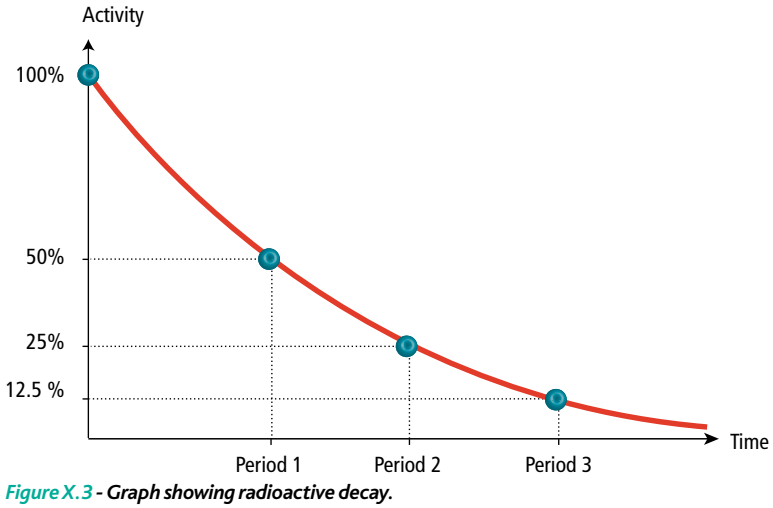


Figure X.3 - ***Graph showing radioactive decay.***

Understanding radioactivity units of measure

To measure radioactivity and its effects, three specific units of measure are used: the becquerel, the gray and the sievert.

Becquerel (Bq)

The radioactivity in a sample is measured by counting the number of disintegrations of radioactive nuclei produced per second. Radioactivity is measured in becquerels (Bq).

1 Bq = 1 disintegration per second

This is a very small unit of measure. For example, the activity in the skeleton of a man weighing 60 kg represents roughly 6,000 Bq of radioactive potassium. The activity of radioactive sources is often expressed in multiples of the becquerel (kBq, MBq, GBq, TBq), while the activity of environmental samples is expressed in Bq, mBq or µBq.

Activity is often related to volume (activity concentration in Bq/L or Bq/m³) *(Table X.2)*, mass (specific activity in Bq/kg) or surface (surface activity in Bq/m²). The old unit of measure for radioactivity is the curie (Ci), defined as the activity of 1 gram of radium, i.e. 1 Ci = 37 billion Bq.

Table X.2 - ***Order of magnitude of activity in different natural radioactive sources.***

Rainwater	0.5 Bq/L
Sea water	14 Bq/L
Milk	70 Bq/L
Fish	100 Bq/kg
Human body	120 Bq/kg
Potatoes	150 Bq/kg
Sedimentary soil	400 Bq/kg
Phosphate fertilizer	3,000 Bq/kg
Granite soil	8,000 Bq/kg

This measurement indicates the number of disintegrations, but not the energy involved or the effect on humans. That is why two other units are used: the gray and the sievert *(Figure X.4)*.

Gray (Gy)

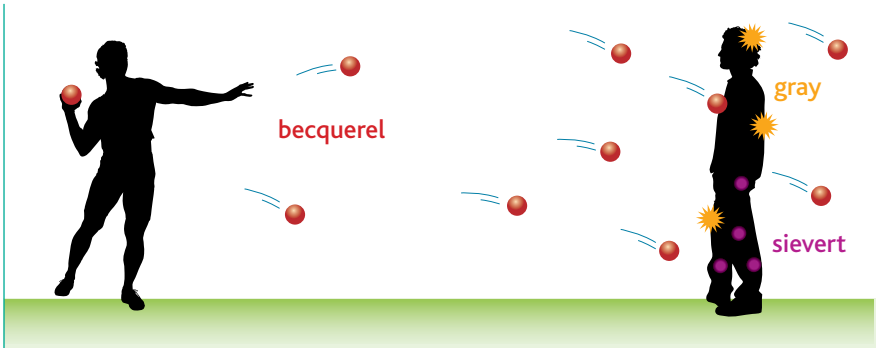
Absorbed dose is measured using the gray (Gy), representing the amount of energy radiated per unit of mass.
This unit can be used to measure the amount of radiation absorbed by an organism or an object exposed to radiation. The gray replaced the rad in 1986: 1 gray = 100 rads = 1 joule per kilo of irradiated matter.

Sievert (Sv)

The impact of radioactivity on living organisms or inert matter is not directly related to the becquerel for several reasons: the decay of an atom of cesium does not release the same amount of energy as that of an atom of iodine; the rays emitted are very different in nature; and organisms are not necessarily affected in the same way.

Furthermore, the effects are different depending on the parts of the organism affected by radiation. To take this into consideration, the absorbed dose is multiplied by a given factor, resulting in the equivalent dose, expressed in sieverts (Sv).

Certain tissues and organs are thus more sensitive to radiation than others. To account for this, the equivalent dose is weighted by a specific risk factor for each tissue or organ, in order to obtain the effective dose. The advantage of this system is that all types of human exposure to ionizing radiation can be assessed according to the same scale of risk. Because the effective dose value is generally quite small, it is often expressed in millisieverts (mSv).



The following description gives a simplified representation of the relationship between these three units of measure. A child throws balls at a friend. Imagine that:
- the number of balls thrown is the amount of radiation emitted by a radioactive source, in other words its activity (in becquerels);
- the number of balls that hit the friend represents the absorbed dose (in grays);
- the marks left on the body, which vary depending on the weight of the balls and the sensitivity of the areas affected, are the produced effect, representing the effective dose (in sieverts).

Figure X.4

How is radioactivity measured?

Radiation from radioactivity can not be perceived directly. Human senses cannot detect radiation emitted by radioactive substances. All methods used to detect radiation are based on the fact that radiation creates ionization (i.e. electrons are torn away from atoms) and excitation (where energy is input to atoms, causing them to pass from a ground state to an excited state), therefore leaving a trace within the matter itself. By calculating the number of ionizations or excitations caused by particles per unit of time, it is possible to measure the energy transmitted to matter through radiation. This energy represents a specific feature of the emitting radionuclide.

The operating principle of the three most commonly used types of monitors (gas counters, scintillators and semi-conductors) is the same: they all convert the photons or electrons created by radiation into an electronic signal.

The function of most radiation monitors is therefore to separate and count the ions (or electrons) produced by radiation passing through the monitor. This process is achieved by subjecting the detector to an electrical field. In general, radiation penetrates the detection zone inside the monitor, which may consist of a gas, a solid or a liquid, depending on the type of radiation to be measured. This interaction generates a series of discrete events involving ionizing electrons, photons, heat, etc.

Whatever the operating mode of the monitor and the corresponding principle on which radiation detection is based, monitors always consist of the same components:

- a sensor capable of operating within the range where the radiation in question interacts with matter;
- an amplification system that shapes and amplifies the signal produced by the sensor;
- a signal processing system, where applicable;
- a display system that indicates:
  - particle flow (on a counter);
  - particle energy (on a spectrometer);
  - absorbed dose or absorbed dose rate (on a dosimeter or ratemeter).

Figure X.5 - ***Radio-photo-luminescent dosimeter.***

Figure X.6 - ***Probe for continuous monitoring of ambient gamma dose rate.***

Concepts important to understanding radioactivity measurement results

Background

In metrology, background shows the count rate generated by just the environment, the composition of any reagents used, and the electronics in the measuring device. Background must be removed from the raw measured value to determine the activity actually contained in a sample. In terms of the environment, background represents a level of activity that cannot be avoided, measured at a point that is not affected by any source of artificial radioactivity.

Uncertainty

Measuring instruments, though highly sensitive, are not infinitely accurate. Simply stated, there is no such thing as an exact measurement. Uncertainty is a parameter associated with the result of a meaningful measurement that describes the possible range of values in which the true value may be found within the limits of a predefined probability.

Measurement uncertainty comes from the characteristics of the measuring device, the operator, the measuring environment (temperature, vibrations, etc.), the measuring procedure, and other factors. The value read on the measuring device may be anywhere within the measurement uncertainty range, therefore more or less close to the true value of the quantity measured *(Figure X.7)*.

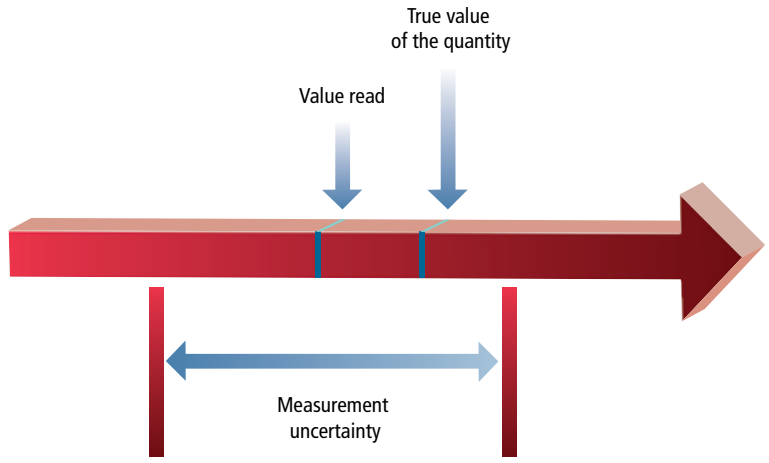


Figure X.7 - ***Readout value, true value and measurement uncertainty.***

Detection limit and decision threshold

When searching for very low-level activity, measurements from a sample may show a result very close to that obtained while determining the instrument's background (the signal detected in the absence of the radionuclide that the instrument is designed to search for).

Given the random nature of the radioactive decay process, results that are only slightly higher than the background measured do not necessarily imply that radioactivity is present. Similarly, results that are only slightly lower than the background do not guarantee that radioactivity is not present.

To reach a decision, analysts must therefore apply the concepts of decision threshold and detection limit, which characterize the measuring techniques used.

The decision threshold represents a count value for which, given the statistical fluctuations of the background, it can be stated with a reasonable amount of certainty that a count greater than this decision threshold value indicates that radioactivity is actually present in the sample measured. The sample activity and activity uncertainty can then be calculated.

If, however, the measurement from the sample gives a count lower than the decision threshold, it can only be stated, with a quantified probability of certainty, that even if radioactivity is present but has not been detected, it is lower than a value called the **detection limit**.

Depending on the measuring techniques used, the detection limit is approximately equal to two times the value of the decision threshold.

X.3 BIOLOGICAL EFFECTS OF RADIATION AND THE VARIOUS EXPOSURE PATHWAYS

Biological effects of ionizing radiation

Humans are constantly exposed to natural and/or man-made (i.e. artificial) radiation. Energy generated by ionizing radiation can lead to changes in the cells of living matter, and may consequently lead to lesions.

Two approaches, epidemiology and live cell analysis, are used to study the various biological effects of radiation. The impact of radiation on an organism varies depending on the dose received and other various factors, such as the source (activity or intensity during operation, type of source, energy, etc.), exposure pathways (time, dose rate, etc.) and the target (tissues or organs affected, age of the person, etc.).

There are two types of biological effects:

- **immediate (or deterministic) effects**: intense exposure to ionizing radiation causes immediate effects on living organisms, such as varying degrees of burns. Depending on the dose and organ affected, symptoms may appear within a few hours (as in the case of nausea and radiodermatitis) or several months later. Secondary effects, such as fibroses and

For the general public, the annual exposure limit of 1 mSv applies to doses received from sources other than natural radioactivity and medical applications.

If this limit was applied to these two sources, we would not be able to receive a medical scan, fly in an airplane, go mountaineering, or live in granite regions.

The maximum permissible dose of 1 mSv per year, which represents, on an average, roughly 40% of natural exposure, may seem high compared to the 0.06 mSv resulting from human activities other than medical procedures, and even more so compared to the 0.002 mSv due to nuclear power plants. But in terms of radiation protection, a dose of 1 mSv is considered as quite a small dose.

*For people working with ionizing radiation, the regulatory limit is 20 mSv per year over a period of 12 consecutive months (*Figure X.8*).*

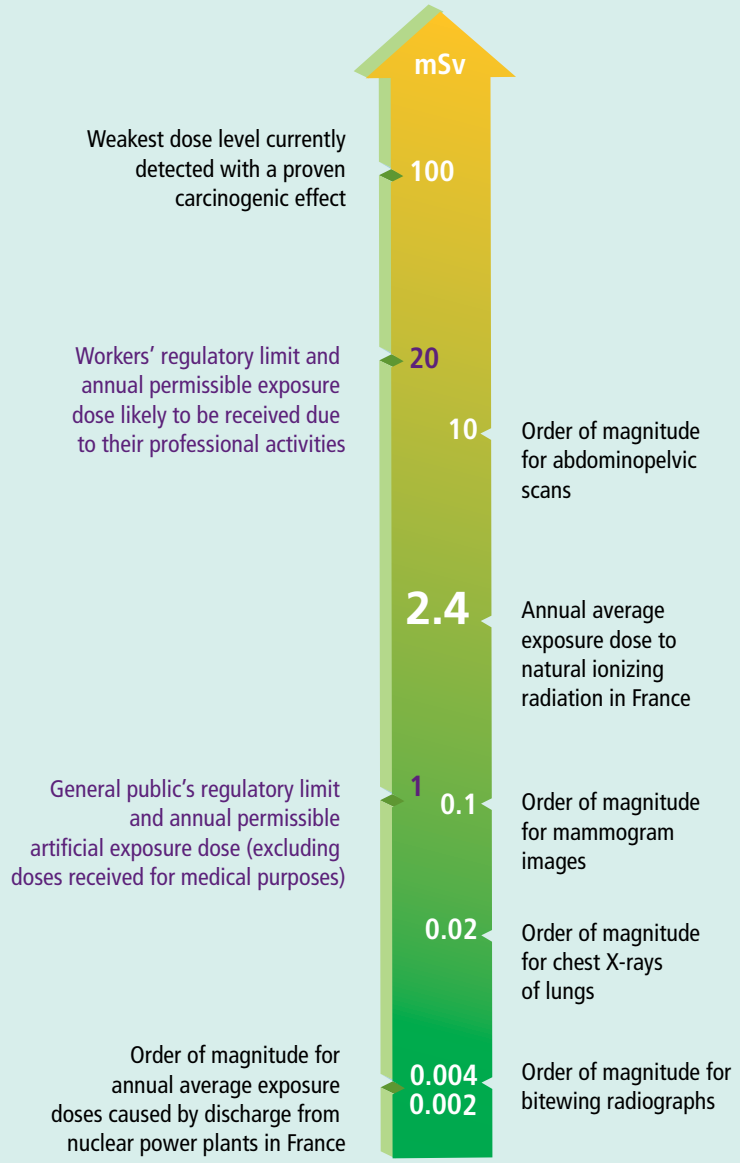


Figure X.8 - ***Examples of effective doses and regulatory limits expressed in millisieverts (mSv) (ASN source).***

cataracts, can even be observed years after irradiation;

- **long-term effects (random or stochastic effects)**: exposure to varying doses of ionizing radiation can lead to long-term effects such as cancer and leukemia. The stronger the dose, the greater the likelihood that it will have an effect. These effects appear several years after exposure.

Radio-induced illnesses do not have specific features. There is no biological marker that distinguishes between, for example, lung cancer caused from smoking tobacco and radio-induced lung cancer.

What are the effects on human health of low-level dose exposure?

Given that there are no directly measurable effects of low-level exposure, the related risks are estimated by extrapolating data from studies on survivors of the Hiroshima and Nagasaki explosions who were exposed to radiation, or patients who have undergone radiotherapy, where the exposure parameters (dose, dose rate, etc.) can vary significantly. Even if there is a relationship between exposure to ionizing radiation and excess rates of solid cancer, this relationship has not been proven for very low-level doses. The effects of exposure to doses below 100 mSv on human health are currently a topic of scientific debate.

Radiation protection

The goal of radiation protection is to prevent or reduce the risks associated with ionizing radiation. To achieve this goal, radiation protection is based on three important principles that figure in the French Public Health Code:

- **justifying activities** involving a risk of exposure to ionizing radiation;
- **optimizing exposure to radiation** so that levels are kept as low as possible;
- **limiting the radiation doses** to which individuals are exposed.

These three fundamental principles stem from one general precautionary principle: the "ALARA" (As Low As Reasonably Achievable) principle. Moreover, radiation protection regulations specify that special provisions are applicable to each of the following three population categories: the public, patients and workers.

Technical and organizational procedures implemented to comply with all of these principles are the main focus of regulatory monitoring carried out by public authorities. The French Nuclear Safety Authority (ASN) defines regulations and continuously conducts checks, on behalf of the State, to ensure that the radiation protection system is applied correctly.

Radiation exposure pathways

A distinction is made between external and internal exposure, depending on how radiation reaches the body.

- **External exposure:** in this case, the person is not in direct contact with the source of radiation and the dose received depends only on the length of exposure. External exposure takes place when a person is exposed to radiation sources that are outside their body, such as radioactive substances in the form of clouds or deposits on the ground, sources used for industrial or medical purposes, etc. Exposure can affect all or part of the body.
- **Internal exposure:** in this instace, radionuclides usually enter the body through ingestion or inhalation, but can also penetrate through skin wounds or intraveinously (for example during scintigraphy procedures); these cases are referred to as internal contamination. How radionuclides spread within the body depends on the nature of the radionuclide. Exposure results from the presence of radioactive atoms in tissues and organs. It therefore continues beyond the initial moment of absorption, but decreases according to the radioactive period of the radionuclide involved and its biokinetics. Exposure periods can be short (as when taking x-rays), or long (in the case of natural exposure).

1 *External exposure to radiation in the air*
2 *Internal exposure after inhalation and ingestion of contaminated items*
3 *External exposure to radiation from deposits*

Figure X.9


rayonnements
mSv
rayonnement
radioactifs
électrons
unité
atomes
mesure
comme
échantillon
isotope
type
feuille
radon
potassium
fusion
stables
temps
milliards
détection
radium
présents
ensemble
naturel
manière
atomique
représente
terrestre
gamma
désintégration
compte
sous
moyenne
seconde
complage
naturelle
descendants
symbole
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bêta
isotopes
effets
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Sv
RAYONNEMENTS
becquerels
équivalent
élément
radioactive
correspond
réaction
radioactif
global
Station
cette
organisme
rad
Direction
source
nucléaire
absorbée
interne
exposition
dose
nombre
suffisamment
partie
origine
rem
résultats
noyau
sources
rayons
valeurs
sol
particules
matière
exemple
plus
activité
possible
RADIOACTIVITE
externe
personne
fission
IONISANTS
arrêter
radionucléides
neutrons
an
France
gray
radioactives
biologiques
littérature
vivants
Installation
équivalente
milieu
mesures
forme

XI

APPENDICES

XI.1 PRESENTATION AND ANALYSIS OF RESULTS

The results analyzed in this report and presented in graphs and summary tables cover the period from January 1, 2010 to June 30, 2011, and to July 10, 2011 for results in the RNM database. Measurements transmitted beyond that date for the period considered could not be analyzed in this report. They can, however, be consulted on the RNM website: www.mesure-radioactivite.fr

Results from the regular monitoring of facilities were affected by fallout in France from the Fukushima accident. They are therefore shown separately so as not to interfere with results obtained outside this period.

Monitoring results for the marine and coastal compartment (sea water, sediments, aquatic fauna and flora) close to nuclear facilities are given in Chapter IV (Marine and coastal environment) to allow analysis of all the data available per shoreline. Similarly, all passive and active environmental dosimetry results are dealt with in Chapter IV (Atmospheric compartment).

In addition:

- The '<' sign indicates that measurement results are below the decision thresholds of the measuring instruments or protocols used. In graphs, such values are represented by empty bars (*) or lines stretching to the origin.
- The letters 'nm' in the tables indicate that a parameter or radionuclide has not been measured.
- The averages given are values calculated by weighting the uncertainty associated with each individual result. An uncertainty is associated with this average value.
- The results come with comments that sometimes refer to measurements obtained previously. In this case, the report highlights certain chronological series, in particular through specific 'Focus' articles.

Expression of results as average values

In order to provide the reader with a broader, more representative perspective of environmental radioactivity measurements, IRSN has chosen to express results as a single estimator that takes into account all values measured at a given point over the period in question, including values below decision thresholds. This method avoids over-repetition of individual results in tables or graphs, while remaining scientifically rigorous.

The selected estimator is a weighted average (m), associated with an uncertainty value (um). The method consists in taking significant values with their associated uncertainty value, and substituting a value Y, associated with an uncertainty value Y/2, for values considered below the decision threshold (< Y). Although this substitution method is not the most mathematically accurate, it does not minimize the possible impact of values that are not considered meaningful.

The best estimator for the average of a set of values Yi associated with uncertainty values ui (including the previously substituted values), can be calculated as follows:

Weighted average: $m = \sum_i \frac{1}{u_i^2} Y_i / (\sum_i \frac{1}{u_i^2})$

with uncertainty value: $u_m = \sqrt{1/(\sum_i \frac{1}{u_i^2})}$

For the following measurement results (Bq/L) for example:

Sample	Result	Uncertainty
A1	130	20
A2	140	10
A3	< 160	

The results table for calculating the weighted average is as follows (Bq/L):

Sample	Result	Uncertainty
A1	130	20
A2	140	10
A3	160	80

This average is calculated as follows:

$$m = \frac{(\frac{130}{20^2} + \frac{140}{10^2} + \frac{160}{80^2})}{(\frac{1}{20^2} + \frac{1}{10^2} + \frac{1}{80^2})} = 138{,}0$$

The associated uncertainty is:

$$u_m = \sqrt{\frac{1}{(\frac{1}{20^2} + \frac{1}{10^2} + \frac{1}{80^2})}} = 9{,}0$$

The weighted average for the three measurements A1, A2 and A3 is therefore equal to 138.0 ± 9.0 Bq/L.

Rounding

The rounding principle applied for expressing results as an average is aimed at obtaining two significant digits for the uncertainty associated with the result.

When the third significant digit is between 0 and 5, the second digit is rounded down to the next digit. When the third significant digit is between 5 and 9, the second is rounded up to the next digit. Each result is then given to the same number of decimal places as its uncertainty.

For the following result, for example: 23.12548 ± 1.58569 Bq/L

- The significant value for uncertainty will be 1.6
- The result will be expressed as = 23.1 ± 1.6 Bq/L

The rules for rounding measurement values and averages is described in a document entited: "*Moyenne, arrondissage et nombre de chiffres significatifs pour les essais interlaboratoires organisés par le STEME/LEI*" Technical document IRSN/STEME/DT/2009 – 07. (Averages, rounding and number of significant digits for interlaboratory tests organized by STEME/LEI).

Conversion of certain results for improved understanding

For the purpose of analyzing results sent to the RNM and providing overall, comprehensible data, while minimizing the number of different units of measure, IRSN has sometimes applied conversion factors to raw results (for example Bq/kg wet<-> Bq/kg dry). The conversion factors applied are taken from various IRSN databases, such as En-Cours and Sylvestre.

XI.2 GLOSSARY

AASQA: *Association agréée de surveillance de la qualité de l'air* (Approved Air Quality Monitoring Association).

Absorbed dose: amount of energy absorbed at a point per unit mass of inert matter or living tissue. It is expressed in grays (Gy). One gray represents 1 joule of absorbed energy per kilogram of matter or tissue.

ACRO: *Association pour le contrôle de la radioactivité dans l'Ouest* (Association for Radioactivity Monitoring in Western France).

Actinide: group of chemical elements with an atomic number of at least 89 (actinium has an atomic number of 89). Four actinides occur naturally: actinium (89), thorium (90), protactinium (91) and uranium (92). Man-made actinides also exist, namely the transuranium elements: plutonium, americium, neptunium, and curium. A distinction is made between minor actinides, which cannot be recycled to generate electricity, and major actinides, which can be recycled, namely uranium and plutonium.

Activation: process whereby atomic nuclei are made radioactive by neutron or gamma irradiation induced by a flux of neutrons or other particles.

Activity: number of spontaneous disintegrations - or decays - occurring in atomic nuclei per unit time. The unit of activity is the becquerel (Bq).

Aerosol: suspension of solid or liquid particles - or both - in a gaseous medium, with negligible fall velocity. Under normal conditions in the air, aerosols have diameters of less than 100 micrometers, while the finest particles among them attain just fractions of a nanometer.

AFNOR: *Association française de normalisation* (French Standards Association).

Alpha radiation (symbolized as α): a highly ionizing form of particle radiation with low penetration consisting of helium-4 nuclei. A simple sheet of paper can prevent its propagation.

ANCCLI: *Association nationale des comités et commissions locales d'information* (French National Association of Local Information Commissions and Committees).

ANDRA: *Agence nationale pour la gestion des déchets radioactifs* (French National Radioactive Waste Management Agency).

ANSES: *Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail* (French Agency for Food, Environmental and Occupational Health and Safety).

Areva: French industrial group involved mainly in the fuel cycle and the construction of nuclear facilities.

ARS: *Agence régionale de santé* (Regional Health Agency).

AS station: stationary aerosol sampling station.

ASN: *Autorité de sûreté nucléaire* (French Nuclear Safety Authority).

Atom: the basic unit of matter. It is made up of a nucleus (neutrons + protons) with electrons orbiting around it.

Background: in metrology, refers to the count rate induced by the environment, reagent composition and instrument electronics. The background must be subtracted (using a 'blank run') from the gross measured value to determine the net activity of a sample. In environmental terms, it represents an activity level measured at a given point, away from any man-made source of radioactivity, and which cannot be avoided.

Becquerel (Bq): official international unit of measurement used for radioactivity. The becquerel is equal to one transformation per second. The most common multiples are: mega (MBq) for 1 million becquerels, giga (GBq) for 1 billion becquerels, and tera (TBq) for one thousand billion becquerels. The most frequent submultiple is the millibequerel (mBq) representing one thousandth of a becquerel.

Beta radiation (symbolized as β): radiation consisting of electrons with a positive or negative charge. Propagation can be stopped by leaving a space of a few meters around the source or providing a barrier using a simple sheet of aluminum foil.

BNEN: *Bureau national de normalisation d'équipements nucléaires* (Nuclear Equipment Standardization Office). The BNEN is one of the 31 sector standardization offices that make up the French national standardization system headed by AFNOR.

CEA: Commissariat à l'énergie atomique et aux énergies alternatives (French Alternative Energies and Atomic Energy Commission).

Cesium (Cs, atomic number 55): Toxic rare metal with characteristics comparable to those of potassium. The 134 and 137 isotopes are radioactive fission products with respective half-lives of 2.2 and 30.17 years.

CLI: *Commission local d'information* (Local Information Commission.

COFRAC: *Comité français d'accréditation* (French Accreditation Committee).

Comurhex: An Areva subsidiary with two industrial sites in France. The Comurhex Malvési plant in southwest France carries out the first step in the conversion of uranium concentrates taken from mining sites into uranium tetrafluoride (UF_4) for electric utilities all over the world. The conversion process is continued at the Comurhex Pierrelatte plant in the Rhône valley, where uranium tetrafluoride is converted into uranium hexafluoride (UF_6), which is the last step before enrichment.

CRIIRAD: *Commission de recherche et d'information indépendantes sur la radioactivité* (Commission for Independent Research and Information on Radioactivity).

CSP: French public health code.

DDCSPP: *Direction départementale de la cohésion sociale et de la protection des populations* (Departmental Directorate for Social Cohesion and Public Health and Safety).

DDPP: *Direction départementale de la protection des populations* (Departmental Directorate for Public Health and Safety).

Decision threshold: a threshold value on a measuring instrument above which it can be considered, with a reasonably low probability of error, and allowing for statistical background fluctuations, that a count indicates that radioactivity is actually present in the sample measured.

Detection limit: the detection limit is the lowest activity level that can be detected by a measuring method under defined conditions, and for a specified confidence level.

DGAL: *Direction générale de l'alimentation* (Directorate General on Food Safety).

DGCCRF: *Direction générale de la concurrence, de la consommation et de la répression des fraudes* (Directorate for Competition, Consumer Rights, and Protection Against Fraud).

DGPR: *Direction générale de la prévention des risques* (Directorate General for Risk Prevention). The DGPR is divided into the Technological Risks Department, which deals with radiological risks, the Department for the Prevention of Pollution and for Environmental Protection, and the Department for Natural and Water-based Risks.

DGS: *Direction générale de la santé* (Directorate General for Health).

Discharge permit: every facility in France must apply to the Ministries of Industry, Health, and the Environment for a discharge permit that sets limits on the liquid and gaseous waste that may be discharged, and defines the associated inspection conditions. The permit is granted by government order.

Dismantling: all the operations involved in removing the structural parts and other components of a decommissioned nuclear facility. Dismantling can be partial or total.

Dose rate: radiation intensity (energy absorbed by matter per unit mass and time). The SI unit is the gray per second (Gy/s).

Dosimetry: assessment or measurement of the dose of ionizing radiation absorbed by a substance or an individual.

DREAL: *Direction régionale de l'environnement, de l'aménagement et du logement* (Regional Directorate for the Environment, Town and Country Planning and Housing).

Dose coefficient: dose received per unit activity by an individual exposed to one or more types of radiation. It is a general term and its definition varies with the exposure pathway considered:

- in the case of internal exposure (inhalation or ingestion), the dose coefficient is represented by the (committed) dose per unit intake(DPUI). It is expressed in Sv/Bq;
- in the case of external exposure to a plume, or immersion in water, the dose coefficient is the dose rate per unit activity concentration. It is expressed in (Sv/s)/(Bq/m^3);
- in the case of external exposure to radioactivity deposited on the surface of the ground, the dose coefficient is the dose rate per unit surface activity and is expressed in (Sv/s)/(Bq/m^2);
- in the case of external exposure to a radioactive deposit located underground, the dose coefficient is the dose rate per unit activity concentration and is expressed in (Sv/s)/(Bq/m^3).

In the case of internal exposure (DPUI), dose coefficients take into account the radionuclides in the body following ingestion or inhalation, the type and energy of the radiation emitted, and tissue sensitivity to radioactivity (radiosensitivity).

DPUI dose coefficients are calculated using models that describe the path taken by radionuclides as they travel through different parts of the body, as well as dosimetric models. These models incorporate the latest available knowledge in radiobiology. Dose coefficient tables are frequently updated. Various databases of internal and external dose coefficients are available, such as the Euratom 96/29 database, or the International Commission on Radiological Protection database. The choice of which database to consult will depend on the exposure pathway considered.

EDF: *Electricité de France*. - the French national electric utility.

Effective dose: sum of dose equivalents delivered to an individual's organs and body tissues, weighted by a factor specific to each organ or tissue. It is expressed in sieverts (Sv).

Effluent: any radioactive or non-radioactive gas or liquid discharged by a facility.

Electron: an elementary particle with a negative electrical charge. It is part of an atom.

EMM: French naval staff.

Euratom: treaty signed in Rome in 1957 that established the European Atomic Energy Community. The community was set up primarily to develop nuclear energy and to pool knowledge, infrastructure, and funding of nuclear energy, and ensure the security of atomic energy supply through a centralized monitoring system.

EURODIF: European Gaseous Diffusion Uranium Enrichment Consortium.

Exposure: the fact of being exposed to ionizing radiation (external exposure if the source is located outside the body, internal exposure if the source is located inside the body, etc.).

FANC: *Federaal Agentschap voor Nucleaire Controle* (Belgian Federal Agency for Nuclear Control)

FBFC: *Société franco-belge de fabrication de combustibles* (Franco-Belgian Fuel Fabrication Company).

Fissile: term used to describe atomic nuclei in which fission can be induced by capture of a single neutron. The energy configuration of fissile nuclei is very close to spontaneous fission.

Fission product: fragments of heavy nuclei produced by nuclear fission or the subsequent radioactive decay of nucleides formed by this process.

Fission: the splitting of an atom's nucleus as a result of bombardment by neutrons. During this reaction, neutrons and ionizing radiation are emitted and a great amount of heat is released. Nuclear power plants use this heat to generate electricity.

Fuel cycle: all the industrial operations undergone by nuclear fuel. The fuel cycle includes: extraction and processing of uranium ore, conversion and enrichment of uranium, fuel fabrication, spent fuel processing, recycling fissile materials that have been recovered for making new fuel, and radioactive waste management. It is called a 'once-through' cycle if the spent fuel is not recycled but considered as waste to be disposed of directly after use in the reactor. It is known as a 'closed' cycle if the spent fuel is processed and the fissile material resulting from processing is recycled.

Fusion: a reaction in which two light nuclei unite to form a heavy nuclei. Energy is given off during this reaction. Research is under

way to use the energy released by fusion to generate electricity.

Gamma (symbol γ): high-penetration, but low-ionization, electromagnetic energy emitted when radioactive elements disintegrate. Protection is provided by concrete or lead screens.

GCR: gas-cooled, graphite-moderated reactor. Reactors of this type operated at Bugey, Chinon and Saint-Laurent-des-Eaux nuclear power plants.

Gray (Gy): unit of energy transmitted to matter per unit mass (joule/kg) during absorption of a radiation dose.

Gross α (gross alpha activity): radioactivity index representing the activity of alpha-emitting radionuclides.

Gross β (gross beta activity): radioactivity index representing the activity of beta-emitting radionuclides.

GSIEN: *Groupement de scientifiques pour l'information sur l'énergie nucléaire* (Organization of Scientists for Information about Nuclear Energy).

Helium-4: nucleus consisting of two protons and two neutrons. This particularly stable assembly can be emitted by heavy nuclei as they seek stability. It is then known as an alpha ray.

ICPE: Installation classée pour la protection de l'environnement (environmentally regulated facility).

ILL: *Institut Laue–Langevin* (Laue-Langevin Institute). International research organization located in Grenoble, France. It possesses a 58 MW research reactor, called the high-flux reactor (RHF, INB No. 67), used to generate neutron beams.

INB: *Installation nucléaire de base* (basic nuclear installation).

INBS: *Installation nucléaire de base secrète* (secret basic nuclear installation).

InVS: *Institut national de veille sanitaire* (French Institute for Public Health Surveillance).

Iodine (I, atomic number 53)**:** an elemental substance whose radioactive isotopes are found in fission products. All forms of radioactive iodine (131, 132, 133, etc.) are short-lived (for example, iodine-131 has a radioactive half-life of 8.02 days). The exception is iodine-129, which has a half-life of nearly 16 billion years.

Ionizing radiation: radiation capable of displacing electrons from matter.

IRSN: *Institut de Radioprotection et de Sûreté Nucléaire* (French Institute for Radiological Protection and Nuclear Safety).

Isotopes: elements whose atoms have the same number of electrons and protons, but a different number of neutrons. They have the same name and the same chemical properties. There are currently 325 known natural isotopes and 1,200 artificial isotopes.

K: chemical symbol for potassium. Potassium content is generally expressed in mg/L or mg/kg (milligrams per liter or per kilogram). One gram of natural potassium has an activity (β/γ) of 31 Bq, resulting from the decay of ^{40}K, a radioactive isotope with a mass number of 40.

Matrix: sub-division of an environmental compartment (atmospheric, terrestrial, continental aquatic, or marine). Examples: rainwater, soil, vegetable produce, sediments, mollusks.

Measurement uncertainty: parameter characterizing the dispersion of values attributed to the measurement of a physical variable.

MES: Suspended matter.

MOX (Mixed Oxide): a mixture of uranium and plutonium oxides used in fabricating some types of nuclear fuel.

MW: megawatt.

Neutrino: elementary particle with no electric charge and unknown mass, emitted during weak interactions.

Neutron: electrically neutral fundamental particle which, with the proton, makes up the nucleus of an atom. The neutron causes the nuclear fission reaction that provides the energy used in nuclear reactors.

Noble gases: gases with no chemical affinity that do not form compounds readily. The noble gases are argon, helium, krypton, neon, radon and xenon.

NPP: Nuclear Power Plant.

Nuclear fuel: fissile material forming the active part of a reactor core. In order for a fission chain reaction to take place, natural uranium, a mixture composed of 0.7% uranium-235, which is fissile, and 99.3% uranium-238, which is not fissile, must first be enriched to 4% uranium-235. This uranium is used as uranium oxide, which is particularly stable chemically.

Nucleus: the positively charged central region of an atom. It contains almost all the mass of the atom, although it is ten thousand times smaller. The nucleus is composed of protons and neutrons bound by the strong interaction (or strong force).

Opera-Air: IRSN environmental atmospheric radioactivity monitoring network comprising stationary aerosol samplers (AS) and very high-volume aerosol samplers (TGD).

Outfall or discharge stack: Facilities discharge liquid effluent through an outfall, and gaseous effluent through a discharge stack.

Photon: elementary particle with zero charge and zero mass that acts as a mediator of the electromagnetic interaction.

Plutonium (Pu, atomic number 94)**:** transuranium element. Plutonium-239 has a half-life of 24,100 years.

Proton: positively charged elementary particle which, with the neutron, makes up the nucleus of an atom.

PWR: Pressurized Water Reactor. A nuclear reactor that uses uranium or a mixture of uranium and plutonium oxides for fuel, and ordinary water maintained at high pressure (155 bar to avoid vaporization) as coolant. French nuclear power is dependent on the use of this reactor design and the country has more PWR units in operation than any other country in the world.

Radiation protection: all the steps taken to protect the population and workers from the harmful effects of ionizing radiation.

Radiation therapy: use of the destructive power of radioactivity to destroy diseased

cells, while minimizing damage to the healthy cells around them.

Radiation: electromagnetic waves (gamma) or particles (alpha and beta particles, neutrons) emitted when radionuclides decay. X-rays are also electromagnetic waves but are emitted by electron tubes. The term 'ionizing' radiation refers to radiation that produces ions as it passes through matter. Gamma, X- and ultraviolet rays and visible light are similar but do not have the same penetrating power or capacity to produce ions.

Radioactive decay: natural decrease in the nuclear activity of a radioactive substance through spontaneous disintegration.

(Radioactive) half-life: the time required for radionuclide activity to be halved. The half-life varies from one radionuclide to another.

Radioactive waste management: all the regulatory or technical provisions made and operations performed concerning radioactive waste, from generation up to and including disposal, aimed at protecting persons and the environment.

Radioactivity: process in which the nuclei of certain elements spontaneously disintegrate to form other elements, with the emission of ionizing radiation.

Radionuclide: a radioactive isotope of an element. Examples: ^{3}H: tritium, a radioactive isotope of hydrogen. ^{14}C: carbon-14, a radioactive isotope of carbon.

Radon (Rn): a radioactive gas found all over the world. There are three naturally occurring istopes (^{219}Rn, ^{220}Rn, ^{222}Rn), which are the decay products of radioelements found in soil (^{235}U, ^{232}Th and ^{238}U).

Reactor system: term used to describe types of nuclear reactors capable of generating energy. A reactor system is characterized by shared specifications, such as the type of fuel, the moderator, the type of coolant, etc. Reactor systems include, for example, gas-cooled reactors (GCR), light-water reactors, and fast neutron reactors (FNR).

RNM: *Réseau national de mesures de la radioactivité de l'environnement* (French National Environmental Radioactivity Measurement Network).

RPL: radiophotoluminiscent dosimeter

SCL: *Service commun des laboratoires* (Joint Laboratory Service Unit), formerly the DGCCRF (Directorate for Competition, Consumer Rights, and Protection Against Fraud) laboratories. Since 1986, the year of the Chernobyl accident, the SCL has regularly monitored radioactivity levels in consumables.

SET: *Société d'enrichissement du Tricastin* is an Areva subsidiary located on the Tricastin nuclear site in the Rhône valley. SET is the project owner for and operator of the Georges Besse II enrichment plant.

SICN: *Société industrielle de combustible nucléaire*, an Areva subsidiary, produced nuclear fuel for gas-cooled, graphite-moderated reactors (GCRs) at two plants. One of these plants (Annecy) has now been converted for conventional activities, while the other (Veurey-Voroize) is being dismantled.

Sievert (Sv): legal unit of dose equivalent (or effective dose) used to determine 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 tissue and the type of radiation and tissue involved.

SOCATRI: *Société auxiliaire du Tricastin*, an Areva subsidiary, consists of a basic nuclear installation (INB 138) and a cleanup and uranium recovery facility (ARU).

Spectrometry: method used to analyze the intensity of radiation emitted by a source according to its energy level. It can both identify radioelements and specify their 'activity'.

Spent fuel processing: all the operations involved in extracting fissile and fertile materials (uranium and plutonium) from spent fuel for reuse, and for conditioning various categories of waste in a form compatible with storage or disposal.

SPRA: *Service de protection radiologique des armées* (Armed Forces' Radiation Protection Department). The SPRA reports to the French Central Directorate for Defence Medical Services.

Storage: temporary measure for radioactive waste pending disposal.

Strontium (Sr, atomic number 38): alkaline earth metal. Some of its isotopes are very widespread in nature, in particular strontium-90, which is taken up by bone tissue and has a half-life of 28.15 years.
TGD station: IRSN very high-volume aerosol sampling station.

TLD: thermoluminescent dosimeter.

Transuranium elements: group of chemical elements heavier than uranium (atomic number 92). The main transuranium elements are neptunium (93), plutonium (94), americium (95), and curium (96).

U content: uranium content by weight in a matrix, regardless of its isotopic composition. It can be measured or deduced from the activity (expressed in Bq) of each isotope (in which case it is called 'U content equivalent').

Uranium (U, atomic number 92): chemical element with three naturally occurring isotopes: uranium-234, uranium-235, and uranium-238. Uranium-235 is the only naturally occurring fissile nuclide, which is why it is used as a source of energy.

Waste rock: rock containing such low concentrations of mineral that it cannot be economically processed.

Waste: any residue from a production or transformation process or use, any substance, material produced or, more generally, any good that is no longer of any use to its owner and that is intended for disposal.

WHO: World Health Organization.

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