REPORT

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

Faire avancer la sûreté nucléaire

2011 report on radioactivity monitoring in French Polynesia

Summary of results from the IRSN monitoring network

PRP-ENV/SESURE/2013-08

Radiation Protection Division - Environment

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ABSTRACT

Radiological monitoring of the French environment is one of IRSN's permanent tasks as part of public policy on nuclear safety and radiological protection. It helps to guarantee the best possible protection for the population.

Carried out in Polynesia since 1962, this monitoring focuses on seven islands (Tahiti, Maupiti, Hao, Rangiroa, Hiva Oa, Mangareva and Tubuai) which are representative of the five archipelagoes. It consists in taking monthly samples of various kinds from the different environmental compartments (air, water, soil, food, etc.) with which the population may be in contact.

Regarding food, the samples analyzed are representative of the diet of Polynesians living in the five archipelagoes of the region and are taken from the marine environment of the open sea, the lagoon environment and the terrestrial environment.

Almost all samples are measured at the IRSN Laboratory for the Study and Monitoring of the Environment, based in Vairao on the island of Tahiti, plus a few samples at the IRSN Orsay Laboratory.

The year 2011 was marked by the Fukushima nuclear accident, which occurred on March 11. Within this context, IRSN stepped up its monitoring activities in French Polynesia and was able to confirm the absence of radiological impact in New Caledonia and Polynesia. As the results of these analyses were published in the previous annual report (report DEI/SESURE 2011-40), this report does not include all the data and results relating to the accident, but provides a summary for the year 2011.

As in recent years, levels of radioactivity, which fell steadily as of 1974 when French atmospheric nuclear weapons testing came to an end, were stable and very low in 2011. The residual radioactivity is mainly due to ^{137}Cs. In terms of additional dose, this artificial and residual radioactivity is lower than 5 $\mu Sv.yr^{-1}$ (5 microsieverts per year). This corresponds to less than 0.5% of exposure due to natural radioactivity in Polynesia (approximately 1000 $\mu Sv.yr^{-1}$).

RESUME

La surveillance radiologique de l'environnement français est une mission permanente de l'IRSN dans le cadre des politiques publiques de sûreté nucléaire et de radioprotection, participant à garantir au mieux la protection des populations.

Exercée depuis 1962 en Polynésie, cette surveillance, qui concerne sept îles (Tahiti, Maupiti, Hao, Rangiroa, Hiva Oa, Mangareva et Tubuai) représentatives des cinq archipels, consiste à prélever régulièrement des échantillons de nature variée dans les différents milieux (air, eau, sol, aliments…) avec lesquels la population peut être en contact.

En ce qui concerne les denrées, les échantillons analysés sont représentatifs de la ration alimentaire des polynésiens vivant dans les cinq archipels de ce territoire, et proviennent du milieu marin de pleine mer, du milieu marin lagonaire et du milieu terrestre.

La quasi-totalité des échantillons prélevés sont mesurés au Laboratoire d'Etude et de Suivi de l'Environnement de l'IRSN, implanté sur l'île de Tahiti à Vairao, quelques échantillons étant mesurés au laboratoire d'Orsay de l'IRSN.

L'année 2011 a été marquée par l'accident nucléaire de Fukushima, survenu le 11 mars. Dans ce contexte, l'IRSN a réalisé une surveillance renforcée de la Polynésie française, confirmant ainsi l'absence d'impact radiologique en Polynésie et en Calédonie. Les résultats des analyses liés à cette surveillance renforcée ayant été publiés dans le bilan annuel précédent (rapport DEI/SESURE 2011-40), le présent rapport ne reprend pas l'ensemble des données et résultats relatifs à cet accident, mais établit une synthèse pour cette année.

Après une diminution régulière des niveaux de radioactivité depuis l'arrêt, en 1974, des essais atmosphériques français d'armes nucléaires, l'état radiologique constaté en 2011 est stable, dans la continuité des années antérieures récentes, et se situe à un très bas niveau. Cette radioactivité résiduelle est essentiellement attribuable au césium 137. La dose efficace annuelle liée à la radioactivité d'origine artificielle est inférieure à 5 $\mu Sv.an^{-1}$ (5 microsieverts par an), soit moins de 0,5 % de la dose associée à l'irradiation naturelle en Polynésie (environ 1 000 $\mu Sv.an^{-1}$).

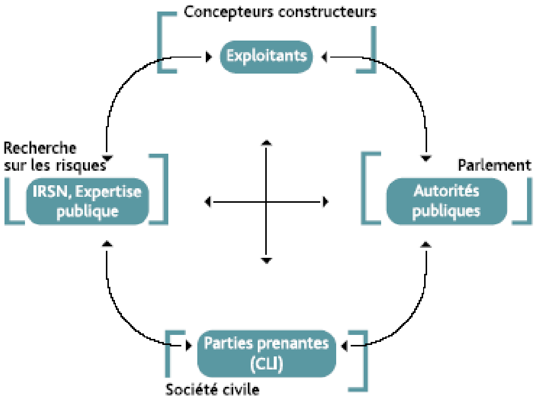
CONTENTS

1 INTRODUCTION

1.1 OVERVIEW OF IRSN MISSIONS

The French Institute for Radiological Protection and Nuclear Safety was set up under Act 2001-398 of May 9, 2001. It contributes to public policies concerning nuclear safety and security, and health and environmental protection against ionizing radiation, and interacts with all parties concerned by these policies.

In France, nuclear and radiological risk prevention is based on four complementary pillars :



- **Operators** are responsible for the safety of their nuclear facilities. They must demonstrate the relevance of technical and organizational resources applied for this purpose (safety files and release impact studies).
- **Public authorities** define nuclear safety and radiation protection policies. They organize and implement inspection activities.
- **IRSN, a public centre of expert appraisal** of nuclear and radiological risks, assesses reports submitted by operators for the various competent authorities. It continuously analyzes plant operating experience feedback as well as human and environmental radiation exposure. IRSN expertise is based on its research efforts, which are usually part of an international effort, and ensure it outstanding investigational resources.
- **Local information committees (CLI)** bring together stakeholders concerned by a specific nuclear facility. They have special access to information and monitor safety, health and environmental protection issues.

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

- the Ministry of Ecology, Sustainable Development and Energy (see the Ministry website) ;
- the Ministry of Industrial Renewal (see the Ministry website) ;
- the Ministry of Higher Education and Research (see the Ministry website) ;
- the Ministry of Defense (see the Ministry website) ;
- the Ministry of Social Affairs and Health (see the Ministry website).

Its budget : €210.8 million of its total budget of €282 million in 2011 was financed by a subsidy from the Ministry of Ecology under the constitutional bylaw on budget acts (mission: "Research and higher education", program: "Research on energy and sustainable development and energy", action: "Research on risks"). This subsidy is supplemented by national, European and international public or private financing assigned to specific research or expert appraisal programs. IRSN has almost 1,700 employees, including over one thousand experts and researchers.

Resource allocation :

- 40.2 % for research. The most intensive programs requiring research reactors and considerable resources (fuel performance, accident simulation, etc.) are shared jointly at international level ;
- 50.2 % for technical support for public authorities ;
- 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;
- safe transportation of radioactive and fissile materials;
- protection of workers exposed to ionizing radiation: IRSN manages data on the personal exposure of around 350,000 workers;
- protection of the population and the environment against ionizing radiation risks;
- protection and control of nuclear materials;
- protection of nuclear facilities and radioactive and fissile material shipments against malicious acts.

IRSN contributes to nuclear transparency :

- its activities include keeping the public informed. Its Internet portal (www.irsn.fr) provides readers from many backgrounds with a wide variety of information;
- IRSN has signed a framework agreement with the French National Federation of Local Information Committees, the ANCCLI, to make its expertise accessible to stakeholders and thus facilitate understanding of often complex technical files;
- at the request of the public authorities, IRSN coordinates interdisciplinary expert groups on potential socially controversial issues.

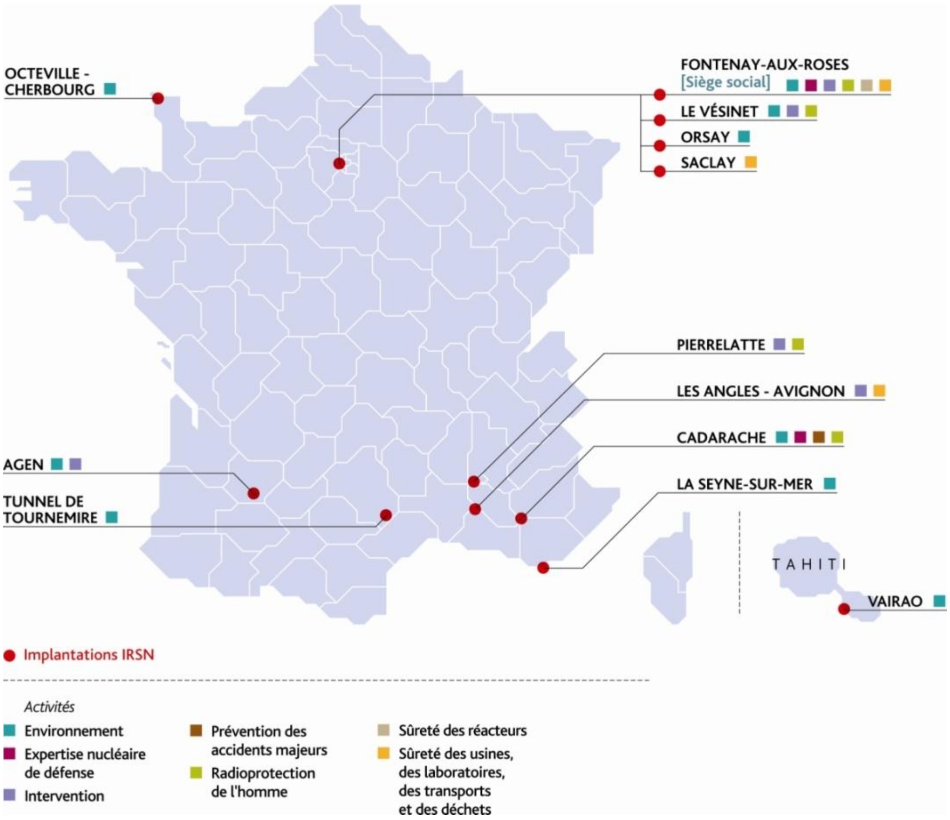


Figure 1: Map of IRSN sites

1.2 LESE, IRSN'S POLYNESIAN BRANCH

LESE, IRSN's Polynesian branch, moved to Vairao in the summer of 2009 after 44 years in Mahina. It has carried out continuous radioactivity monitoring in French Polynesia since 1962.

From the outset, this activity has been part of the broader French global radiological monitoring network (RMFSR) initiative.

An annual report on this monitoring - excluding the experimental sites of Mururoa and Fangataufa - has been submitted to UNSCEAR through the French Ministry of Foreign Affairs since 1966.

IRSN's activities in French Polynesia have a twofold objective :

-to monitor levels of artificial radioactivity in all the environmental compartments where Polynesians live and in the main foodstuffs they consume;

-to help assess doses received by Polynesians.

Monitoring was set up at a time when atmospheric nuclear weapons testing was being carried out by the major powers (the United States, the Soviet Union, the United Kingdom, France and China). The tests led to radioactive fallout on a planetary scale over several years. In French Polynesia, IRSN focused particularly on fallout from the 41 tests carried out by France in this part of the world between 1966 and 1974, and on its impact on the population.

Today, just as in metropolitan France, LESE continues this work as part of IRSN's continuous radiation protection monitoring activities.

Monitoring focuses on seven islands (Tahiti, Maupiti, Hao, Rangiroa, Hiva Oa, Mangareva and Tubuai), which are representative of the five archipelagoes. It consists in taking monthly samples of various kinds from the different environmental compartments (air, water, soil, food, etc.) with which the population may be in contact.

A reinforced environmental strategy

However, falling levels of artificial radioactivity detected in the environment, together with pressure from society for improved characterization of pollution, no matter how slight, have led LESE to gradually shift the focus of its monitoring strategy from human health measurements to increasingly precise measurements of radioactivity levels still detectable in the environment today.

Since 2009, LESE has therefore been working to develop an observatory of pollutants in Polynesian lagoons, in partnership with IFREMER and CRIOBE (CNRS). The aim of this project, funded by the Secretary of State for the French Overseas Departments and Territories from 2009 to 2011, then by the joint State-Country project contract from 2012 to 2014, is to monitor contamination of a biological indicator (nacre) by metals, radioactive substances, hydrocarbons, and organochloride compounds.

The project was selected as one of the top priorities of GOPS, the South Pacific Integrated Observatory for the Environment and Terrestrial and Marine Biodiversity, of which IRSN has been a part further to an agreement signed in Paris on March 9, 2010. The project was also among the priorities for the 2010-2013 action plan defined as part of the *Grenelle de la mer* marine environment round table in French Polynesia.

Supporting the public authorities in emergencies

LESE also carries out specific assessments, such as conducting analyses on the quality of the environment around sites, or radiological inspections, for the public authorities and private enterprises.

Given the small number of nuclear facilities in the southern hemisphere, and their distance from France, a radiological emergency is highly unlikely. However, even if an accident were to occur in the northern hemisphere, monitoring would be required because of trade and fish migration.

In 2011, reinforced monitoring had to be set up in French Polynesia and New Caledonia [3] in the wake of the Fukushima nuclear accident in Japan. This operation confirmed that the accident had had no radiological impact in these regions. Pelagic fish are still being monitored as they could carry radioactive traces when they migrate southwards from the North Pacific.

Chapter 2 of this 2011 report includes a brief description of French Polynesia in terms of geography, climate and habitat, together with an overview of the main dietary habits of the region's three main areas: Tahiti, the other high islands, and the low islands or atolls.

Chapter 3 describes the seven sampling zones in the different archipelagoes (two islands each for the Society Islands and the Tuamotu Islands, one of the Gambier Islands, one of the Austral Islands, and one of the Marquesas Islands).

The three main types of samples are also presented, namely samples from the physical, marine and terrestrial environments. Almost all samples of the last two types enter into the Polynesian population's diet.

Levels of radioactivity are given in Chapter 4. The first results for 2012 in the oceanic marine environment reveal no traces of radioactivity in French Polynesian territorial waters that can be attributed to the Fukushima nuclear accident.

Chapter 5 discusses the dosimetric significance of these radioactivity levels.

Chapter 6 summarizes the main results for 2011.

Another document relating to this report (Report PRP-ENV/SESURE 2012-18) can be consulted on the IRSN website to find out more about radioactivity and radiation protection, together with the radioactivity monitoring results in French Polynesia for 2011. It includes:

- activity levels in the physical environment;
- activity levels in the biological environment;
- dose calculation results.

2 BRIEF DESCRIPTION OF FRENCH POLYNESIA AND ITS POPULATION'S LIFESTYLE

French Polynesia is made up of 118 islands, 76 of which are inhabited, divided into five archipelagoes: the Society, Tuamotu, Gambier, Austral and Marquesas Islands. The islands are scattered over an area of five million square kilometers in the South Pacific (see Figure 2), with a total emerged land area of around 3,500 sq km. The islands are not heavily populated; according to the August 2007 census, there are fewer than 260,000 inhabitants. Most of the population (70%) lives on the island of Tahiti.

Polynesia has a wet tropical climate with no extremes. Average annual temperatures are moderate (21 to 28°C) and there is little temperature difference between seasons. Average rainfall is high, although not excessive: 1,800 to 2,000 mm per year. The islands are very sunny, with 250 sunshine hours per month on the west coast of Tahiti. The lagoons are warm, with water temperatures between 23 and 27°C all year round. These conditions are conducive to an outdoor lifestyle. In view of the long distances, small populations and differences in lifestyle, seven islands of volcanic origin and representative of the five archipelagoes were selected as sampling areas.

- **Tahiti and Maupiti**, high islands in the Society Islands;
- **Mangareva**, a high island in the Gambier Islands;
- **Tubuai**, a high island in the Austral Islands;
- **Hiva Oa**, a high island in the Marquesas Islands.

The high islands (e.g. Hiva Oa shown opposite) are made up of mountains that can be more than 2,000 m high and deep, narrow valleys, so most of the population is concentrated along the coasts. Market gardening, fruit growing and some livestock farming are carried out there.

People in **Tahiti** have a varied diet and can find an abundance of produce from all over Polynesia. There are two markets in Papeete and its suburbs, which alone provide some 40,000 people with local produce such as fish and shellfish, vegetables, fruit, and pork, both from Tahiti and the other islands. Many well-stocked food stores can also be found there selling local and imported foods. The other **high islands** have access to a wide range of local produce including fruit, vegetables, and fish, as well as imported essentials such as rice, flour, oil and sugar, which are shipped in regularly.

- **Hao** and **Rangiroa** (photo opposite), two inhabited atolls in the Tuamotu Islands.

These low islands or atolls are simply ring-shaped coral reefs, almost level with the sea, and for the most part are planted with coconut trees.

Their population lives mostly on locally caught fish, coconuts and some chicken and pigs from family livestock farms. Imported produce is not so varied and is shipped in less regularly.

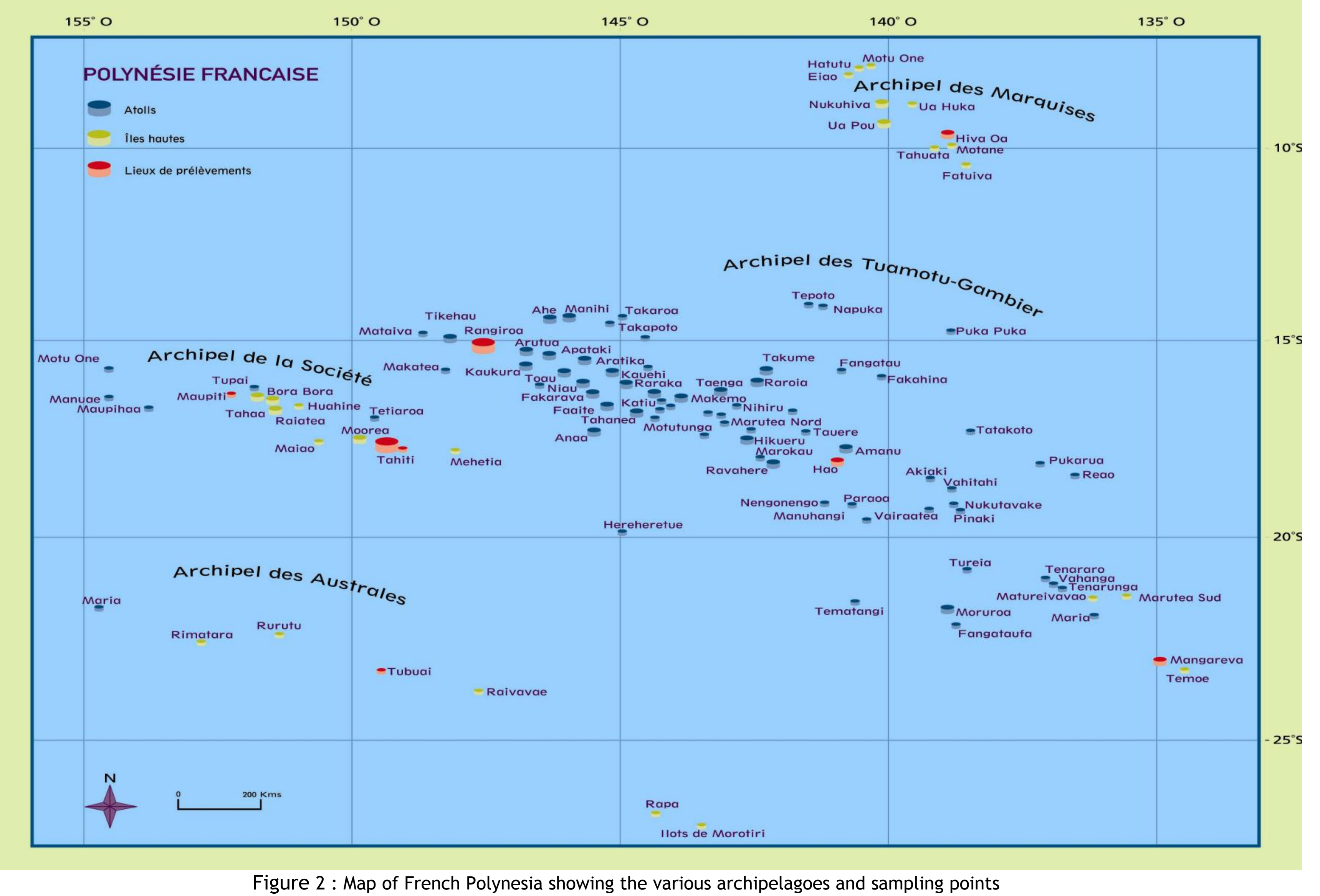


Figure 2 : Map of French Polynesia showing the various archipelagoes and sampling points

3 SELECTED LOCATIONS AND SAMPLES

3.1 SELECTED LOCATIONS

The seven islands selected had to meet certain essential criteria, namely :

- ensure geographical coverage of all of French Polynesia, i.e. nearly 3,000 km from east to west and 2,000 km from north to south, and a total area of more than 5,000,000 sq km ;
- take into account the two types of islands: high islands and atolls ;
- allow for the highly irregular population distribution ;
- take into account the location of the Mururoa and Fangataufa atolls, where French nuclear weapons testing was carried out between 1966 and 1974, and the prevailing easterly trade winds, which have a major impact on the trajectories of fallout from these tests ;
- select the most populated islands of each archipelago; Maupiti was selected in addition to Tahiti in the Society Islands because it is the westernmost island, and Hao was selected in addition to Rangiroa in the Tuamotu Islands to allow for the very wide area covered by this archipelago and because it is nearer to the former nuclear test sites.

3.2 SELECTED SAMPLES

Samples are selected on the basis of two monitoring objectives in French Polynesia :

- to monitor levels of artificial radioactivity in the environment ;
- to estimate population exposure to this artificial radioactivity.

Six permanent assistants work with the laboratory to collect and send samples. Samples from Tahiti are gathered by laboratory staff.

In 2011, a total of 177 samples were taken; 24 from the physical environment and 153 from the biological environment.

In view of falling environmental radioactivity levels, analyzing the same samples taken from the same island several times a year is no longer justified. For this reason, the number of lagoon fish samples was reduced compared to previous years in favor of analyses on nacre from P*inctada margaritifera*. These analyses are to be used in a planned network for monitoring pollutants, radioactive substances, heavy metals, and organochloride compounds [1]. The network is currently being implemented in collaboration with IFREMER and CRIOBE (CNRS) teams. In 2011, five gamma spectrometry analyses, supplemented by chemical pollutant analyses, were carried out at two stations, one in Vairao and the other in Papeete port.

3.2.1 PHYSICAL ENVIRONMENTAL SAMPLES

Physical samples included air samples obtained by filtering, sea, rain (photo opposite), river and spring water samples taken in Tahiti, and sediment samples from the various islands. Rainwater analyses were performed monthly until 2009, then on a half-yearly basis as of 2010. Sampling was carried on uninterruptedly but the collection surface area was reduced.

3.2.2 BIOLOGICAL ENVIRONMENTAL SAMPLES

The number of biological samples taken in 2011 per island was as follows : 67 for Tahiti, 17 for Maupiti, 14 for Tubuai, 8 for Rangiroa, 19 for Hiva Oa, 13 for Mangareva and 7 for Hao. A further eight samples were taken of imported produce consumed throughout the archipelagoes.

Of the 153 samples taken in 2011, 23 concerned three categories of the marine environment, namely pelagic fish, lagoon fish and other marine samples (shellfish, etc.) and 130 were terrestrial samples (photos below).

- Pelagic fish samples

  Three samples of pelagic (or open sea) fish (yellowfin tuna).

- Lagoon fish samples

  Seven samples of fish living in the lagoon or in its immediate vicinity close to the reef, exclusively loaches and groupers. Several different species were analyzed until 2010, including snappers, emperors and trigger fish. Loaches and groupers were taken as bioindicators of ^{137}Cs concentrations in lagoon water as they are the most likely to concentrate cesium in their flesh [2].

- Other marine samples

  Thirteen samples of mollusks and shellfish: 6 giant clams (tridacna), 5 nacres and 2 octopuses.

- Terrestrial samples

  One hundred and thirty samples broken down as follows: 31 drinks (4 drinking waters, 8 coconut waters, 1 beer, 1 fruit juice, 1 soda and 16 milk samples), 35 vegetables (11 leaf vegetables, 14 fruit vegetables, and 10 root vegetables), 32 fruits, 4 meats and eggs, 11 pasture grasses and 8 additional samples concerning imported produce (1 beer, 1 milk, 3 meats and 3 other products : bread, rice, and potato).

Grapefruit tree

Pinctada margaritifera, nacre

4 RADIOACTIVITY LEVELS AND CHANGES

All radioactivity measurements in Polynesia were performed by LESE, except for the gamma spectral analyses performed by the IRSN Environmental Radioactivity Measurement Laboratory (LMRE) in Orsay, France (Essonne - 91).

To perform these measurements, LESE has various equipment for direct measurement via gamma spectrometry or after selective radiochemistry for Pu and ^{90}Sr analyses.

Gamma spectrometry

Proportional counting (^{90}Sr)

4.1 PHYSICAL ENVIRONMENT

4.1.1 AIRBORNE RADIOACTIVITY

Continuous aerosol sampling was performed by filtering on a high-flow aerosol collector station (approximately 300 m^3/h).

Table 1 below lists the annual mean activity levels obtained over the past three years for ^{137}Cs, ^{7}Be, ^{22}Na, ^{40}K and ^{210}Pb. The indicated uncertainties are due to the measurement techniques and not natural variations. These results are compared with the levels obtained in Orsay, near Paris.

The monthly mean activity levels, along with the sampled air volume for each period for the Tahiti and Orsay stations, are shown in Tables AI 1 and AI 2 of the Appendix report, which can be found on the IRSN website (report PRP-ENV/SESURE 2012-18).

Table 1 : Annual mean activity levels (µBq.m^{-3}) from 2009 to 2011 for the 5 radionuclides detected in the continuous aerosol samples obtained in Tahiti and Orsay. These activity levels are calculated based on the weighted monthly mean activity levels for the sampled air volumes.

Radionuclide	Tahiti			Orsay		
	2009	2010	**2011**	2009	2010	**2011**
^{137}Cs	0.08 ± 0.04	0.08 ± 0.04	**0.10 ± 0.06**	0.15 ± 0.07	0.15 ± 0.06	**3.9 ± 1.6**
^{7}Be	3970 ± 1180	2990 ± 930	**3260 ± 950**	3680 ± 1060	3550 ± 990	**3900 ± 760**
^{22}Na	0.46 ±0.20	0.26 ± 0.11	**0.29 ± 0.12**	0.46 ±0.18	0.44 ±0.17	**0.33 ± 0.14**
^{40}K	8.1 ± 3.1	8.0 ± 2.6	**8.3 ± 2.7**	6.2 ± 2.2	5.4 ± 2.1	**7.0 ± 3.2**
^{210}Pb	121 ± 36	78 ± 25	**86 ± 26**	380 ± 110	350 ± 100	**550 ± 120**

The only artificial radionuclide that is still detected in French Polynesia is ^{137}Cs. This indicates the persistence of fallout from atmospheric nuclear weapons testing. No changes were detected in the atmospheric concentration of this radionuclide over the 2009-2011 period. However, two values slightly above "normal" were recorded from August 1 to 10 (0.43 ±0.15 µBq.m-3) and August 10 to 20 (0.14 ±0.06 µBq.m-3). If the increased concentration of ^{137}Cs was linked to the accident in Fukushima, other radionuclides that "accompany" ^{137}Cs and which are characteristic of the accident would also have been detected; but no other artificial radionuclide, and in particular ^{134}Cs, were detected. This increased concentration is therefore not linked to the Fukushima accident. The resuspension of dust carrying old ^{137}Cs deposits (from the Taravao plateau, for example) may explain this observation.

In metropolitan France, a sharp increase was noted in the concentration of airborne ^{137}Cs following the accident at the Fukushima nuclear power plant, which affected the entire northern hemisphere. Other radionuclides that are characteristic of this accident were also detected (^{131}I, ^{132}I, ^{134}Cs, ^{136}Cs, ^{121}Te, ^{129m}Te and ^{132}Te) [3].

The four natural radionuclides come from the upper atmosphere (^{7}Be, ^{22}Na) and lower atmosphere (^{40}K, ^{210}Pb).

The following figures show variations in ^{137}Cs activity levels in aerosol samples taken in Tahiti (Figure 3) and in Essonne, France (Figure 4) over the past 40 years. The effects of the Chernobyl and Fukushima accidents on activity levels in France can be noted. Overall, the concentrations have decreased by a factor of 1000 over the past four decades, with activity levels in France remaining approximately five times higher than in Polynesia.

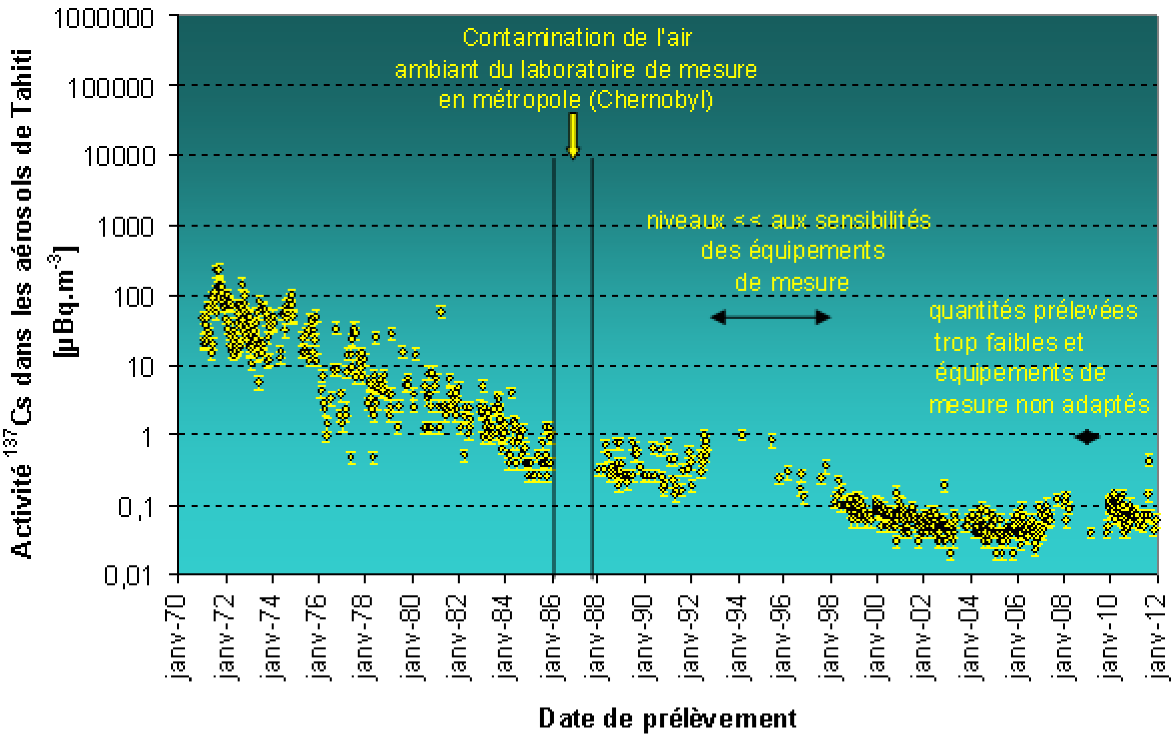


Figure 3 : ^{137}Cs activity levels (µBq.m^{-3}) in aerosol samples taken in Tahiti from Jan 1971 to Dec 2011

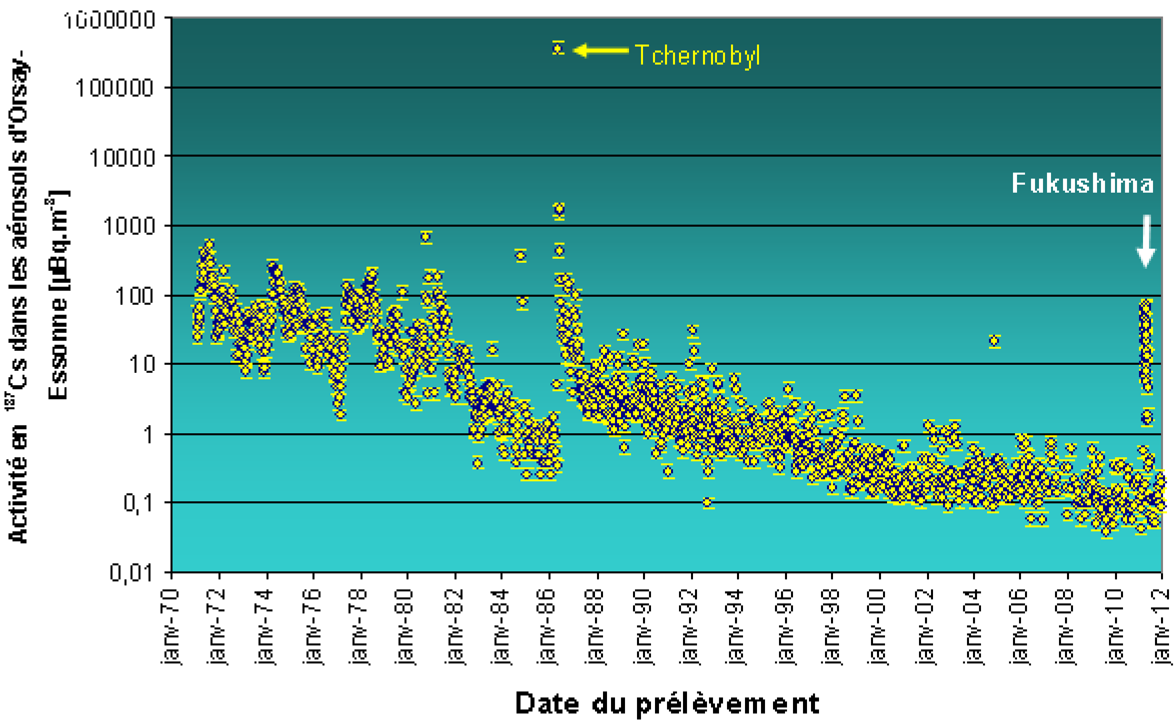


Figure 4 : ^{137}Cs activity levels (µBq.m^{-3}) in aerosol samples taken in Orsay (Essonne) from Jan 1971 to Dec 2011

4.1.2 RADIOACTIVITY IN WATER

A 360-liter seawater sample was taken in 2011 south of Tahiti (at Vairao) in the lagoon at a depth of 1.5 meters. The value of 1.05 ± 0.05 $mBq.L^{-1}$ measured for ^{137}Cs (Table AI-3 of the Appendix available on the IRSN web site – PRP-ENV/SESURE 2012-18) is compliant with the values generally obtained in this region of the Pacific Ocean, and with the values obtained in previous years north of Tahiti (at Point Venus – Mahina sampling station).

This year, commercial spring water from Tahiti, which is widely consumed on all the archipelagoes, was analyzed. The artificial radionuclide ^{137}Cs was not detected in this sample, nor in the freshwater samples (rainwater and spring water collected in Tahiti and drinking water collected in Tubuai, Hiva Oa and Maupiti). All these results are below detection limits (DL) (Table AI-3). River water collected on the peninsula was analyzed in 2011. An extremely low ^{137}Cs concentration (0.10 ± 0.02 $mBq.L^{-1}$) was detected in the sample. These results were the same as those obtained in 2009 and 2010 from sampling at the same location. This value is close to the detection limit, and is nearly the same as the measurements taken in previous years north of Tahiti (Papenoo).

Only naturally-occurring ^{40}K is systematically detected in these samples.

4.1.3 RADIOACTIVITY IN SEDIMENTS

Sediments are not systematically sampled each year. From 2009 to 2011, a sediment sampling campaign was conducted at various points on the seven islands in the radioactivity monitoring network, and also on one of the other Tuamotu islands (Apataki).

The gamma spectrometry results cover 19 marine sediment samples taken in the lagoons of Tahiti, Maupiti, Tubuai, Hao, Mangareva (Gambiers), Rangiroa and Apataki, and also ocean sediments from Hiva Oa and Rangiroa. For artificial radionuclides (Table AI-4 for 2011 results and reference [5] for the other results), only ^{137}Cs was detected at low activity levels (< 0.25 $Bq.kg^{-1}$ for dry sample) in four locations : Tahiti (the port of Papeete and the black sands of Vairao), Tubuai and Gamblers . The other 15 results are expressed at the detection limit (pink dots on figure 5).

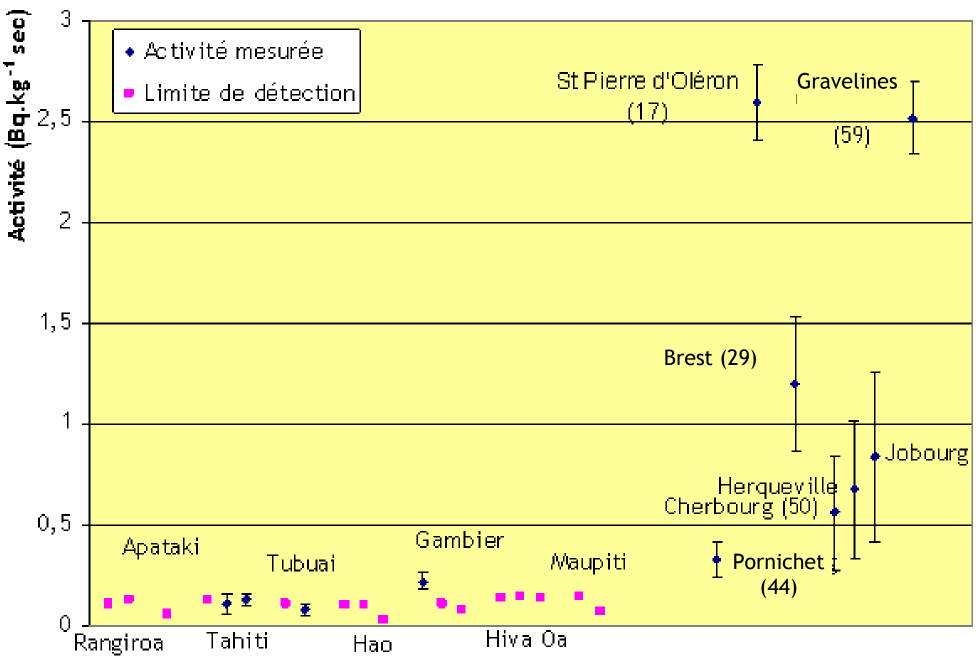


Figure 5 : Activity levels for ^{137}Cs in marine sediments from French Polynesia (Rangiroa, Tahiti, Hao, Gambiers, Hiva Oa, Maupiti, Tubuai and Apataki) and in France (Pornichet, St Pierre d'Oléron, Brest, Jobourg, Herqueville, Cherbourg and Gravelines).

Figure 5 shows a comparison of the results obtained in French Polynesia with the results from marine sediments taken from beaches of the Atlantic and the English Channel in France in 2009 [4]. The concentration levels in Polynesia are 10 to 20 times lower than those found in France, which was affected by the Chernobyl accident and greater atmospheric fallout from nuclear tests in the northern hemisphere.

4.2 BIOLOGICAL ENVIRONMENT

The analyses of biological samples, primarily foodstuffs, covered the edible parts. The 153 samples were measured by gamma spectrometry, including 19 that were subject to radiochemistry followed by alpha spectrometry to determine the plutonium isotope doses. The ^{90}Sr measurements for these 19 samples could not be completed due to difficulties procuring the gas (Ar-CH_4) required to operate the counters. These results will be included in the 2012 report.

Only a few traces of ^{137}Cs and plutonium were measured in these samples. The samples analyzed in 2011 contained no traces of ^{60}Co, which has only been detected in a few samples of giant clams (tridacna) in recent years.

4.2.1 MARINE ENVIRONMENT

4.2.1.1 **Pelagic fish**

In 2011, three samples of yellowfin tuna (*Thunnusalbacares*, see picture opposite) from coastal fisheries in Mangareva, Hao and Rangiroa were analyzed by gamma spectrometry. Tables AII-1 to AII-7 in the Appendix report available on the IRSN website (report PRP-ENV/SESURE 2012-18) list detailed results for each island.

The ^{137}Cs values are the same as the values observed in recent years, and the residual levels remain fairly uniform, 0.1 to 0.2 Bq.kg^{-1} for a wet sample. The maximum level (0.20 Bq.kg^{-1} on wet sample) was detected in the sample from Hao.

For the other gamma-emitting artificial radionuclides, such as ^{60}Co, alpha emitters, ^{238}Pu and $^{239+240}$Pu (three samples analyzed), the results are below the detection limits.

FOCUS

Monitoring the impact of Fukushima on the marine environment in French Polynesia

In response to the accident at Fukushima-Dai-ichi, special monitoring was implemented by IRSN-LESE in French Polynesia and New Caledonia [3, 5]. The purpose of the monitoring was to detect any atmospheric contamination between March and July 2011.

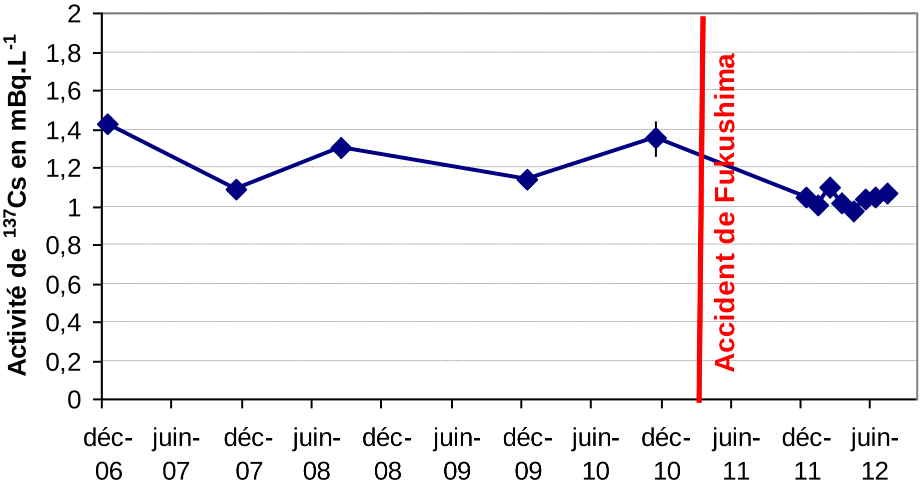
Beginning in September 2011, special attention was given to pelagic fish that may have conveyed contamination from the North to the South Pacific. Fish samples were taken at an increased frequency, and seawater sampling is performed on a monthly basis.

The monitoring is focused on the primary radionuclides that were released to the environment during the accident in Japan in March 2011: cesium-134 and cesium-137.

The cesium-137 isotope has a radioactive half-life of 30 years, and has remained in the environment since atmospheric nuclear tests (1.3 x 10^{18} Bq released into the environment between 1945 and 1980). Other sources of cesium-137 include fallout from the Chernobyl accident (less than 10^{17} Bq, found mainly in Europe) and releases from fuel reprocessing plants and nuclear power plants (1.3 x 10^{8} Bq in 1999 for a 1300 MWe reactor). The impact of the Fukushima accident is characterized by the detection of cesium-134 (radioactive half-life of 2.1 years) and an increased concentration of ^{137}Cs.

Seawater

In French Polynesia, the concentration of ^{137}Cs is measured once a year by LESE in a single sample, taken at the Pointe Venus sampling station north of Tahiti until 2008, and taken at Vairao south of Tahiti since 2009. Since January 2012, the sampling has been performed once a month. To account for the low concentrations of ^{137}Cs in seawater, several hundred liters of seawater were sampled.



Concentration of ^{137}Cs in seawater from Tahiti

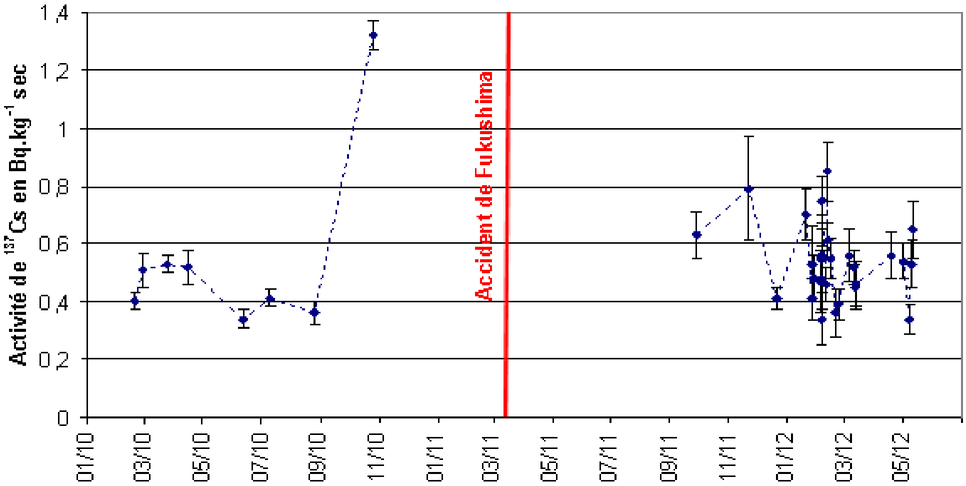
Pelagic fish

Pelagic fish samples are provided by the local fishing industry, a long-standing partner of LESE. The fish are provided from all five archipelagoes of French Polynesia. These are non-industrial fish caught for local consumption in the vicinity of the islands in question. The species of fish is variable (tuna, bonito, swordfish, Mahi-mahi, etc.). In addition, as part of the "Pakaihi i te moana" oceanography campaign, 6 samples were taken from the waters off the Marquesas Islands in February 2012.

The only artificial radionuclide detected in fish in 2010, prior to the Fukushima accident, was ^{137}Cs at very low levels (between 0.34 and 1.32 Bq.kg^{-1} for a dry sample, the latter figure being the equivalent of 0.44 Bq.kg^{-1} for a wet sample). The maximum permitted levels for cesiums in foodstuffs is 500 Bq.kg^{-1} (Commission Implementing Regulation (EU) no. 351/2011 of 11 April 2011). The admissible level was reduced to 100 Bq.kg^{-1} (Commission Implementing Regulation (EU) no. 284/2012 of 29 March 2012) in response to the regulations recently implemented by the Japanese authorities.

The samples taken in Polynesian waters following the Fukushima accident, from September 2011 to May 2012, show no traces of ^{134}Cs. The detection limits (DL) are between 0.16 and 0.68 Bq.kg^{-1} for a dry sample. The activity levels for ^{137}Cs are consistent with the results obtained in previous years, between 0.34 and 0.85 Bq.kg^{-1}, on a dry sample.

Recent data obtained concerning fish caught off the coast of California [6] indicate that the releases from the Fukushima accident had an impact on the flesh of bluefin tuna (*Thunnus orientalis*) in 2011, with a mean ^{134}Cs value of 4.0 ± 1.4 (SD), and 6.3 ± 1.5 (SD) Bq.kg^{-1} of ^{137}Cs on a dry sample, whereas the measurements in 2008 indicated '0' and 1.4 ± 0.2 respectively for ^{134}Cs and ^{137}Cs. However, analyses of yellowfin tuna (*Thunnus albacares*) do not show any contamination in 2011. The passage of certain species through contaminated waters and their rapid migration explain these observations.



Concentration of ^{137}Cs in pelagic fish, for all species, sampled off Polynesian coast

Other samples are scheduled for 2012 in order to confirm these observations. It is probable that, if some of the species that were initially contaminated in Japanese coastal waters or in the Kuroshio ocean current had been caught in the South Pacific, the concentrations would have been difficult to detect. The competition between the duration of the migration period and the biological half-life of cesium in the muscles of the fish may significantly reduce the possibility of measuring any signs of contamination for species caught in the South Pacific.

4.2.1.2 Fish and other marine products in the lagoon environment

Twenty samples were taken in 2011, 7 fish (groupers and loaches only) and 13 other products (giant clam, octopus and nacre). All were measured by gamma spectrometry. The seven fish and six giant clams underwent plutonium analysis. Tables AII-1 to AII-7 in the Appendix report available on the IRSN website (report PRP-ENV/SESURE 2012-18) provide detailed results of activity levels.

Radioactivity levels remain low for all the samples and all the locations.

- It is still possible to quantify ^{137}Cs in all the fish from the analyzed lagoons, but rarely in the other lagoon samples. The higher concentration levels found in fish than in other marine organisms, in particular mollusks, can be explained by the fact that fish is higher up the food chain and by the active retention of ^{137}Cs, a chemical equivalent of potassium, in fish muscle.

  Values are always higher in the flesh of groupers or loaches than in other fish, which is why it has been decided that samples will only be taken from these fish. The highest values were observed in groupers at Hao (0.33 $Bq.kg^{-1}$ wet) and Tubuai (0.22 $Bq.kg^{-1}$ wet).

- In recent years, ^{60}Co has only rarely been quantified in the analyzed samples. The only quantifications possible were for giant clams, which contain concentrations of radionuclides due to the fact that they filter seawater. In 2011, all the results were below the detection limit of 0.04 $Bq.kg^{-1}$ wet.

- It was possible to quantify ^{238}Pu in five of the six giant clams analyzed, and $^{239+240}$Pu in all six giant clams. These radionuclides were not detected a single time in the flesh of the lagoon fish analyzed in 2011.

4.2.2 TERRESTRIAL ENVIRONMENT

4.2.2.1 Cow's milk

In response to the accident in Fukushima, weekly analyses were performed from March 16 to May 11, 2011, and then monthly through the end of the year, on milk samples taken from the Taravao plateau in Tahiti. Levels of ^{137}Cs remained consistent with those measured prior to the accident, and no trace of ^{134}Cs, ^{60}Co or ^{131}I was detected in these samples. The activity levels for ^{137}Cs were comparable to the values observed in New Zealand in 2010 [7].

A sample of UHT (or "long-life" milk) from France was measured, providing a detection limit of 0.2 $Bq.L^{-1}$. Table AII-7 in the Appendix report available on the IRSN website (report PRP-ENV/SESURE 2012-18) lists the detailed results.

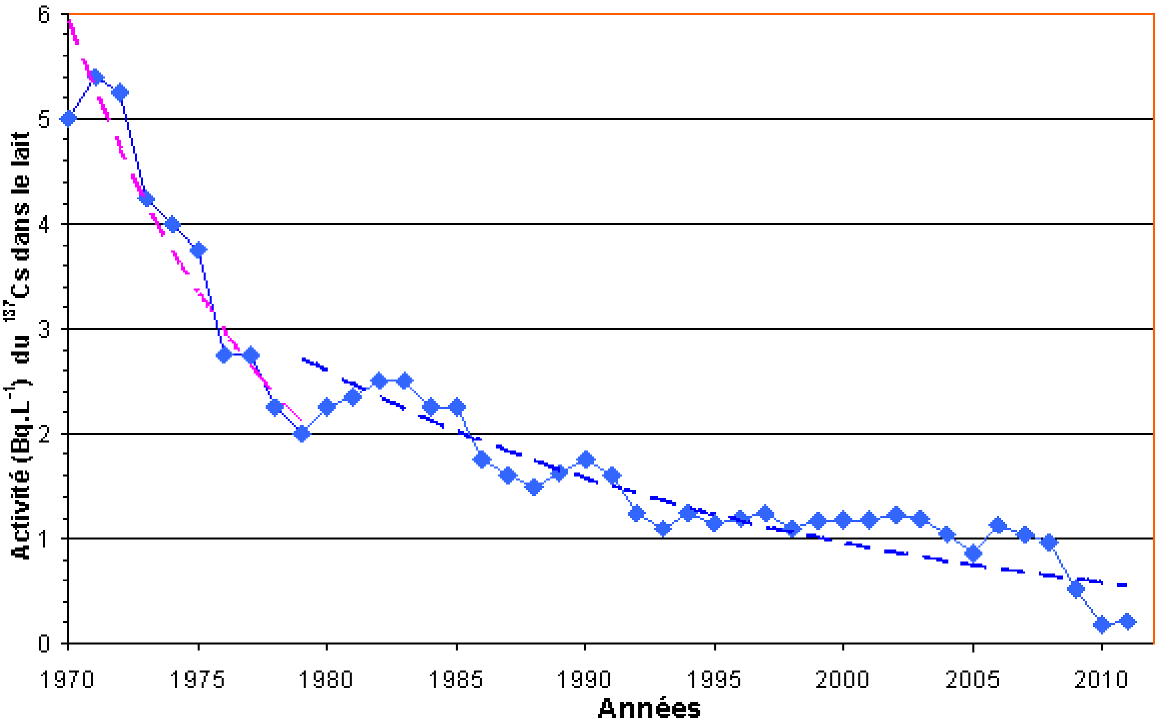


Figure 6 : ^{137}Cs activity levels since 1970 for cow's milk from the Taravao plateau

A very slow decrease in radioactivity can be observed since the 1990s (blue slope). This decrease is much slower than that observed following the atmospheric nuclear tests in the 1970s (pink slope). As in previous years, the concentration of ^{137}Cs in locally produced milk was slightly higher in 2011 than in the imported UHT milk (0.05 Bq.L^{-1} measured in a 2010 sample from France). This observation is linked to soil-plant transfer factors, which are approximately 100 times greater than those normally measured in Europe [8]).

4.2.2.2 Other terrestrial samples

In 2011, 95 samples were taken from foodstuffs produced locally and regionally on the five archipelagoes:

- 15 drinks (not including milk),
- 35 vegetables,
- 32 fruits,
- 4 meats,
- 11 grass samples,
- 7 samples of imported products (not including milk).

- The results of gamma spectrometry analyses, (alpha for Pu) are shown in the tables in Appendix III. Beginning in 2011, only the copra samples underwent analysis for plutonium. More than half the analyses still have quantifiable traces of ^{137}Cs, and six measurements showed values above 1 Bq.kg^{-1} wet (2 in 2009 and 2010, 6 in 2008 and 10 in 2007). Phenomena causing dilution of this radionuclide in the environment make it increasingly difficult to measure, as its durability is several hundred years due to its radioactive half-life.
- ^{60}Co was never quantified in these terrestrial samples.
- In the 6 measured copra samples, ^{238}Pu has never been detected, and there was only one result for $^{239+240}$Pu, close to the detection limit, at a value of 0.06 ± 0.03 mBq.kg^{-1} wet.

General comment concerning measured concentrations of radionuclides in foodstuffs

For informational purposes, the maximum permitted levels of radioactive contamination are indicated for foodstuffs and feed for livestock. These levels are set by regulation No. 3954/87 (Euratom), and were modified following the Fukushima accident (Commission Implementing Regulation (EU) no. 284/2012 of March 29, 2012). In Table 2 below, the levels are compared with the **maximum values** found in food produce consumed in French Polynesia.

Table 2 : Maximum permitted levels (MPL) of radioactive contamination for foodstuffs (left-hand column) compared with maximum concentration levels measured in 2011 for foodstuffs in Tahiti (right-hand column)

	MPL in $Bq.kg^{-1}$ (LH column)/maximum concentrations measured in foodstuffs (RH column) in French Polynesia in $Bq.kg^{-1}$					
Radionuclide	Milk, baby food		Other foodstuffs		Liquids	
^{137}Cs or ^{60}Co	50	0.4±0.04[1]	100	5[2]	1 0	0.032±0.014[3]
Plutonium and alpha emitters	1	nm[4]	80	1.7±0.2[5]	20	nm

It should be noted that the maximum values measured in the foodstuff samples are well below the maximum permissible levels

[1] Measured value on milk sample from Tahiti
[2] Measured value on copra sample from Tubuai
[3] Measured value on pineapple juice sample from Tahiti
[4] nm: Pu was not detected in any milk sample or other drink
[5] Measured value in a giant clam sample from Tubuai

5 POPULATION EXPOSURE TO IONIZING RADIATION IN FRENCH POLYNESIA

5.1 GENERAL INFORMATION

All sources of natural and artificial radioactivity contribute to exposure levels. Exposure to natural radioactivity may come from several different sources. In Polynesia, **naturally-occurring radioactivity** is primarily due to:

- Cosmic radiation, resulting in external exposure that varies depending on altitude, of approximately 0.3 mSv/year at sea level ;
- Exposure through ingestion of natural radionuclides in food and water, of approximately 0.25 mSv/year (approximately 0.18 mSv/year due to potassium-40 alone) ;
- The presence of natural radionuclides in soils, a cause of terrestrial radiation and external exposure (^{239}U, ^{235}U, ^{232}Th, ^{40}K, etc.): this radiation varies a great deal with the type of soil, and is relatively low in French Polynesia (less than 0.05 mSv), whereas it may reach levels as high as several mSv/year in some parts of the globe (8 to 17 mSv/year in Brazil, for example) ;
- Radon, a noble radioactive gas produced by the disintegration of uranium in the Earth's crust, is widely abundant in air and can accumulate in enclosed, poorly ventilated spaces. Very little radon is detected in Polynesia due to the soil types (non-granitic with low uranium content) and the local lifestyle: the houses are very open and well-ventilated, meaning that there are only negligible quantities of radon accumulation. The radon dose for French Polynesia is relatively low, and is estimated at 1 mSv/year.

It is estimated that natural radioactivity in French Polynesia results in a cumulative exposure of 1 to 2 mSv/year. A comparison should be made between exposure to natural radiation and exposure to **artificial radioactivity**. Considering the specific nature of nuclear activities in French Polynesia (no industrial nuclear facilities, nuclear weapons testing from 1966 to 1974), artificial radioactivity mainly results from the following factors :

- Residue from atmospheric fallout due to nuclear weapons testing, a source of ^{137}Cs, ^{90}Sr, ^{3}H, ^{14}C and uranium and plutonium isotopes :
  - the percentage of these radionuclides found in the air as aerosols is now negligible. The majority are found in soil deposits or in the substrate, and contribute to **external radiation** ;
  - They are then incorporated in the region's fish and locally produced foodstuffs (primarily copra, lagoon fish, coconut water, milk and beef) and become a source of **contamination through ingestion**.
- Radionuclides in local foodstuffs and drinks that have been imported. In which case, it is possible to find, in addition to the radionuclides present in French Polynesia, other isotopes produced by nuclear activities outside of Polynesia ;
- Medical examinations and treatments: in industrialized countries, a person receives an average of 1.6 mSv per year, and the worldwide average is approximately 0.6 $mSv.year^{-1}$.

The purpose of the following chapters is to estimate the doses received by local populations from artificial radioactivity via ingestion of local and imported foodstuffs, from external exposure to radionuclides present in the air and ground, and from the inhalation of radionuclides in the air.

5.2 DOSES RECEIVED BY POPULATION DUE TO ARTIFICIAL RADIOACTIVITY

The effects on individuals exposed 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 sub-units: 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 beyond the moment when the radionuclide enters the body, and will decrease based on the radioactive half-life of the incorporated radionuclide and the rate at which it is eliminated.

For an internal contamination by a radionuclide with a long half-life, the confirmed dose is calculated. This dose indicates, at the moment the contamination occurs, 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 then be the lifetime of the individual, ranging from 50 years for an adult to 70 years for a child 0-1 years old.

The annual effective doses due to residual artificial radioactivity that are calculated in this report comprise three elements :

- external exposure, due mainly to activity in the soil ;
- inhalation, due to radioactivity carried by aerosols ;
- ingestion, from food and drink.

By convention, the detection limit (DL) values are included in the calculations if the measured values are below the DL. It should be noted that this simplified calculation method is not precise, and may result in biases when estimating the received dose. The methodology for calculating doses is to be reviewed in the near future.

The dose coefficients per inhaled activity unit and per ingested activity unit are those recommended by the ICRP 71 [9] and ICRP 67 [10].

The tables in Appendix III show all the raw results. The doses are indicated for each sampling site and for two populations: adults and children under the age of five.

5.2.1 EFFECTIVE ANNUAL DOSE DUE TO EXTERNAL EXPOSURE

External ambient exposure in French Polynesia comes primarily from natural sources. A small amount of artificial sources also exist due to fallout from former nuclear weapons testing in the atmosphere.

The additional effective dose from artificial sources due to external exposure, estimated based on ^{137}Cs deposits (the only artificial radionuclide still detectable in the soil), does not exceed a few µSv/year. The external dose values are for ^{137}Cs activity levels in soil samples taken in 2000 in Faa'a for the island of Tahiti, and in 2005-2006 for the other islands [11].

5.2.2 EFFECTIVE ANNUAL DOSE DUE TO INHALATION

The additional effective artificial dose due to inhalation, calculated based on the concentration of ^{137}Cs measured in the air in Tahiti, is less than 10^{-5} µSv/year, both for adults and children under the age of five. It is considered negligible in comparison with the other two components (ingestion and external exposure).

5.2.3 EFFECTIVE ANNUAL DOSE DUE TO INGESTION

The additional effective artificial dose due to ingestion is calculated based on food intake (1982 survey [12] updated in 1991), which makes a distinction between products that are only produced locally, regional products from Polynesia, and imported products.

All imported produce, except for yogurt and pasta, were measured in 2011. Local yogurt production has grown significantly, and the imported product is now rare and expensive. It can no longer be justified as an imported product in the food intake. The analysis is performed every five years for pasta, the same as for local products when the quantity in the food intake is less than 5 kg [2].

When the sample is not taken, the dose is calculated using the sampling results from the previous year (or from previous years) on the same island, or, if this is not possible, with the results obtained for the same matrix on another island.

For radioactivity levels as low as those observed in French Polynesia, the sampling variability is the main source of the temporal and geographic differences found in the calculated doses in recent years. In order to limit this effect, high quantities are sampled (several kilograms). In addition, the radioactivity analyses for these samples have been improved (longer measurement periods, more effective detector) in order to reduce the detection limits.

Figure 7 shows that the dose contributions for adults (the same trends can be observed for children) from local and imported produce have decreased from 2008 to 2009 compared with the two previous years. However, these findings do not indicate any changes in radioactivity in the environment. They mainly indicate variations in concentration levels measured in certain foodstuffs. They also result from improved analysis protocols which have made it possible to obtain lower detection limits since 2009. In particular, a longer counting period was introduced for the most consumed products when performing gamma spectrometry measurements (^{137}Cs and ^{60}Co) to reduce detection limits to a minimum (it ranges from 24 to 72 hours, depending on the samples).

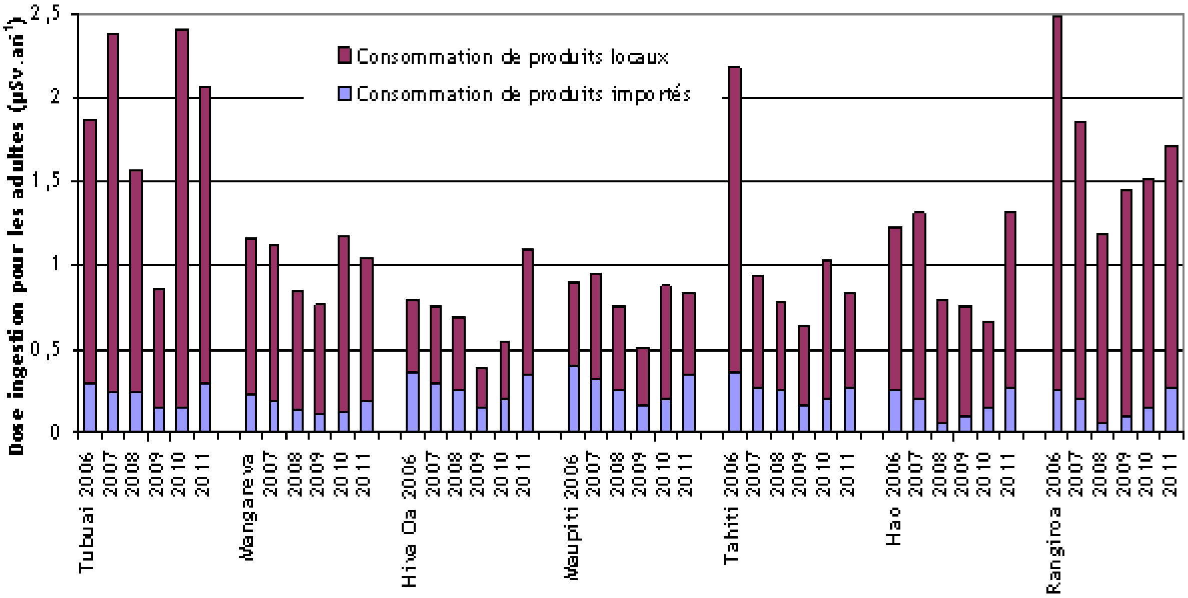


Figure 7 : Additional ingested doses from 2006 to 2011 for adults due to consumption of local and imported products on the various islands.

Values increased significantly in 2010 [5], mainly for the islands (all except Hao and Rangiroa) where beef from Tahiti is included in the food intake.

In 2011, the concentration of ^{137}Cs in beef was 3 $Bq.kg^{-1}$ wet (8.8 in 2010 and 0.9 in 2009), which means a lower dose in 2011 compared with 2010. This decrease was compensated for by the increased doses measured in imported rice and UHT milk, and also an increase in the local beer due to worse ^{137}Cs and ^{60}Co detection limits that year.

In addition, slightly higher ^{137}Cs values in a single product, such as lettuce in Hiva Oa or fish from the Hao lagoon, also increase the annual dose for consumers on these islands.

And finally, the difference in dose contributions between local and imported foodstuffs are, in general, not only due to different concentrations of radioactivity, but also to the respective portions they represent in food intake. For example, fish consumption is up to eight times higher on the atolls than on the upper islands. As a result, the calculated dose may be up to eight times higher on these atolls for the same concentration level measurements.

In 2011, the estimated doses due to the consumption of Polynesian products was between 0.5 and 1.8 $\mu Sv.year^{-1}$ (Maupiti and Tubuai) for adults, and between 0.29 and 0.9 $\mu Sv.year^{-1}$ for children on the same islands.

In 2011, as in previous years, the same foodstuffs were the primary contributors to the dose for adults :

Drying copra in Tuamotu

- beef from Tahiti (0.04 $\mu Sv.year^{-1}$), also consumed in even larger quantities on Maupiti (0.13 $\mu Sv.year^{-1}$), Mangareva (0.24 $\mu Sv.year^{-1}$) and Tubuai (0.29 $\mu Sv.year^{-1}$) ;
- pork from Tahiti (0.11 $\mu Sv.year^{-1}$ in 2011, 0.38 $\mu Sv.year^{-1}$ in 2010) ;
- copra from Rangiroa (0.75 $\mu Sv.year^{-1}$) and Tubuai (0.24 $\mu Sv.year^{-1}$) ;
- fish from the Hao lagoon (0.72 $\mu Sv.year^{-1}$) and Rangiroa (0.41 $\mu Sv.year^{-1}$), due to the fact that consumption of this product (85.5 kg per year) is 4 to 10 times higher than on the other islands ;
- lettuce from Hiva Oa (0.37 $\mu Sv.year^{-1}$). In 2010, it was cabbage that had the highest value (0.11 μSv.year-1) ;
- And finally, in 2011, higher values were recorded for papaya from Mangareva (0.2 $\mu Sv.year^{-1}$).

Over the past six years, no foodstuff has contributed an additional artificial dose greater than 1 $\mu Sv.year^{-1}$. In 2006, values greater than 1 $\mu Sv.year^{-1}$ were still measured for two samples (1.3 $\mu Sv.year^{-1}$ for pineapple consumption by adults in Tahiti and 1.2 $\mu Sv.year^{-1}$ for copra consumption in Rangiroa).

To put these values into perspective, they should be compared with the dose of natural radioactivity presented in Chapter 5.1. This dose is approximately 1 to 2 $mSv.year^{-1}$ if all sources are taken into account (radon, radiation of cosmic or terrestrial origin, natural radionuclides such as ^{40}K, etc.).

CONCLUSION

In 2011, IRSN once again performed radiological monitoring in French Polynesia, excluding the Mururoa and Fangataufa sites. Monitoring covered seven islands from five archipelagoes, with 70% of the territory's population concentrated in Tahiti. In response to the Fukushima accident, monitoring was stepped up over a four-month period to determine whether releases from the damaged plant had any impact on the population.

The implemented radioactivity measurements (gamma spectrometry measurements for ^{137}Cs and ^{60}Co and alpha emitter measurements for Pu isotopes) cover almost the entire range of artificial radionuclides likely to be detected in the considered environment.

Twenty-four samples were taken from the physical environment (air, water and sediments) and 153 from the biological environment, which included pelagic fish, lagoon fish and other lagoon products, and land samples (fruit and vegetables, milk, various drinks). The sampling was used to address two objectives :

- determine the levels of artificial radioactivity in all compartments of the environment and in major foodstuffs ;
- assess the additional dosimetric impact in this environmental situation: for the additional dose due to ingestion, all the samples from Polynesian diet were taken into account. For external exposure and inhalation, dose estimates are based on measurements from the physical environment.

The radioactivity levels measured in 2011 were not markedly different from those measured in 2010. The observed differences should be considered in light of the high natural variability, as was observed for beef [5].

^{137}Cs was detected the most often. The maximum values obtained in 2011 are less than 0.4 Bq.kg^{-1} wet for fish (pelagic and lagoon), and ten times lower for other lagoon products. These values show that the Fukushima accident had no radiological impact on French Polynesia.

The values remain extremely low, in general less than 1 Bq.kg^{-1} wet, and often less than 0.01 Bq.kg^{-1} wet for solid foodstuffs. Six out of 153 results analyzed in 2011 were greater than 1 Bq.kg^{-1} of ^{137}Cs wet: 5 for copra and 2.5 for taro from Tubuai, 3.3 for beef from Tahiti, 2.1 for lettuce and 1.3 for papaya from Hiva Oa, and 1.4 for copra from Rangiroa (values in Bq .kg^{-1} wet).

No ^{60}Co was detected in any sample.

When Pu activity levels were detected, they were extremely low. Beginning in 2011, Pu was measured in three selected matrices [2]: the grouper and giant clam for lagoon environments, and copra for land environments.

The Pu isotopes ^{238}Pu and $^{239+240}$Pu were measured in very small concentrations in samples taken on six islands (except for ^{238}Pu, which was at the detection limit for the sample from Tahiti). All the other results for lagoon fish (grouper) and for copra, except for a trace of $^{239+240}$Pu detected in copra from Mangareva, were below the detection limit.

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).

No food product was a source of a dose through ingestion greater than 1 μSv.year^{-1}. Some food products that are consumed in greater quantities may result in a dose of over 0.1 μSv.year^{-1}. This was the case in 2011 for beef from Tahiti that is also consumed in Tubuai, Mangareva and Maupiti, pork from Tahiti, copra from Tubuai and Rangiroa, lagoon fish from Hao and Rangiroa, lettuce from Hiva Oa and papaya from Mangareva.

In general, the annual total dose that can be attributed to artificial radioactivity (Appendix IV), which is the sum of external exposure, inhalation and ingestion doses, is comparable for all five archipelagoes over the past twenty years. Overall, the average values for this period are approximately 3.5 $\mu Sv.year^{-1}$ for children and 4.5 $\mu Sv.year^{-1}$ for adults.

This order of magnitude comprises all three components of the "additional" dose, and can be compared with the total dose (natural and artificial) of 1,000 µSv per year on average in the South Pacific, as established by the SPREP (South Pacific Regional Environment Program) in 1983 [13]. The "additional" dose due to artificial radionuclides in French Polynesia therefore represents less than 0.5% of the total average dose for the region.

In light of these findings, monitoring will evolve and diversify (radiological reports, nacre networks) to continue providing the most detailed information possible concerning radiological conditions in French Polynesia and to meet the concerns of the local population, who are increasingly conscious of environmental quality. Furthermore, discussions are already underway to adapt the estimation methodologies for assessments both in French Polynesia and in France.

The concerns of the population were heightened after March 11, 2011 as to the radiological consequences for the South Pacific following the accident at the Fukushima nuclear power plant. IRSN employed its technical means in the French overseas departments and territories and in France to evaluate any possible radiological impact on the environment, and to inform the public of the resulting observations and analyses. Specific sampling plans covering the atmospheric environment (air, rain) and terrestrial environment (grass, cow's milk) were implemented for several weeks after radioactive release to the atmosphere stopped. All the results, together with their interpretation, and information about the current situation in Japan were immediately made available on the site www.irsn.fr.

The monitoring of South Pacific marine environments will continue to be reinforced in 2012 to detect any impacts due to the significant radioactive releases in the sea that occurred during the disaster in Fukushima.

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