NUCLEAR ACTIVITIES: IONISING RADIATION AND HEALTH AND ENVIRONMENTAL RISKS

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CHAPTER 1

Nuclear activities are defined by the Public Health Code as “activities involving a risk of human exposure to ionising radiation, emanating either from an artificial source – whether a material or device – or from a natural source when natural radionuclides are or have been processed for their fissile or fertile radioactive properties, as well as interventions designed to prevent or mitigate a radiological risk following an accident or contamination of the environment”. These nuclear activities include those conducted in basic nuclear installations (BNIs) and for the transport of radioactive materials, as well as in all medical, veterinary, industrial and research facilities where ionising radiation is used.

The various principles with which the nuclear activities must comply, and particularly those of nuclear safety and radiation protection, are set forth in chapter 3.

In addition to the effects of ionising radiation, BNIs are similar to all industrial installations in that they are the source of non-radiological risks and detrimental effects such as the discharge of chemical substances into the environment, or noise. The provisions relative to environmental protection are described in chapter 3.

1 KNOWLEDGE OF THE HAZARDS AND RISKS FROM IONISING RADIATION

Ionising radiation is defined as being capable of producing ions-directly or indirectly - when it passes through matter. It includes X-rays, alpha, beta and gamma rays, and neutronic radiation, all of which have different energies and penetration powers.

1|1 Biological and health effects

Whether it consists of charged particles, for example an electron (beta radiation) or a helium nucleus (alpha radiation), or of electromagnetic radiation photons (X rays or gamma rays), ionising radiation interacts with the atoms and molecules making up the cells of living matter and alters them chemically. Of the resulting damage, the most significant concerns the DNA of the cells and is not fundamentally different from that caused by certain toxic chemical substances, whether exogenous or endogenous (resulting from cellular metabolism).

When not repaired by the cells themselves, this damage can lead to cell death and the appearance of health effects once tissues are no longer able to carry out their functions.

These effects, called “deterministic effects”, have been known for a long time, as the first effects were observed with the discovery of X rays by Roentgen (1895). They depend on the type of tissue exposed and are certain to appear as soon as the quantity of radiation absorbed exceeds a certain dose level. These effects include, for example, erythema, radiodermatitis, radionecrosis and cataract formation. The higher the radiation dose received by the tissue, the more serious the effects.

Cells can also repair the damage thus caused, although imperfectly or incorrectly. Of the damage that persists, that to the DNA is of a particular type, because residual genetic anomalies can be transmitted by successive cellular divisions to new cells. A genetic mutation is still far removed from transformation into a cancerous cell, but the damage due to ionising radiation may be a first step towards cancerisation.

The suspicion of a causal link between exposure to ionising radiation and the appearance of a cancer dates back to the early 20th century (observation of skin cancer on a case of radiodermatitis).

Since then, several types of cancers have been observed in occupational situations, including certain types of leukaemia, broncho-pulmonary cancers (owing to radon inhalation) and bone sarcomas. In addition to the study of occupational cancers, the monitoring of a cohort of about 85,000 people irradiated in Hiroshima and Nagasaki shed light on the morbidity and mortality from cancer following exposure to ionising radiation. Other epidemiological work, for example, has revealed a statistically significant rise in cancers (secondary

Preparation for radioactivity counting using a beta-gamma counter in the laboratory of the cancer biology and infections unit of the CEA Grenoble centre

UNSCEAR

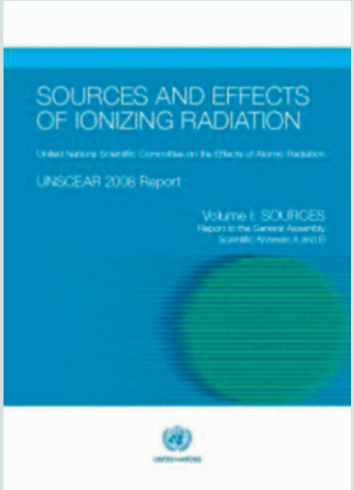
The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was set up in 1955 during the 10th session of the General Assembly of the United Nations. It comprises representatives from 21 countries and reports to the General Assembly of the United Nations. It is a scientific organisation created to conduct global and regional studies and evaluations of exposure to radiation and its effects on the health of the exposed groups. The committee also studies the progress made in understanding the biological mechanisms whereby radiation influences health or the environment.

Recent publications:

– Summary of low-dose radiation effects on health (2010 report)

– Sources and effects of ionising radiation (2008 report):

- *Volume 1 – annex A (Medical radiation exposures), annex B (Exposures of the public and workers from various sources of radiation).*
- *Volume 2 – annex C (Radiation exposures in accidents), annex D (Health effects due to radiation from the Chernobyl accident) and annex E (Effects of ionising radiation on no-human biota).*



UNSCEAR 2008 Report
"Sources and effects of ionizing radiation"

effects) among patients treated using radiotherapy and attributable to ionising radiation. The Chernobyl accident which, as a result of the radioactive iodines released, caused a peak in the incidence of thyroid cancers in children in the areas near the accident, should also be mentioned.

The occurrence of carcinogenic effects is not linked to a dose threshold; only a probability of occurrence can be stated for any given individual. This is the case with occurrence of radiation-induced cancers. These are called probabilistic, stochastic or random effects.

The internationally established health goals of radiation protection are to prevent the appearance of deterministic effects and to reduce the probability of occurrence of radiation-induced cancers.

1|2 Evaluation of risks linked to ionising radiation

Cancer monitoring is organised on the basis of *département*[1] registers (10 registers covering 11 *départements* i.e. about 15% of the general public) and specialised registers (12 specialised registers, including 2 national registers for cancers in children under 15 years old, concerning haematological malignancy and solid tumours in children).

The aim of the register for a given area is to highlight spatial differences in incidence and to reveal trends in terms of increased or reduced incidence over time in the different cancer locations, or to identify clusters of cases.

This method of monitoring, which is primarily descriptive, does not however make it possible to reveal a possible link between these cancers and exposure to ionising radiation, given that other environmental factors can be suspected.

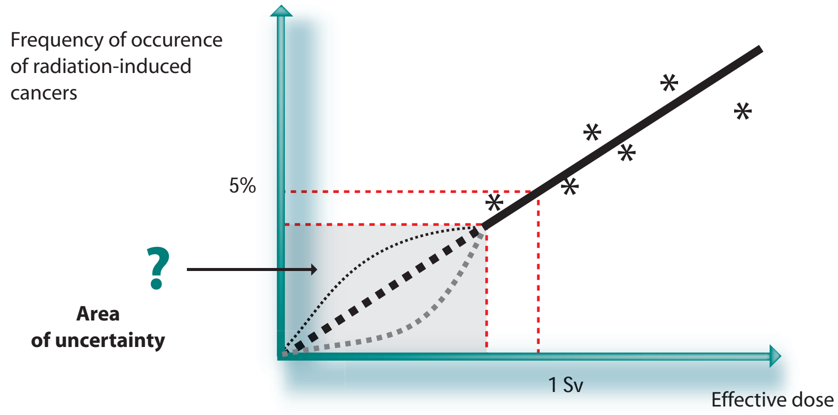
Epidemiological investigation supplements monitoring. The purpose of epidemiological surveys is to highlight an association between a risk factor and the occurrence of a disease, between a possible cause and an effect, or at least to enable such a causal relation to be postulated with a very high degree of probability. However, one should not ignore the difficulty in conducting these surveys or arriving at convincing conclusions when the latency of the disease is long or when the number of expected cases is small, which are both characteristics of exposure to ionising radiation of less than 100 mSv. The epidemiological surveys were thus only able to link pathologies to ionising radiation for relatively high radiation doses at high dose rates (for example: monitoring of the populations exposed to the Hiroshima and Nagasaki bombings).

With a view to risk management, use is then made of the risk evaluation technique which uses calculations to extrapolate the risks observed at higher doses in order to estimate the risks incurred during exposure to low doses of ionising radiation. For these estimates, the prudent hypothesis of a linear no-threshold relationship between exposure and the number of deaths from cancer (see diagram 1) has been adopted internationally. With this hypothesis, it is considered that there is no dose threshold below which one can claim that there is no effect. The legitimacy of these estimates and this hypothesis however remain controversial within the scientific community.

On the basis of the scientific work of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (see publication ICRP 103, chapter 3,

1. Administrative region headed by a *préfet*.

Diagram 1: linear "dose-effects" relationship (no-threshold)



point 1|1|1) has published risk coefficients for death from cancer due to ionising radiation, showing a 4.1% excess risk per sievert for workers and 5.5% per sievert for the general public. Use of this model, for example, would lead to an estimate of about 7,000 deaths in France every year, as a result of cancer due to natural ionising radiation.

Evaluation of the risk of lung cancer due to radon is the subject of a specific model, based on observation of epidemiological data concerning mine workers. Assuming a linear no-threshold relationship for low-dose exposures, the relative risk linked to radon exposure, for a radon concentration of 230 Bq/m^3, would be about the same as passive smoking (USA Academy of Science, 1999).

1|3 Scientific uncertainty and vigilance

The action taken in the fields of nuclear safety and radiation protection in order to prevent accidents and limit detrimental effects has led to a reduction in risks but not to zero risk, whether in terms of the doses received by workers or those associated with discharges from BNIs. However, many uncertainties and unknown factors persist and require that ASN remain attentive to the results of the scientific work in progress, for example in radiobiology and radiopathology, with possible spin-offs for radiation protection, particularly with regard to management of risks at low doses.

There are several examples of areas of uncertainty concerning high dose radiation-induced pathologies, the effects of low doses and environmental protection.

1|3|1 Radio-sensitivity

The effects of ionising radiation on personal health vary from one individual to the next. Since it was stated for the first time by Bergonié and Tribondeau in 1906, it is for example known that the same dose does not have the same effect when received by a growing child and when received by an adult.

Individual hypersensitivity to high doses of ionising radiation has been extensively documented by radiotherapists and radiobiologists. This is the case with genetic anomalies in DNA repair and cell signalling, which means that certain patients may display extreme hypersensitivity that can lead to "radiological burns".

At low doses, there is both cell radiosensitivity and individual radiosensitivity, which could concern about 5 to 10% of the population. Recent methods of immunofluorescence of molecular targets for signalling and repairing DNA damage help to document the effects of ionising radiation at low doses, reducing the detection thresholds by a factor of 100. The effects of a simple X-ray examination then become visible and measurable. The research carried out using these new investigative methods is producing results, although they still have to be confirmed before they can be considered conclusive.

This then raises delicate questions, some of which go beyond the strict context of radiation protection:

– once individual radiation hypersensitivity tests become available, should screening prior to any radiotherapy or repeated computed tomography examinations be recommended?

– should hypersensitivity screening be carried out on all workers liable to be exposed to ionising radiation?

– should the general regulations, for example, provide for specific protection for those concerned by hypersensitivity to ionising radiation?

These questions have ethical implications owing to the potential use of the results of individual radiation sensitivity tests, for example to discriminate between potential employees.

Whatever the case, there should be no unnecessary exposure of individuals to ionising radiation, in other words without justification. Children should receive particularly close attention in the event of exposure to ionising radiation for medical purposes.

1|3|2 Effects of low doses

The linear no-threshold relationship - This assumption, adopted to model the effects of low doses on health (see point 1|2), albeit practical from the regulatory standpoint, and albeit conservative from the health standpoint, is not as scientifically well-grounded as might be hoped for: there are those who feel that the effects of low doses could be higher, while others believe that these doses could have no effect below a certain threshold, and some people even assert that low doses have a beneficial effect! Research into molecular and cellular biology is leading to progress, as are epidemiological surveys of large groups. But faced with the complexity of the DNA repair and mutation phenomena, and faced with the limitations of the methods used in epidemiology, uncertainties remain and the public authorities must exercise precaution.

Dose, dose rate and chronic contamination – The epidemiological studies performed on individuals exposed to the Hiroshima and Nagasaki bombings have given a clearer picture of the effects of radiation on health, concerning exposure due to external irradiation (external exposure) at high dose and high dose rate. The studies begun in the countries most affected by the Chernobyl accident (Belarus, Ukraine and Russia) could also advance current knowledge of the effects of radiation on human health, for lower dose and lower dose rate internal contamination levels (internal exposure), as well as of the consequences of chronic exposure to ionising radiation (by external exposure and contamination through food) owing to the long-term contamination of the environment.

Hereditary effects – The appearance of possible hereditary effects from ionising radiation in man remains uncertain. Such effects have not been observed among the survivors of the Hiroshima and Nagasaki bombings. However, hereditary effects are well documented in experimental work on animals: the mutations induced by ionising radiation in the embryonic germ cells can be transmitted to the descendents. The recessive mutation of a chromosome gene will remain invisible as long as the same gene carried by the other counterpart chromosome is not affected. Although it cannot be absolutely ruled out, the probability of this type of event nonetheless remains low.

Environmental protection – The purpose of radiation protection is to prevent or mitigate the direct or indirect harmful effects of ionising radiation on individuals, including in situations of environmental contamination. Over and above environmental protection with a view to protecting man and present or future generations, there remains the practical question of protecting nature in the specific interests of the animal and plant species (see point 3|5), now that the protection of non-human species is among the ICRP recommendations (ICRP 103).

Sea bed in Brittany

TO BE NOTED IN 2011

Child leukaemia

In 2008, ASN, the DGS (General Directorate for Health) and the DGPR (General Directorate for Risk Prevention) set up a pluralistic working group on the risks of leukaemia around basic nuclear installations (BNIs). This group, chaired by Professor Ms Danièle Sommelet, was mandated to assess current knowledge concerning the risk of leukaemia in children living in the vicinity of BNIs. The working group's report was submitted in April 2011 and then presented to the press on 7 November 2011. It is available on the ASN website. To address the group's recommendations, several measures are currently under preparation:

- *definition of a new study and research programme (by the INCa), taking account of those currently ongoing nationally and internationally;*
- *international evaluation of the methods used in the epidemiological studies looking at the risk of leukaemia in children living near nuclear facilities (by IRSN);*
- *creation of a new information and communication working group, whose aim will be to better understand the needs of the populations and improve how they are informed, in particular with respect to cancers (Cancer Plan).*

2 NUCLEAR ACTIVITIES

The activities involving a risk of exposure to ionising radiation can be grouped into the following categories:
– basic nuclear installations;
– transport of radioactive and fissile material for civil use;
– small-scale nuclear activities;
– disposal of radioactive waste;
– management of contaminated sites;
– activities enhancing natural ionising radiation.

2|1 Basic nuclear installations

2|1|1 Definition

The regulations classify nuclear facilities, called basic nuclear installations (BNI), in various categories corresponding to more or less restrictive procedures, depending on the scale of the potential risks (see chapter 3, point 3).

The main BNIs are:
– nuclear reactors;
– particle accelerators;
– plants for the separation, manufacture or transformation of radioactive materials, in particular nuclear fuel manufacturing plants, spent fuel reprocessing plants or radioactive waste packaging plants;
– facilities designed for the disposal, storage or use of radioactive materials, including waste.

The list of BNIs on 31 December 2011 is given in appendix A.

2|1|2 Accident prevention and nuclear safety

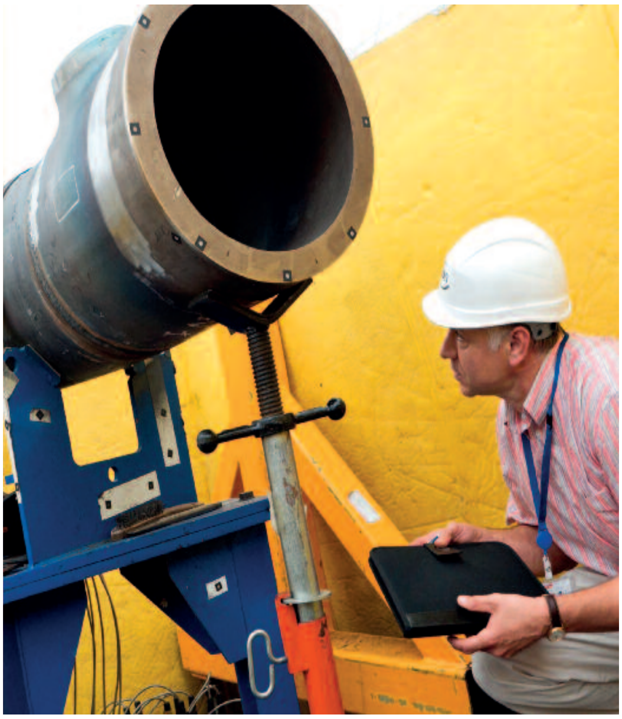
The fundamental principle underpinning the organisational system and the specific regulations applicable to nuclear safety is that the licensee is responsible for safety (see chapter 2). The public authorities ensure that this responsibility is fully assumed, in compliance with the regulatory requirements.

As regards the prevention of risks for workers, BNI licensees are required to implement all necessary means to protect workers against the hazards of ionising radiation, and more particularly to apply the general rules applicable to all workers exposed to ionising radiation (work organisation, accident prevention, medical monitoring of workers from outside contractors, etc.) (see chapter 3).

As regards protection of the population and the environment, the BNI licensee must also take all necessary steps to achieve and maintain an optimum level of protection. Discharges of liquid and gaseous effluents, whether or not radioactive, are in particular strictly limited (see chapter 4).

2|2 Transport of radioactive and fissile material for civil use

When transporting radioactive or fissile materials, the main risks are those of internal or external exposure, criticality, or



ASN check on prefabrication of a secondary system pipe during replacement of steam generators at Fessenheim 2 – September 2011

ASN transport inspection at La Hague – September 2011

chemical hazard. Safe transport of radioactive materials relies on an approach called defence in depth:
– the package, consisting of the container and its content, is the first line of defence. It plays a vital role and must be able to withstand all foreseeable transport conditions;
– the transport means and its reliability constitute the second line of defence;
– finally, the third line of defence consists of the response resources implemented to deal with an incident or accident.

2|3 Small-scale nuclear activities

Ionising radiation, whether emitted by radionuclides or generated by electrical equipment (X-rays), is used in many areas, including medicine (radiology, radiotherapy, nuclear medicine), human biology, research, industry, but also for veterinary and forensic applications as well as for the conservation of foodstuffs.

The employer is required to take all necessary measures to protect workers against the hazards of ionising radiation. The licensee must also adhere to the provisions of the Public Health Code for the management of the ionising radiation sources in its possession - radioactive sources in particular, and where applicable manage the waste produced and limit discharges of liquid and gaseous effluents. In the case of use for medical purposes, patient protection issues are also taken into account (see chapter 3).

2|4 Disposal of radioactive waste

Like all industrial activities, nuclear activities can generate waste. Some are radioactive. The three fundamental principles on which strict radioactive waste management is based are the responsibility of the waste producer, the traceability of the waste and public information.

The technical management provisions to be implemented must be tailored to the hazard presented by the radioactive waste. This hazard can be mainly assessed through two parameters: the activity level, which contributes to the toxicity of the waste, and the lifetime defined by the half-life, the time after which the activity level is halved.

Finally, management of radioactive waste must be determined prior to any creation of new activities or modification of existing activities in order to:
– optimise the waste disposal routes;
– ensure control of the processing channels for the various categories of waste likely to be produced, from the front-end phase (production of waste and packaging) to the back-end phase (storage, transport and disposal).

2|5 Management of contaminated sites

Management of sites contaminated by residual radioactivity resulting either from a past nuclear activity, or an activity which generated deposits of natural radionuclides, warrants specific radiation protection actions, in particular if rehabilitation is envisaged.

In the light of the current or future uses of the site, decontamination targets must be set and disposal of the waste produced during clean-out of the premises and the contaminated soils must be controlled, from the site up to the storage or disposal location. The management of contaminated objects also follows these same principles.

2|6 Industrial activities enhancing natural ionising radiation

Exposure to natural ionising radiation, when enhanced by human activities, justifies monitoring and even risk evaluation and management, if likely to generate a risk for exposed workers and, as applicable, the population in general.

Certain professional activities which are not covered by the definition of "nuclear activities" can thus significantly increase exposure to ionising radiation on the part of the workers and, to a lesser extent, the populations living in the vicinity of the locations where these activities are carried out, in the event of discharge of effluents or disposal of low-level radioactive waste. This is in particular the case with activities using raw materials or industrial residues containing natural radionuclides which are not used for their fissile or fertile radioactive properties.

The natural families of uranium and thorium are the main radionuclides found. The industries concerned include the phosphate mining and phosphated fertiliser manufacturing industries, the dyes industries, in particular those using titanium oxide and those using rare earth ores such as monazite.

The radiation protection actions required in this field are based on precise identification of the activities, estimation of the impact of the exposure on the individuals concerned, taking corrective action to reduce this exposure if necessary, and monitoring.

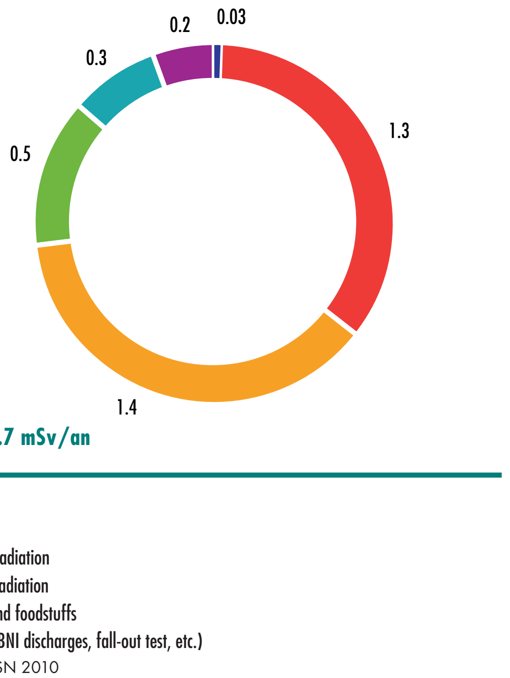
3 MONITORING OF EXPOSURE TO IONISING RADIATION

The pathology monitoring systems set up (cancer registers for example) do not enable those pathologies attributable to ionising radiation to be determined. Nor do we have reliable and easily measurable biological indicators which could be easily used to reconstruct the doses to which the individuals were exposed. In this context, "risk monitoring" is performed by measuring ambient radioactivity indicators (measurement of dose rates for example), internal contamination or, failing which, by measuring values (concentration of radionuclides in radioactive effluent discharges) which can then be used - by modelling or calculation - to estimate the doses received by the exposed populations.

The entire population of France is potentially exposed to ionising radiation of natural or anthropogenic origin, but to different extents across the country. The average exposure of the French population per inhabitant is estimated at 3.7 mSv per year, but this exposure is subject to wide individual variability, in particular depending on the place of residence and the number of radiological examinations received (source: IRSN 2010). Depending on the location, the average individual effective dose can vary by a factor of 2 to 5. Diagram 2 represents an estimate of the respective contributions of the various sources of French population exposure to ionising radiation.

These data are however still too imprecise to allow identification of the most exposed categories or groups of individuals for each exposure source category.

Diagram 2: the French population's exposure to ionising radiation



Source : IRSN 2010

3|1 Exposures of the population to natural ionising radiation sources

People have always been exposed to natural ionising radiation owing to the presence of radionuclides of terrestrial origin in the environment, radon emanations from the ground and exposure to cosmic radiation. Exposure to natural radioactivity represents about 65% of the total annual exposure on average.

3|1|1 Radiation of natural origin (excluding radon)

Natural radionuclides of terrestrial origin are present at various levels in all aspects of our environment, including inside the human organism. They lead to external exposure of the population owing to gamma radiation emissions produced by the uranium 238 and thorium 232 chains and by the potassium 40 present in the soil, but also to internal exposure by inhalation of particles in suspension and by ingestion of foodstuffs or drinking water.

The levels of natural radionuclides in the ground are extremely variable. The highest external exposure dose rates in the open air in France, depending on the region, range from a few nanosieverts per hour (nSv/h) to 100 nSv/h.

The dose rate values inside residential premises are generally higher owing to the contribution of construction materials (about 20% higher on average).

Based on scenarios covering the time individuals spend inside and outside residential premises (90% and 10% respectively), the average effective dose due to external exposure to gamma radiation of terrestrial origin in France is estimated at about 0.5 mSv per person per year.

The doses due to internal exposure of natural origin vary according to the quantities of radionuclides of the uranium and thorium families incorporated through the food chain, which depend on each individual's eating habits. According to UNSCEAR (2000), the average dose per individual is about 0.23 mSv per year. The average concentration of potassium 40 in the organism is about 55 Bq per kg, resulting in an average effective dose of about 0.18 mSv per year.

Waters intended for human consumption, in particular groundwater and mineral waters, become charged in natural radionuclides owing to the nature of the geological strata in which they spend time. The concentration of uranium and thorium daughters, and of potassium 40, varies according to the resource exploited according to the geological nature of the ground. For waters with high radioactivity, the annual effective dose resulting from daily consumption (2 litres/inhabitant/day) may reach several tens or hundreds of microsieverts (µSv).

The results of the Regional Health Agencies' monitoring of the radiological quality of the tap water distributed to consumers between 2008 and 2009 (DGS/ASN/IRSN report published in 2011) showed that 99.83% of the population receives tap water whose quality complies at all times with the total indicative dose of 0.1 mSv/year set by the regulations.

3|1|2 Exposure to radon

Monitoring human exposure to radon in premises open to the public is a priority radiation protection measure in geographical areas where there is a high potential for exhalation of radon owing to the local geological characteristics. A strategy to reduce this exposure is necessary, should the measurements taken exceed the action levels laid down in the regulations.

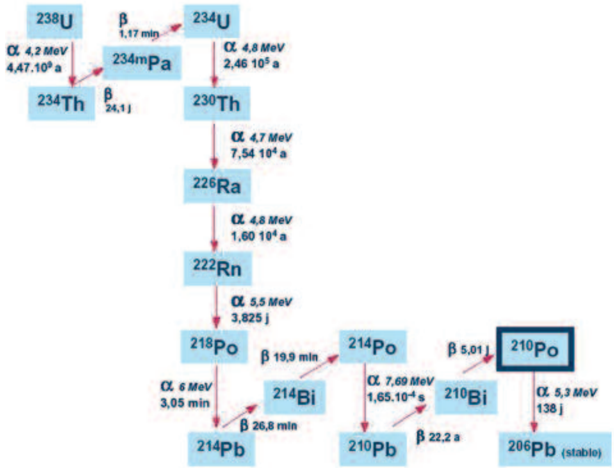
Exposure to radon in dwellings was estimated by measurement campaigns, followed by statistical interpretations (see IRSN atlas). The average radon activity value measured in France is 63 Bq/m³, with about half the results being below 50 Bq/m³, 9% above 200 Bq/m³ and 2.3% above 400 Bq/m³.

These measurements led to a classification of the *départements* according to the radon exhalation potential of the land (see chapter 3 point 2). For methodological reasons, the results of this monitoring are however still too imprecise to allow an accurate assessment of the doses associated with the actual exposure of the individuals.

In premises open to the public, and in particular in teaching and health and social care establishments, radon measurements have been taken since 1999.

Since August 2008, this monitoring has been extended to workplaces located in priority geographical areas. It should be extended to residential buildings as of 2012.

Results of the measurement campaigns conducted since 2005 by organisations approved by ASN are presented in table 1. The percentages of the measurement results higher than the action levels (400 and 1000 Bq/m³) remain comparable from one year to the next. A new screening cycle (10 years) was started in 2009.



Uranium 238 chain

3|1|3 External exposure due to cosmic radiation

Cosmic radiation is of two types, with an ionic component and a neutronic component. At sea level, the ionic component is estimated at 32 nSv per hour and the neutronic component at 3.6 nSv per hour. The average dose due to cosmic radiation in France is estimated at 0.3 mSv per person per year.

Considering the average time spent inside dwellings (which itself attenuates the ionic component of the cosmic radiation), the average individual effective dose in a locality at sea level in France is 0.27 mSv per year, whereas it could exceed 1.1 mSv per year in a mountain locality situated at about 2,800 m altitude. The average annual effective dose per individual in France is 0.33 mSv per year. It is lower than the global average value of 0.38 mSv per year published by UNSCEAR.

Finally the exposure of aircrews to cosmic radiation, aggravated by prolonged periods at altitude, also warrants dosimetric monitoring (see point 3|2|3).

Table 1: results of radon measurement campaigns since 2005

Measurement campaign	Number of establishments checked	Establishments classified at less than 400 Bq/m³		Establishments classified between 400 Bq/m³ and 1,000 Bq/m³		Establishments classified at higher than 1,000 Bq/m³	
		number	%	number	%	number	%
2005/2006	2,966	2,570	87	314	10	82	3
2006/2007	3,000	2,560	85	315	11	125	4
2007/2008	1,204	952	79	174	15	78	6
2008/2009	800	659	82	94	12	47	6
2009/2010	510	409	80	78	15	23	5
2010/2011	644	520	81	92	14	32	5

3|2 Doses received by workers

3|2|1 Exposure of nuclear workers

The system of monitoring external exposure of individuals working in facilities where ionising radiation is used has been in place for a number of decades. This system is primarily based on the mandatory wearing of a passive dosimeter by workers liable to be exposed and it is used to check compliance with the regulation limits applicable to workers: these limits concern, on the one hand, the total exposure (since 2003, the annual limit, expressed in terms of effective dose, has been 20 mSv for 12 consecutive months), obtained by adding the dose due to external exposure to that resulting from any internal contamination and, on the other, the external exposure of certain parts of the body, such as hands and the lens of the eye (equivalent dose).

The data recorded give the cumulative exposure dose over a given period (month or quarter). They are collated in the SISERI system managed by IRSN and are published annually.

The results of dosimetric monitoring of worker external exposure in 2010 show on the whole that the prevention system introduced in facilities where sources of ionising radiation are used is effective, because for more than 96% of the population monitored, the annual dose remained lower than 1 mSv (effective annual dose limit for the public).

For each sector, tables 2 and 3 give the breakdown into the populations monitored, the collective dose and the number of times the annual limit of 20 mSv was exceeded. They clearly show a significant disparity in the breakdown of doses depending on the sector. For example, the medical and veterinary activities sector, which comprises a significant share of the population monitored (more than 62%), in fact only accounts for about 34% of the collective dose; however the annual limit of 20 mSv was exceeded in the medical sector 4 times (out of a total of 8), including two occasions (out of a total of 3) when 50 mSv was exceeded.

The latest statistics published by the IRSN in September 2011 show a small but steady increase in the populations subject to dosimetric monitoring since 2005 (see diagram 3), with the milestone of 330,000 people monitored being reached in 2010. This development is largely due to the increase in monitoring of populations involved in medical and veterinary activities, which has gained momentum since 2005, with the progressive implementation of the provisions of the Labour Code and of the implementing orders updated between 2003 and 2005, accompanied by information and verification campaigns. The collective dose, consisting of the sum of the individual doses, has been falling (about 48%) since 1996 at a time when the populations monitored have grown by about 44%. The optimisation approach implemented by the nuclear licensees during the 1990s no doubt explains this positive trend.

TO BE NOTED IN 2011

Results of dosimetry monitoring of worker external exposure to ionising radiation in 2010 (source: IRSN, September 2011)

Total population monitored: 330,618 workers

Monitored population for whom the dose remained below the detection threshold: 254,808, or about 77%

Monitored population for whom the dose remained between the detection threshold and 1 mSv: 61,959, or about 19%

Monitored population for whom the dose remained between 1 mSv and 20 mSv: 13,843 workers, or about 4.2%

Monitored population for whom the annual effective dose of 20 mSv was exceeded: 8 including 3 above 50 mSv

Collective dose (sum of individual doses): 62.40 Man.Sv

Annual average individual dose in the population which recorded a dose higher than the detection threshold: 0.82 mSv

Results of internal exposure monitoring in 2010

Number of routine examinations carried out: 310,342 examinations (of which fewer than 1% were considered positive)

Population concerned by a dosimetric estimation: 531 workers

Number of special monitoring or verification examinations performed: 11,395 (of which fewer than 2% were above the detection threshold)

Population having recorded a committed effective dose exceeding 1 mSv: 15 workers

Results of cosmic radiation exposure monitoring in 2010 (civil aviation)

Collective dose for 19,532 flight crew members: 41 Man.Sv

Annual average individual dose: 2.1 mSv

Table 2: occupational dosimetry in the nuclear field (year 2010 – source IRSN)

	Number of individuals monitored	Collective doses (Man.Sv)	Doses > 20 mSv
Reactors and energy production (EDF)	21,036	5.68	0
Fuel cycle; decommissioning	8,225	2.28	0
Transport	1,118	0.1	0
Logistics and maintenance (contractors)	7,849	6.23	0
Others	22,333	8.27	0

Table 3: dosimetry of workers in small-scale nuclear activities (year 2010 – source: IRSN)

	Number of individuals monitored	Collective doses (Man.Sv)	Doses > 20 mSv
Medicine	146,020	18.28	4
Dental	42,053	2.1	0
Veterinary	17,122	0.67	0
Industry	32,276	16.44	3
Research	14,174	0.56	1
Miscellaneous	13,620	0.96	0

The number of monitored workers whose annual dose exceeded 20 mSv has also been falling significantly (see diagram 4). Each occurrence of the 20 mSv exposure limit being exceeded must be written up in a significant event notification to ASN by the person responsible for the nuclear activity, leading to a specific investigation, jointly conducted with the occupational physician.

With regard to extremity dosimetry (ring and wrist dosimeters), 21,499 workers were monitored and the total dose was 133.2 Sv. An annual dose at the extremities higher than the regulation limit of 500 mSv was recorded on five workers, including four from the medical sector (interventional radiology) and one nuclear facilities logistics and maintenance contractor worker.

Diagram 3: monitored population and collective dose trends, from 1996 to 2010 (source IRSN)

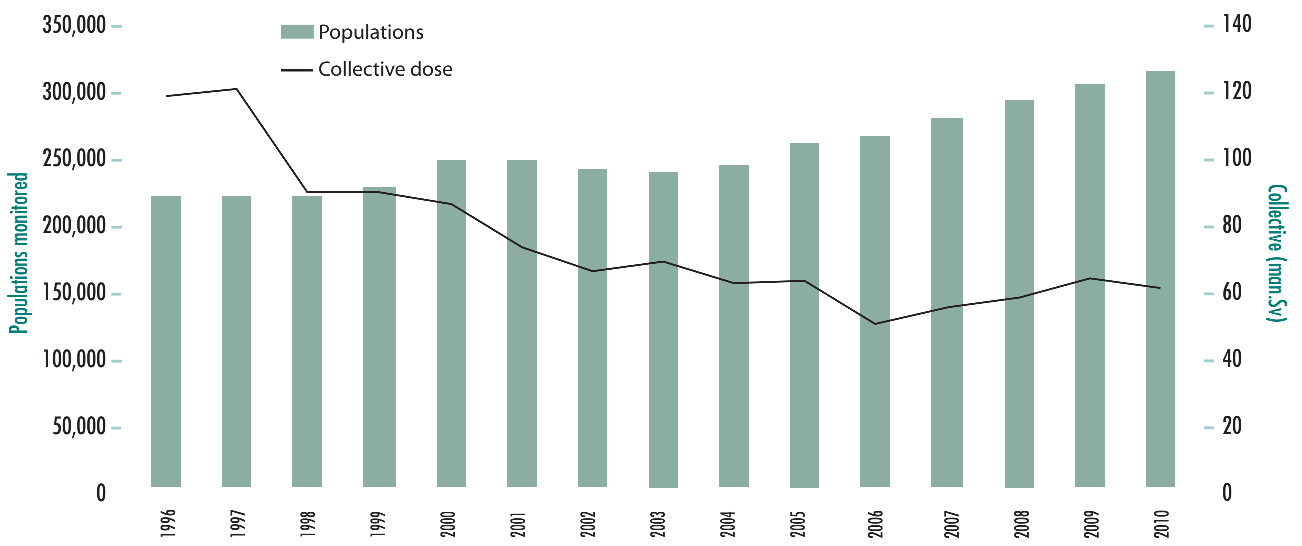
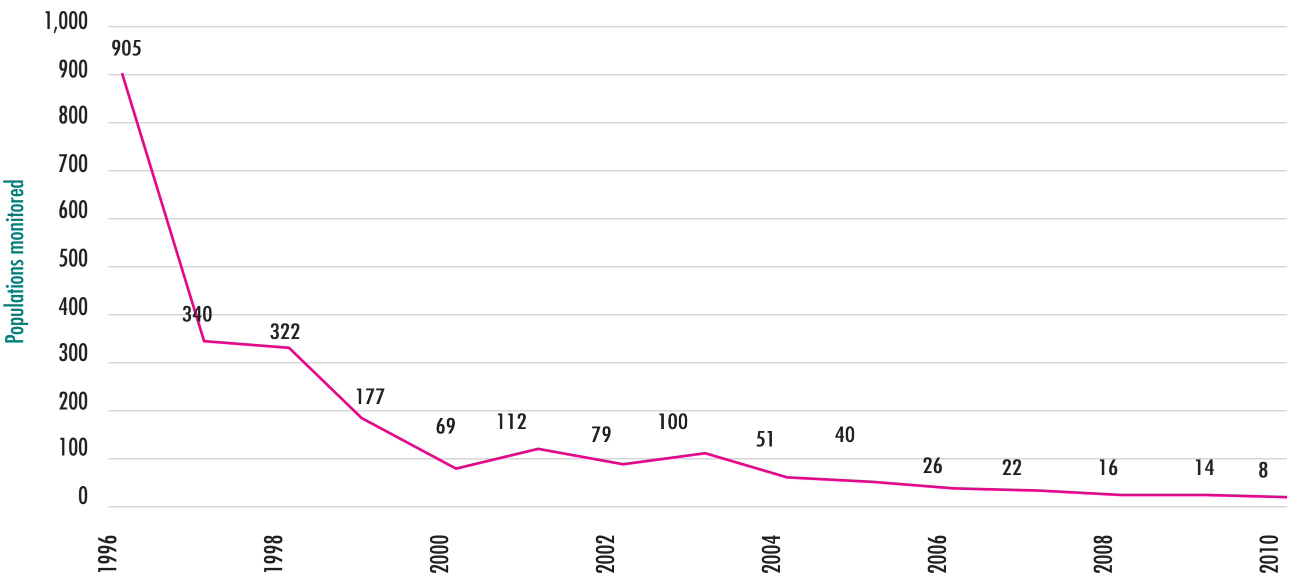


Diagram 4: evolution of number of workers monitored, with an annual effective dose in excess of 20 mSv, from 1996 to 2010



3|2|2 Worker exposure to TENORM

Occupational exposure to enhanced natural ionising radiation is the result either of the ingestion of dust containing large amounts of radionuclides (phosphates, metal ore), or of the inhalation of radon formed by uranium decay (poorly ventilated warehouses, thermal baths) or of external exposure due to process deposits (scale forming in piping for example).

The results of the studies carried out in France since 2005 and published by ASN in January 2010 show that 85% of the doses received by workers in the industries concerned remained below 1 mSv/year. The industrial sectors in which worker exposure is liable to exceed 1 mSv/year are the following: titanium ore processing, heating systems and recycling of refractory ceramics, maintenance of parts comprising thorium alloys in the aeronautical sector, chemical processing of zircon ore, mechanical transformation and utilisation of zircon and processing of rare earths.

3|2|3 Flight crew exposure to cosmic radiation

Airline flight crews and certain frequent travellers are exposed to significant doses owing to the altitude and the intensity of cosmic radiation at high altitude. These doses can exceed 1 mSv/year.

The observation system called “SIEVERT”, set up by the General Directorate for Civil Aviation, the IRSN, the Paris Observatory and the Paul-Émile Victor French Institute for Polar Research (*www.sievert-system.com*), is used to estimate flight crew exposure to cosmic radiation based on the flights they make during the course of the year.

The doses received by 19,532 flight crew members were recorded in SISERI in 2010. 15% of the annual individual doses were below 1 mSv and 85% were between 1 mSv and 5 mSv.

3|3 Doses received by the population as a result of nuclear activities

The automated monitoring networks managed nationwide by IRSN (Téléray, Hydrotéléray and Téléhydro networks) offer real-time monitoring of environmental radioactivity and can highlight any abnormal variation. In the case of an accident or incident leading to the release of radioactive materials, these measurement networks would play an essential role by providing data to back the decisions to be made by the authorities and by notifying the population. In a normal situation, they contribute to the evaluation of the impact of BNIs (see chapter 4).

However, there is no overall monitoring system able to provide an exhaustive picture of the doses received by the population as a result of nuclear activities. Consequently, compliance with the population exposure limit (effective dose set at 1 mSv per year) cannot be controlled directly. However, for BNIs, there is detailed accounting of radioactive effluent discharges and radiological monitoring of the environment is implemented around the installations. On the basis of the data collected, the dosimetric impact of these discharges on the populations in the immediate vicinity of the installations is then calculated using models for simulating transfers to the environment. The dosimetric impacts vary, according to the type of installation and the lifestyles of the reference groups chosen, from a few microsieverts to several tens of microsieverts per year.

There are no known estimates for nuclear activities other than basic nuclear installations, owing to the methodological difficulties involved in identifying the impact of the facilities and in particular the impact of discharges containing small quantities of artificial radionuclides resulting from the use of unsealed radioactive sources in research or biology laboratories, or in nuclear medicine units. For example, the impact of hospital discharges leads to doses of several microsieverts per year for the most exposed persons, in particular workers in the sewer networks (IRSN study 2005).

Situations inherited from the past, such as atmospheric nuclear tests and the Chernobyl accident, can make a marginal contribution to population exposure. Thus the average individual effective dose currently being received in metropolitan France as a result of fall-out from the Chernobyl accident is estimated at between 0.010 mSv and 0.030 mSv/year (IRSN 2001). That due to the fall-out from atmospheric testing was estimated in 1980 at about 0.020 mSv. Given a decay factor of about 2 in 10 years, current doses are estimated at well below 0.010 mSv per year (IRSN, 2006). With regard to the fall-out in France from the Fukushima accident (Japan), the results published by IRSN in 2011 showed the presence of very low levels of radioactive iodine, with no health impact for the populations or the environment.

Installing a filter on one of IRSN's "OPERA AIR" aerosol sampling network stations (OPERA programme: permanent environmental radioactivity observatories)

3|4 Doses received by patients

Exposure to ionising radiation of medical origin is on the increase in most countries (source: UNSCEAR). In the USA, the average annual effective dose per person rose from 0.53 mSv in 1983 to 3 mSv in 2006. Worldwide:

• the number of radiological examinations rose from 1.6 to 4 billion between 1993 and 2008, i.e. an increase of some 150%. About 17 million nuclear medicine examinations were carried out yearly in the 1970s, a figure which leapt to 35 million (+100%) in the early years of this millennium.

• the share of the dose due to computed tomography (CT) represents 42% of medical exposures in 2008, compared with 34% in 2000, while in developed countries the share of CT examinations is 8% and the associated dose represents 47% of medical exposures.

The average effective dose per inhabitant in France resulting from radiological examinations for diagnostic purposes has been reassessed: between 2002 and 2007 it increased from 0.83 to 1.3 mSv per year per inhabitant (the last exposure data update, published by the IRSN and the InVS in April 2010, is based on information relating to 2007).

Conventional radiology represents the largest number of examinations (63 %), but in terms of exposure, CT scans account for almost 58% of the doses delivered to patients (diagram 7).

In 2007, the overall number of procedures and the average effective dose per inhabitant increased with age (diagrams 6 and 7):

• among infants (under 1 year old) the procedures performed most frequently and contributing most to the effective dose are radiography of the pelvis (approximately 0.2 procedures per year per infant) and of the thorax (approximately 0.15 procedures per year per infant);

• among adolescents, an increase in the number of procedures and the average effective individual dose is observed due to an increase in radiography of the limbs (approximately 0.3 procedures per year per child) and extra-oral dental radiography, such as the panoramic dental examination (approximately 0.1 procedures per year per child).

Among adults, the number of procedures and average effective individual doses vary with gender and age. Therefore:

• among women, the average effective individual dose varies from 0.4 mSv per year between 20 and 24 years of age to 2.5 mSv per year between 70 and 90 years of age, the most frequent procedures being mammography (0.4 procedures per year per woman between 50 and 70 years of age), and radiography of the limbs and thorax;

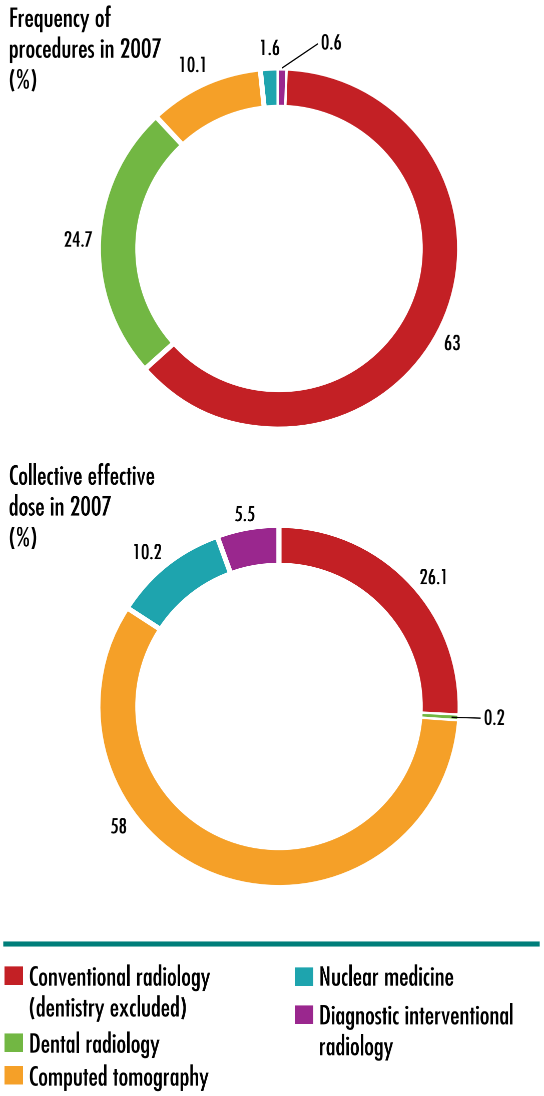
• among men, the individual dose varies from 0.4 mSv per year between 20 and 24 years of age, to 3 mSv per year between 70 and 90 years of age, the most frequent procedure being radiography of the thorax, the frequency of which increases steadily with age, rising from 0.1 to 0.7 procedures per year per man between the age of 20 and 80.

Among both men and women, computed tomography scans contribute more to the average effective individual dose than radiological procedures. The CT procedures delivering the highest doses are abdomino-pelvic and thoracic CT scans. By way of example, at 50 years of age the average effective individual doses that can be attributed to radiological and

Table 4: average number of medical imaging procedures and average effective dose in France in 2002 and 2007 (source IRSN)

Year	Average number of procedures		Average effective dose per inhabitant per year
	Total	Per inhabitant	
2002 • (61.4 million inhabitants)	73.3 million	1.2	0.83 mSv
2007 • (63.7 million inhabitants)	74.6 million	1.2	1.3 mSv

Diagram 5: breakdown of procedures and associated doses per field



CT examinations respectively are 0.5 and 1 mSV per year for women and 0.3 and 1 mSV per year for men.

Medical exposure to ionising radiation (computed tomography, positron emission tomography (PET), interventional radiology) represents the largest contribution to artificial exposure in the developed countries. These practices are continuing to grow and are unavoidable except when alternative techniques can be used.

Particular attention must be given to monitoring and reducing the doses received from medical imaging, because if a given individual undergoes a large number of examinations involving high levels of irradiation, the value of 100 mSv could be reached, and epidemiological studies have shown that above this value there is a significant probability of developing a radiation-induced cancer.

3|5 Protection of non-human species

The international radiation protection system was created to protect man against the effects of ionising radiation. Environmental radioactivity is thus assessed with respect to its impact on human beings and, in the absence of any evidence to the contrary, it is today considered that the current standards also protect other species.

It must however be possible to guarantee that the environment is protected against the radiological risk regardless of the effects on man (see ICRP 103). ASN is in favour of greater consideration being given to the impact of ionising radiation on non-human species in the regulations and in the nuclear activity licenses, while stressing that evaluation methods will need to be published for effective implementation of any new regulations on this subject.

Diagram 6: per individual, average number of conventional radiology (excluding intra-oral dental) and computed tomography procedures, according to gender and age in 2007 (source IRSN/InVS)

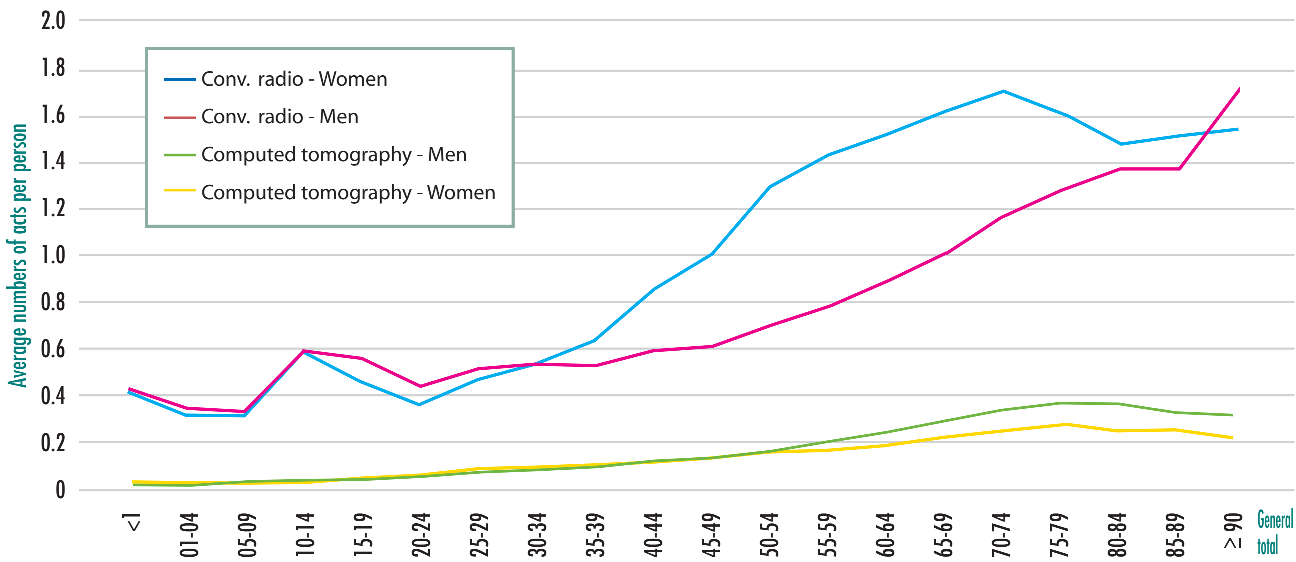


Diagram 7: average effective dose per inhabitant in 2007 linked to radiological procedures (sources IRSN/InVS)

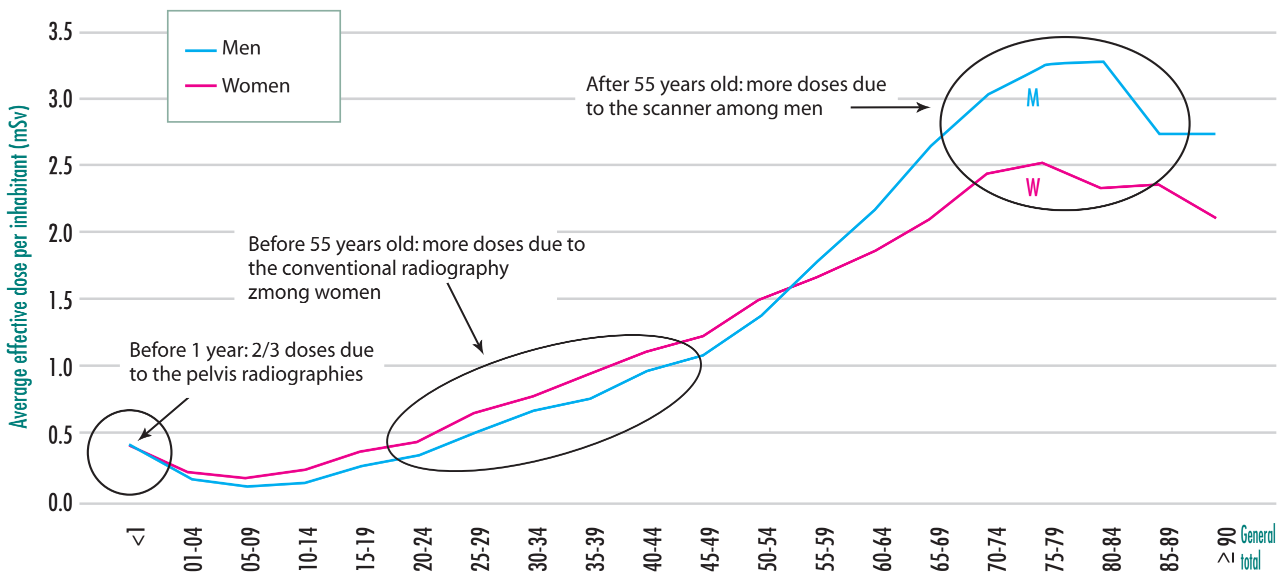
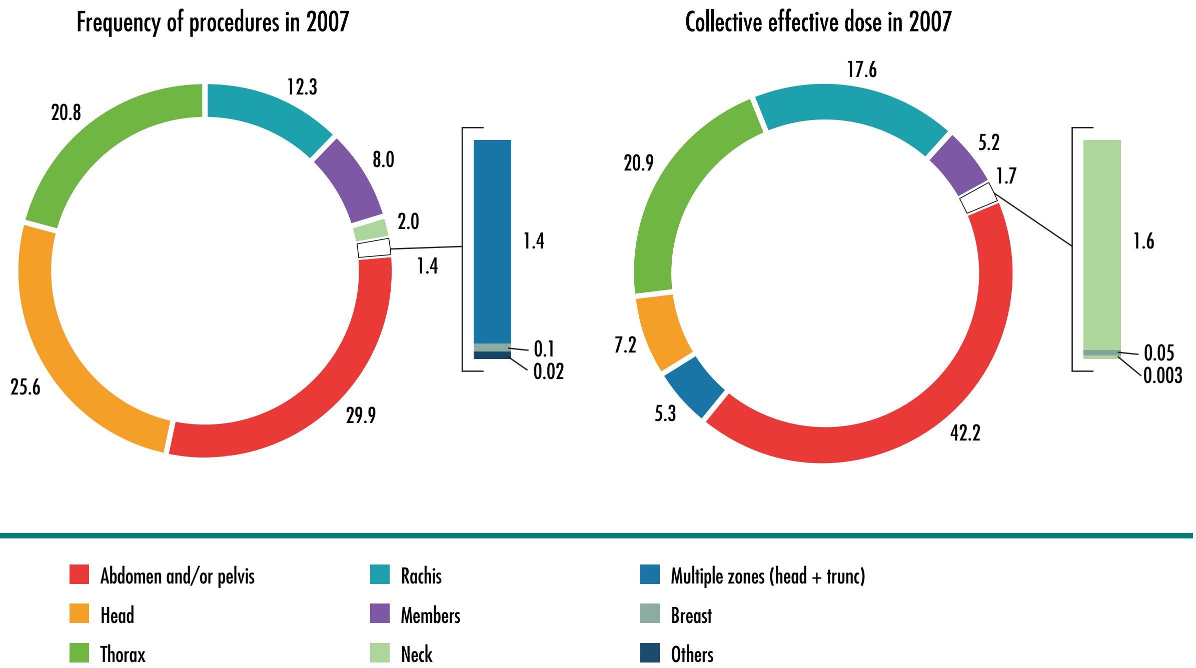


Diagram 8: breakdown of frequency of procedures and collective effective dose per anatomical region examined using computed tomography, all of France – in %



4 OUTLOOK

ASN remains particularly attentive to the correct functioning of the occupational exposure monitoring system set up by IRSN (SISERI), in that the statistics provided constitute valuable national indicators of trends in occupational exposure and are useful in assessing the effectiveness of the measures taken by the licensees to implement the optimisation principle. As in the preceding years, the IRSN-published study of worker exposure in 2010 confirms the stabilisation at a low level of the number of monitored workers whose annual dose exceeded 20 mSv, and the stabilisation at a low level of the collective dose following the reduction that began in 1996. From 2012, owing to the probable reduction in the regulatory exposure dose limit for the lens of the eye, particular attention will need to be given to monitoring this specific exposure in health professionals associated with interventional practices.

The second national action plan for radon-related risks, published in November 2011, highlights the need to develop screening of radon exposure in dwellings. For ASN, the expected publication of new regulations on this subject should be an opportunity to compile all radon exposure data in a single national system comprising the results of measurements taken in premises open to the public, the workplace and dwellings.

ASN also remains attentive to the information produced by the national observatory of patient exposure, run by InVS and IRSN, whose first publication (April 2010) confirmed that, as in the other developed countries, the doses delivered to patients during diagnostic examinations was on the rise in France. Improvements of the precision of this monitoring system, involving the stakeholders, would however appear to be necessary.

The question of hypersensitivity to ionising radiation still requires particular attention in terms of applied research at both national and international level, with a view to rapidly devising a radiosensitivity test for patients, especially prior to radiotherapy treatment. In the field of low doses, this question must also continue to be examined, especially owing to the large-scale use of breast cancer screening using mammography.

Finally, ASN has decided in 2012 to implement pluralistic and effective monitoring of the actions initiated at the national level in response to the 2011 recommendations concerning the link between child leukaemia and environmental factors.