NUCLEAR ACTIVITIES: IONISING RADIATIONS AND HEALTH AND ENVIRONMENTAL RISKS

CHAPTER 1

Nuclear activities are defined by the Public Health Code as “activities involving a risk of human exposure to ionising radiations, 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 during transport of radioactive materials, as well as in all industrial and research facilities and hospitals where ionising radiations are used.

The common goal of nuclear safety and radiation protection is to protect people and property against hazards, detrimental effects or inconveniences of whatever nature, arising from the operation of nuclear or radiological facilities, the transport, use and transformation of radioactive or fissile materials, and exposure to natural ionising radiations.

Nuclear safety is defined as encompassing all technical and organisational provisions relating to the design, construction, operation, shutdown and dismantling of facilities comprising a source of ionising radiations, as well as those relating to the transport of radioactive materials, and intended to prevent accidents and mitigate any consequences thereof.

Radiation protection is defined as the set of prevention and monitoring rules, procedures and means aimed at preventing or minimising the harmful effects of ionising radiations on individuals directly or indirectly exposed, including through environmental contamination.

In addition to the effects of ionising radiations, 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 environmental protection requirements monitored and checked by ASN are presented in chapter 3.

The Nuclear Safety Authority (ASN), created by Nuclear Transparency and Security Act 2006-686 of 13 June 2006, is responsible for the regulation of nuclear safety and radiation protection in all fields using sources of ionising radiations or involving transport of radioactive materials. With regard to radiation protection, other organisations such as the conventional safety inspectorate, the inspectorate for installations classified on environmental protection grounds and the medical devices inspectorate also have specific regulatory roles.

1 KNOWLEDGE OF THE HAZARDS AND RISKS FROM IONISING RADIATIONS

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 radiations interact with the atoms and molecules making up the cells of living matter and alter 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 materials.

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. They are certain to appear, depending on the type of tissue exposed, when the quantity of radiation absorbed exceeds certain dose levels (examples: erythema, radiodermatitis, radionecrosis, cataracts, hematopoietic syndrome, gastro-intestinal syndrome and nervous syndrome); the effects increase with the dose of radiation received by the tissue.

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 radiations may be a first step towards cancerisation.

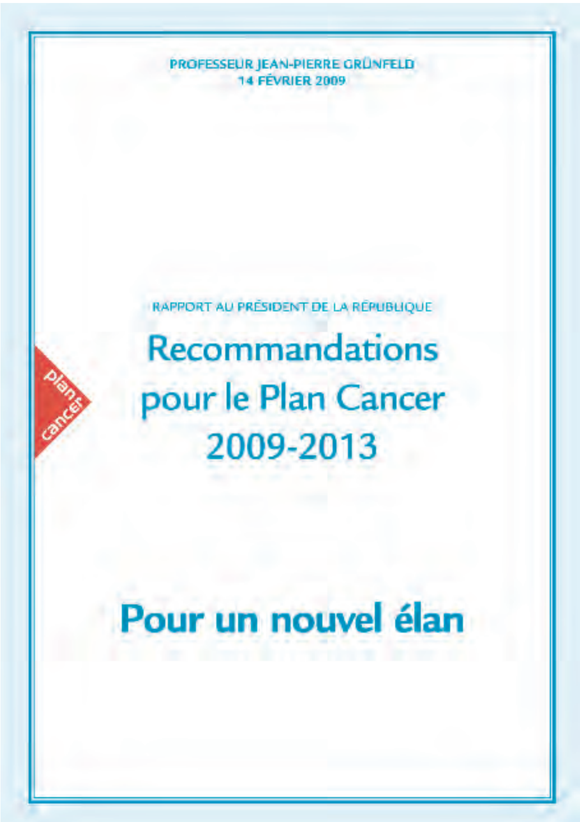
The suspicion of a causal link between the occurrence of cancer and exposure to ionising radiations dates from the

Child leukaemia

After the publication of a German study on the occurrence of leukaemia in children living near nuclear power plants at the end of 2007 and the IRSN (French Institute for Radiation Protection and Nuclear Safety) summary of the epidemiological studies already published on this subject, ASN set up a working group at the end of 2008 to assess the available knowledge on the risk of leukaemia in children living in the vicinity of BNIs. Based on an inventory of the possible causes of child leukaemia, the group is also tasked with proposing the studies and research necessary for improving currently available knowledge. The group brings together scientific experts, from the fields of medicine, epidemiology and radiation protection in particular, and personalities whose personal experience will enable them to make a valuable contribution to the debate. Foreign experts and personalities will also be participating. An interim report is expected early in 2010.

beginning of the 20th century (observation of skin cancer on radiodermatitis).

Since then, several types of cancers have been observed in occupational situations, including leukaemias, primitive 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 induced cancers and the resulting mortality, following



2009-2013 cancer plan drawn up by Pr Jean-Pierre Grünfeld

exposure to ionising radiations. Other epidemiological work, in particular in radiotherapy, highlighted a statistically significant rise in secondary cancers among patients treated using radiotherapy and attributable to ionising radiations. 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 and 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 aim to avoid the appearance of deterministic effects, but also to reduce the probability of radiation-induced cancers appearing.

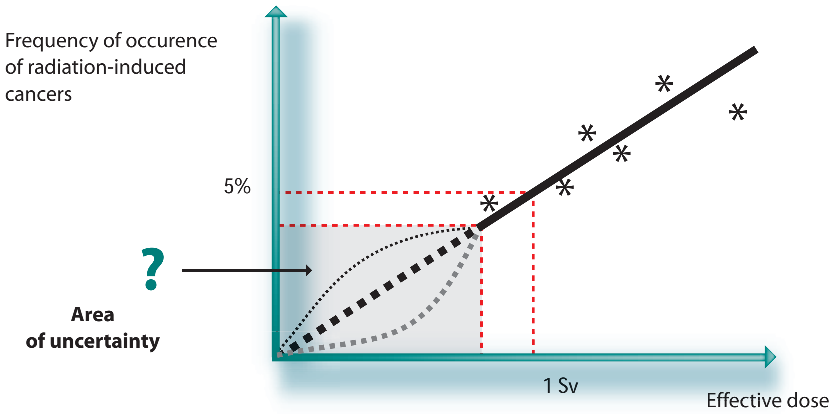
1 | 2 Evaluation of risks linked to ionising radiation

Cancer monitoring is organised on the basis of *département** registers (10 registers covering 11 départements or 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).

As with any monitoring system, the aim is to highlight spatial differences in incidence in the areas covered, to identify trends in terms of increased or reduced incidence in the various cancer locations over time, or to locate a cluster of cases in one of the areas covered. This intentionally

*Administrative region headed by a *préfet*.

Diagram 1: "dose-effects" linear relationship (without threshold)



descriptive monitoring method cannot identify radiation-induced cancers, as their form is not specific to ionising radiations.

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 radiations of less than 100 mSv. The epidemiological surveys were thus only able to link pathologies to ionising radiations 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

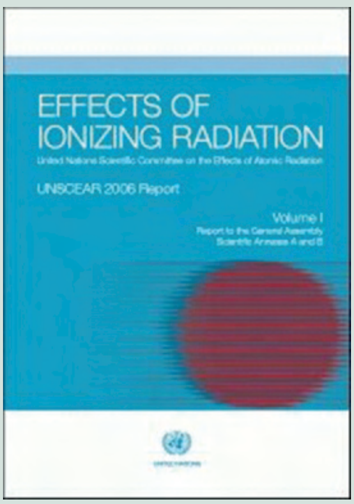
UNSCEAR

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 whose aim is to validate and approve the results of national or international studies into the effects of ionising radiations on man.

Recent publications – Effects of ionizing radiation (2006).

Volume 1 – Annex A (Epidemiological studies of radiation and cancer) and Annex B (Epidemiological evaluation of cardiovascular disease and other non-cancer diseases following radiation exposure).

Volume 2 – Annex C (Non-targeted and delayed effects of exposure to ionizing radiation), Annex D (Effects of ionizing radiation on the immune system) and Annex E (Sources-to-effects assessment for radon in homes and workplaces).



UNSCEAR 2006
report on "Effects of ionizing radiation"

of ionising radiations. Internationally, this estimate uses the conservative scenario of a linear relationship without threshold between exposure and the number of deaths through cancer. Thus an estimate of the number of cancers attributable to exposure to ionising radiations can be calculated, using a linear extrapolation without threshold of the relationship observed at high doses (see diagram 1). The legitimacy of these estimates however remains open to debate 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) published risk coefficients for death through cancer due to ionising radiations, 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 radiations.

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 relationship without threshold for low-dose exposure, 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).

The health goal of reducing the risk of cancer linked to ionising radiations cannot be directly observed through epidemiology; the risk can be calculated if one assumes the existence of a linear relationship without threshold between exposure and the risk of death from cancer.

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 has not reached either zero risk or zero impact, whether in terms of the doses received by medical or industrial 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.

High dose radiation-induced pathologies

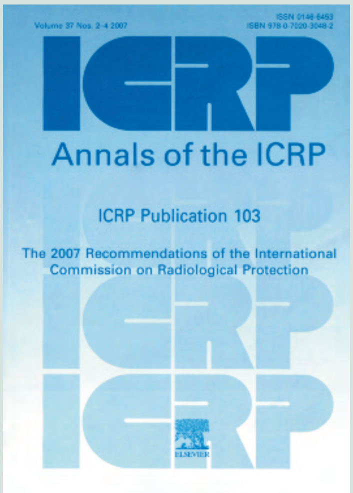
• *Hyper-sensitivity to ionising radiations* - The effects of ionising radiations on personal health vary from one individual

ICRP publication 103

The International Commission on Radiological Protection (ICRP) has for a number of decades now been issuing radiation protection recommendations, which generally constitute the basis for international standards (in particular those issued by IAEA) and EU directives.

The optimisation principle is the core feature of the new recommendations published at the end of 2007 (ICRP 103), although the principles of justification and limitation are maintained. Whatever the type of exposure situation (planned exposure, emergency exposure or existing exposure), the ICRP recommends reducing individual doses to a level as low as is reasonably achievable. For correct implementation of the optimisation principle, the ICRP proposes establishing reference dose values for each exposure situation. The individual dose limits, applicable to exposure arising from all sources to which the individual is exposed, remain unchanged. Finally, the exposure categories (at work, the public and medical applications) are also maintained.

The ICRP thus updated the existing system (ICRP 60), without radically altering it, in order to take account of the need for stability expressed by both professionals and regulatory authorities.



ICRP 103 recommendations – December 2007 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 hyper-sensitivity to high doses of ionising radiations has been extensively documented by radiotherapists and radiobiologists. This is the case with genetic anomalies in DNA repair and cell signalling (for example, ataxia telangiectasia): the homozygotic patients with these mutations are extremely hyper-sensitive, leading to "radiological burns", while heterozygotic carriers experience less hyper-sensitivity. Finally, patients are more susceptible to the development of cancers. In total, about 5% of the population is concerned by hyper-sensitivity to ionising radiations.

Questions then arise, some of which are ethical in nature and go beyond the boundaries of radiation protection:
– do children need to be given particular attention in terms of radiation protection, during the course of exposure to ionising radiations of medical origin?
– once the radiobiologists have developed tests to reveal individual hyper-sensitivity to radiation, should individual screening prior to any radiotherapy be recommended?
– should hyper-sensitivity screening be carried out on all workers liable to be exposed to ionising radiations?
– should the general regulations, for example, provide for specific protection for those concerned by hyper-sensitivity to ionising radiations?

Effects of low doses

• *The linear relationship without threshold* - 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, with some even postulating that low doses could 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, the uncertainties remain and precaution is essential for the authorities.

• *Dose, dose rate and chronic contamination* - The epidemiological surveys performed on individuals exposed to the Hiroshima and Nagasaki bombings, have given a clearer picture of the effects of radiation on health, for high dose and high dose rate external exposure. The studies begun in the countries most affected by the Chernobyl accident, i.e. 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 exposure levels, 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.

International Conference on Modern Radiotherapy organised by ASN – December 2009

• *Hereditary effects* - The appearance of possible hereditary effects from ionising radiations 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 radiations in the embryonic germ cells can be transmitted to the descendents. The recessive mutation of an allele will remain invisible as long as the allele carried by the other chromosome is not affected. Although it cannot be absolutely ruled out, the probability of this type of event nonetheless remains low.

Environment

• *Protection of non-human species* – The purpose of radiation protection is to prevent or mitigate the harmful effects of ionising radiations on individuals directly or indirectly exposed, including through environmental contamination: human protection involves environmental protection, as illustrated by the impact assessments submitted to the public inquiries held to authorise BNI discharges. But quite apart from this environmental protection aimed at protecting present and future generations of mankind, one could also envisage the protection of nature, in the specific interests of animal species or the rights of nature (see point 3|5).

2 NUCLEAR ACTIVITIES REGULATED BY ASN

The activities involving a risk of exposure to ionising radiations 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;
– contaminated sites;
– activities enhancing natural ionising radiations.

2 | 1 Basic nuclear installations (BNIs)

2 | 1 | 1 Definition

The regulations classify nuclear facilities in various categories corresponding to procedures of various stringency, depending on the scale of the potential hazards. The main fixed nuclear installations, known as "Basic Nuclear Installations" (BNIs), are defined in Article 28 of the Nuclear Transparency and Security Act 2006-686 of 13 June 2006. Decree 2007-830 of 11 May 2007 concerning the list of BNIs, gives a more precise definition of BNI categories:
– nuclear reactors, with the exception of those equipping a means of transport;
– 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 last three types of facilities are however only covered by BNI regulations when the total quantity or activity level of the radioactive materials exceeds a threshold set, according to the type of facility and the radionuclide concerned, by a joint order of the ministers for the Environment, Industry and Health.

Nuclear facilities which are not considered to be BNIs may be subject to the provisions of book V of the Environment Code (conditions applicable to installations classified on environmental protection grounds (ICPEs)).

The BNI status as at 31 December 2009 is given in appendix A.

2 | 1 | 2 Accident prevention and nuclear safety

Nuclear safety covers all technical arrangements and organisational measures concerning the design, construction, operation, shutdown and decommissioning of BNIs, as well as the transport of radioactive materials, with the aim of preventing accidents or mitigating their effects.

Radiological check on exiting the reactor building for the Lyon division inspector, during the ten-yearly outage of the Tricastin NPP – May 2009

The fundamental principle underpinning the organisational system and the specific regulations applicable to nuclear safety is that the licensee is responsible for safety. The public authorities ensure that this responsibility is fully assumed, in compliance with the regulatory requirements. The respective roles of the public authorities and the licensee can be summarised as follows:
– the public authorities define the general safety objectives;
– the licensee proposes technical procedures for attaining them, and justifies them;
– the public authorities ensure that these procedures are consistent with the goals set;
– the licensee implements the approved measures;
– during their inspections, the public authorities check correct implementation of these measures and draw the corresponding conclusions.

2 | 1 | 3 Prevention of risks for workers

The licensee is required to take all necessary steps to protect the workers against the hazards of ionising radiations, and more particularly to follow the same general rules as those applicable to all workers exposed to ionising radiations (annual dose limits, categories of exposed workers, definition of supervised areas and controlled areas, etc.), along with the technical and administrative requirements specific to BNIs (organisation of work, prevention of accidents, keeping of registers, medical monitoring of workers from outside contractors, etc.).

2 | 1 | 4 Impact of BNIs on the environment and the population

The licensee of a BNI must also take the steps necessary to attain and maintain an optimum level of protection of the population.

More particularly, and in normal operating conditions, nuclear facilities discharge liquid and gaseous effluents, which may or may not be radioactive. The impact of these discharges on the environment and on the health of the populations living in the vicinity of the installations must be strictly limited.

The installations must therefore be designed, operated and maintained in such a way as to limit the production of these effluents. They must be treated so that the corresponding discharges are kept to a level as low as reasonably achievable. These discharges may not exceed the limit values set on a case by case basis by the public authorities, using the best technologies available at an economically acceptable cost, and taking into account the particular characteristics of the site. Finally, these discharges must be measured and their actual impact regularly evaluated, in particular with regard to radioactive discharges.

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 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.

The consignor is responsible for implementing these lines of defence.

2 | 3 Small-scale nuclear activities

Ionising radiations, whether generated by radionuclides or by electrical equipment (X-rays), are used in very many areas of medicine (radiology, radiotherapy, nuclear medicine), human biology, research, industry, but also for veterinary and medico-legal applications as well as for conservation of foodstuffs.

In terms of radiation protection, most of these activities, which are also considered to be nuclear activities, are covered by the licensing or notification procedures

Radiological check on a lorry using a radiation meter in the logistics building of ANDRA's very low level waste repository (CSTFA) in the Aube *département* – April 2004 stipulated in the Public Health Code or, as applicable, by particular procedures (case of ICPEs) in which, on the basis of information forwarded by the licensee, the various aspects relating to radiation protection are examined, both with regard to the protection of workers and that of the population in general. Protection is also taken into account through the requirements applied to discharges of liquid and gaseous effluents. In the case of use for medical purposes, patient protection issues are also reviewed.

For activities other than ICPEs, authorisations are issued to the persons in charge of using the ionising radiations. The fact that the responsibility is targeted on the user in no way means that the head of the company is relieved of his duty to provide the person in possession of the sources with all resources necessary for radiation protection, be they human (person with competence for radiation protection, medical radiation physics expert), technical (premises and equipment conforming to current standards), organisational, or related to measurements (dosimetry and measuring instruments). Some activities (e.g.: medical or dental radiology facilities) are simply subject to notification.

If they use unsealed radioactive sources, then small-scale nuclear activities also generate radioactive waste, which has to be managed in accordance with the principles described in point 2|4.

Sorting of low and intermediate level waste in a chemistry laboratory, EDF Chinon

2|4 Disposal of radioactive waste

Like all industrial activities, nuclear activities generate waste. Some of this waste is radioactive. The three fundamental principles on which strict radioactive waste

The impact of tritium: ASN's forward-looking approach

Tritium is a radioactive isotope of hydrogen and is to be found in the environment in three forms: a liquid form (tritiated water or HTO), a gaseous form known as HT and an organic form called OBT. Tritium occurs naturally in the environment as a result of the effect of cosmic radiation on nitrogen atoms and is also one of the main radionuclides emitted by nuclear reactors, spent nuclear fuel reprocessing installations, industries and laboratories using this radionuclide and waste management facilities.

Medical authorities in France and abroad, as well as the international health organisations, agree that the radiotoxicity of tritium is low. It has also been accepted that it does not build up in the food chain (no bioaccumulation).

However, recent observations could lead to a review of this opinion: measurements taken in the United Kingdom (Rife reports) showed higher than expected levels of tritium in fish and shellfish. At the same time, studies into the biokinetics of tritium (modelling of the behaviour of tritium in living organisms) could also lead to a reassessment of the parameters used in characterising its radiotoxicity.

As a result of the questions raised by this work, ASN wished to obtain a precise analysis of the existing studies on the subject and at the beginning of 2008, it therefore decided to set up two independent working groups, comprising scientists, licensees and associations:
- *a "tritium impact" group, responsible for producing an inventory of current scientific knowledge on the health impacts of tritium and the real scientific data on the bioaccumulative effect of tritium;*
- *a "defence in depth" group responsible for anticipating changes in discharges resulting from the use of new fuel management programmes and the construction of new installations (EPR and Iter), for examining technical possibilities concerning tritium treatment and for producing an inventory of current knowledge on its environmental impact.*

Each of the two working groups has met five times since 2008. Their work will be completed at the beginning of 2010. The conclusions and recommendations arising from this work will be published by ASN in 2010.

management is based, are the responsibility of the waste producer, the traceability of the waste and public information. For very low level (VLL) waste, application of a management system based on these principles, if it is to be completely efficient, rules out setting a universal threshold below which regulation can be dispensed with.

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, disposal).

2 | 5 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.

2 | 6 Activities enhancing natural ionising radiations

Exposure to natural ionising radiations, 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 radiations on the part of the workers and, to a lesser extent, the populations living in the vicinity of the places 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, construction 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.

Surveillance of human exposure to radon in premises open to the public is targeted on the risk to the general public but also to workers. It is also a priority radiation protection action in geographical areas in which there is high potential exhalation of radon owing to the geographical characteristics of the terrain. A strategy to reduce this exposure is necessary, should the measurements taken exceed the action levels laid down in the regulations.

Teaching establishments, health and social care establishments, spas and prisons are mainly concerned by the radon monitoring measures.

Since August 2008, this monitoring has been extended to workplaces located in priority geographical areas. Finally the exposure of aircrews to cosmic radiation, aggravated by prolonged periods at altitude, also warrants dosimetric monitoring (see point 3|2|3).

3 MONITORING OF EXPOSURE TO IONISING RADIATIONS

The pathology monitoring systems set up (cancer registers for example) do not enable those pathologies attributable to ionising radiations to be determined. Nor do we have reliable and easily measurable biological indicators which could be easily used to recreate the radiation dose to which the individuals were exposed. In this context, "risk monitoring" is performed by measuring ambient radioactivity indicators, or at best by measuring the dose rates linked to external exposure to ionising radiations or internal contamination, or failing which, by measuring values (concentration of radionuclides in radioactive waste discharges) which would then enable an estimate of the doses received by the exposed populations to be calculated.

The entire French population is potentially exposed, although to different extents throughout the country, to ionising radiations of natural origin and to radiation created by human activities. The average exposure of the French population is estimated, per inhabitant, at 3.3 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 2006). Depending on the location, the average individual effective dose can vary by a factor of 2 to 5. Graph 1 represents an estimate of the respective contributions of the various sources of French population exposure to ionising radiations.

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

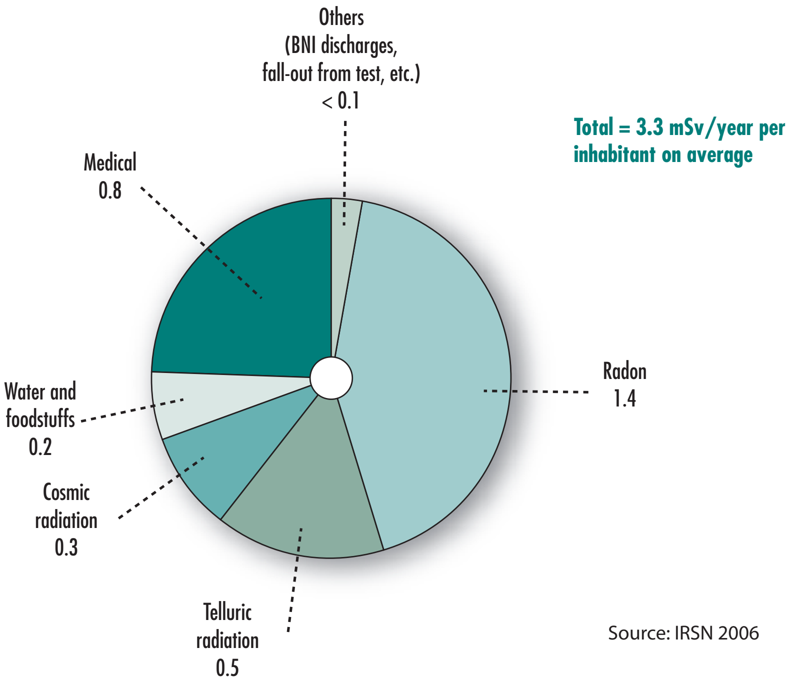
3 | 1 Exposure of the population to natural ionising radiations

People have always been exposed to natural ionising radiations owing to the presence of radionuclides of terrestrial origin in the environment, radon emanations from the ground and exposure to cosmic radiation.

Terrestrial radiation (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

Graph 1: the sources of exposure to ionising radiations of the French population (annual averages)



Source: IRSN 2006

National study of the radiological quality of the water distributed by the mains networks

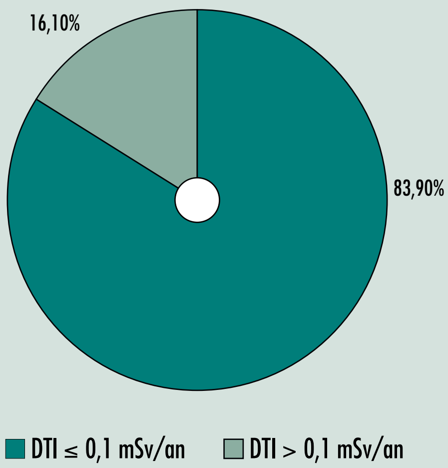
ASN, DGS and IRSN in 2009 published *an initial national study of the radiological quality of the water distributed by the mains networks, conducted on the basis of health analysis results coordinated by the Departmental Health and Social Action Directorates (DDASS).*

These checks are based on the measurement of four indicators: tritium, the activity level of the alpha and beta emitting radionuclides and the total indicative dose (the dose from exposure to ionising radiations attributable to the consumption of water for one year). These indicators give the "radiological profile" of the water linked to the presence of natural radionuclides typical of the geological terrain through which the water passed (natural background), as well as the abnormal presence of artificial or natural radionuclides.

The results of the study show that between 2005 and 2007, of more than 50,000 analyses carried out in wells or on tap water, the stipulated radiology quality benchmarks were met, with the exception of a few isolated small-scale overdoses due to the presence of natural radionuclides as a result of the geological nature of the terrain.

For 2007, the radiological quality of the tap water distributed to the home was evaluated for nearly 87% of the French population. This showed that in 99.9% of cases, the dose from exposure to ionising radiations attributable to the consumption of water for one year remained below the quality reference value set by the regulations.

The study also gives initial results concerning the natural uranium concentration of mains water. Natural uranium is not currently included in the drinking water monitoring. Given the chemical toxicity of natural uranium, the World Health Organisation (WHO) proposed a provisional guideline value beyond which corrective measures would need to be taken. For 455 of the 472 samples containing naturally high radioactivity over the period 2005-2007, this guideline value is met.



Percentage of results below or above the total indicative dose value set by the regulations (0.1 mSv/year) for groundwater – 2005-2007 data

also to internal exposure by inhalation of radon or 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 regions, range between a few $nSv.h^{-1}$ and 100 $nSv.h^{-1}$.

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

Based on scenarios covering the time individuals spend inside and outside residential premises (90% and 10% respectively), the average annual effective dose due to external exposure to gamma radiation of terrestrial origin is estimated at about 0.47 mSv (IRSN, 2006), as compared with the worldwide average of 0.46 mSv, estimated by UNSCEAR (2000).

The internal exposure through inhalation, owing to air suspension of particles of soil, is estimated at 0.002 mSv per year, while that due to the long-lived descendents of radon is estimated at about 0.01 mSv 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

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 1000 Bq/m³		Establishments classified at higher than 1000 Bq/m³	
		number	%	number	%	number	%
2005/2006	2,970	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

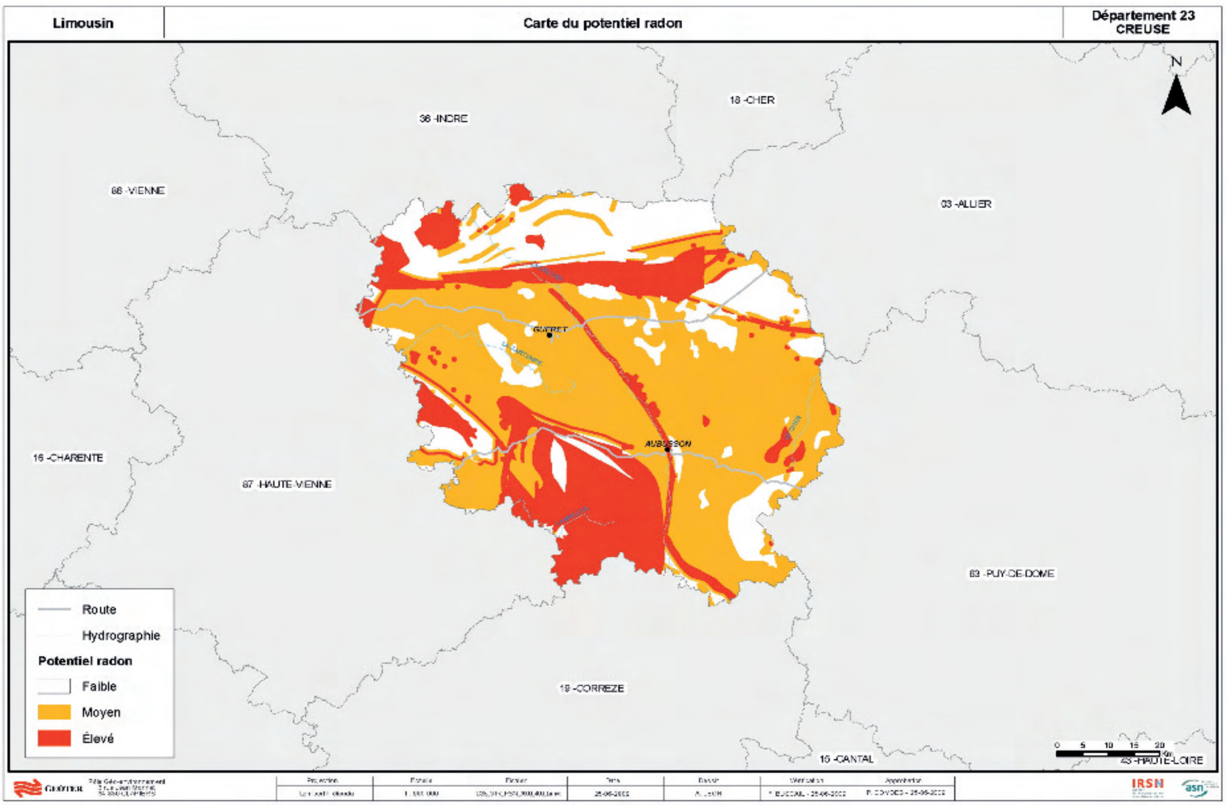
concentration of potassium 40 in the organism is about 55 Bq per kg, resulting in an average effective dose of about 0.18 mSv per year.

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, but also 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 several hundreds of µSv.

Exposure to radon

Exposure to radon in the home 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). For methodological reasons, the results of this supervision are still however too imprecise for an accurate assessment to be made of the doses linked to the actual exposure of the individuals.



Map of potential radon exhalation in the Creuse *département* in 2009

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

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/m^3) remain comparable from one year to the next. The smaller number of measurements taken during the latest campaign indicates that screening of the establishments, which began in 1999, is practically complete. In 2009, a new screening cycle (10 years) started.

External exposure due to cosmic radiation

Cosmic radiation is of two types, 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.

Considering the average time spent inside the home (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 such as Cervières at 2,836 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.

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 radiations are used has been in place for a number of decades. It is based on the mandatory wearing of personal dosimeters by workers likely to be exposed and is used to check compliance with the regulatory limits applicable to workers. The data recorded give the cumulative exposure dose over a given period (monthly or quarterly). They are fed into the SISERI information system managed by IRSN and are published annually. The SISERI system will also eventually allow collection of data supplied by "operational dosimetry", in other words, real-time measurement of external

Results of dosimetry monitoring of worker external exposure to ionising radiations in 2008 (source: IRSN, November 2009)

Total population monitored: 306,629 workers

Monitored population with a recorded dose below the detection threshold: 240,518, or about 78.4%

Monitored population with a recorded dose of between the detection threshold and 1 mSv: 53,070, or about 17.3%

Monitored population with a recorded dose of between 1 mSv and 20 mSv: 13,025, or about 4.2%

Monitored population which exceeded the annual effective dose of 20 mSv: 16 including 4 above 50 Sv

Collective dose (sum of individual doses): 52.36 Man.Sv

Annual average individual dose in the population which recorded a non-nil dose: 0.79 mSv

Table 2: BNI worker dosimetry, excluding defence (year 2008 – source: IRSN)

	Number of individuals monitored	Collective doses (Man.Sv)	Doses > 20 mSv
EDF	19,705	5.76	0
AREVA	11,764	5.64	0
CEA	6,370	0.27	0
IPN Orsay	2,751	0.08	0
Outside companies	17,020	11.01	1
Others	475	0.03	0

Table 3: dosimetry of workers in small-scale nuclear activities (year 2008 – source: IRSN)

	Number of individuals monitored	Collective doses (Man.Sv)	Doses > 20 mSv
Medicine	122,674	13.00	8
Dental	32,073	0.93	0
Veterinary	15,137	0.34	0
Industry	34,374	10.79	7
Research	4,866	0.25	0
Miscellaneous	28,593	1.88	0

exposure doses and the dosimetric results of any internal contamination.

The results of dosimetric monitoring of worker external exposure in 2008 on the whole show that the prevention system introduced in facilities where sources of ionising radiations are used is effective, because for more than 95% of the population monitored, the annual dose remained lower than 1 mSv (effective annual dose limit for the public). However, these statistics do not reflect the whole picture, because in a few cases, the dosimeter exposure did not necessarily correspond to exposure of the worker (dosimeters not worn but exposed) and it is possible that some workers do occasionally fail to wear their dosimeters.

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 considerable disparity between doses according to the sector. For example, the medical and veterinary activities sector, which comprises a significant share of the population monitored (more than 55%), in fact only accounts for 27% of the collective dose; however the annual limit was exceeded in the sector 8 times (out of a total of 16), including two events above 50 mSv.

The latest statistics published by IRSN in November 2009 show relative stability of the population subject to dosimetric monitoring since 2000 (see diagrams 2 and 3), with the figure of 300,000 individuals being reached for the first time in 2008. However, the collective dose, consisting of the sum of the individual doses, has been falling (about -55%) since 1996 at a time when the populations monitored have grown by about 30%. The optimisation approach implemented by the nuclear licensees

Diagram 2: evolution of the populations monitored and of collective doses, from 1996 to 2008 (source IRSN)

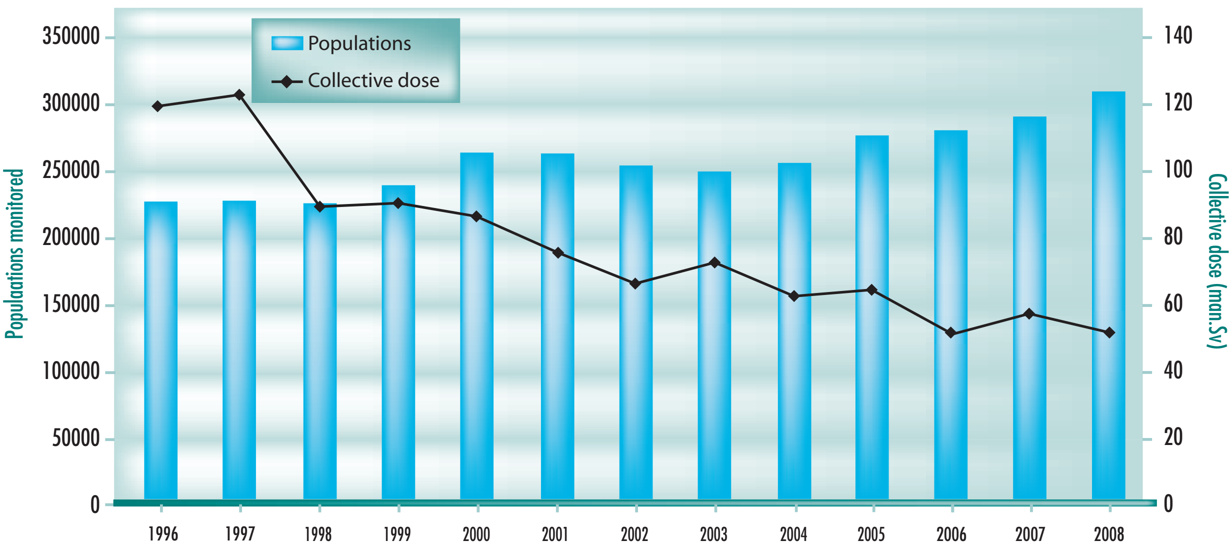


Diagram 3: evolution of number of workers monitored, per area of activity, from 1996 to 2008 (source: IRSN)

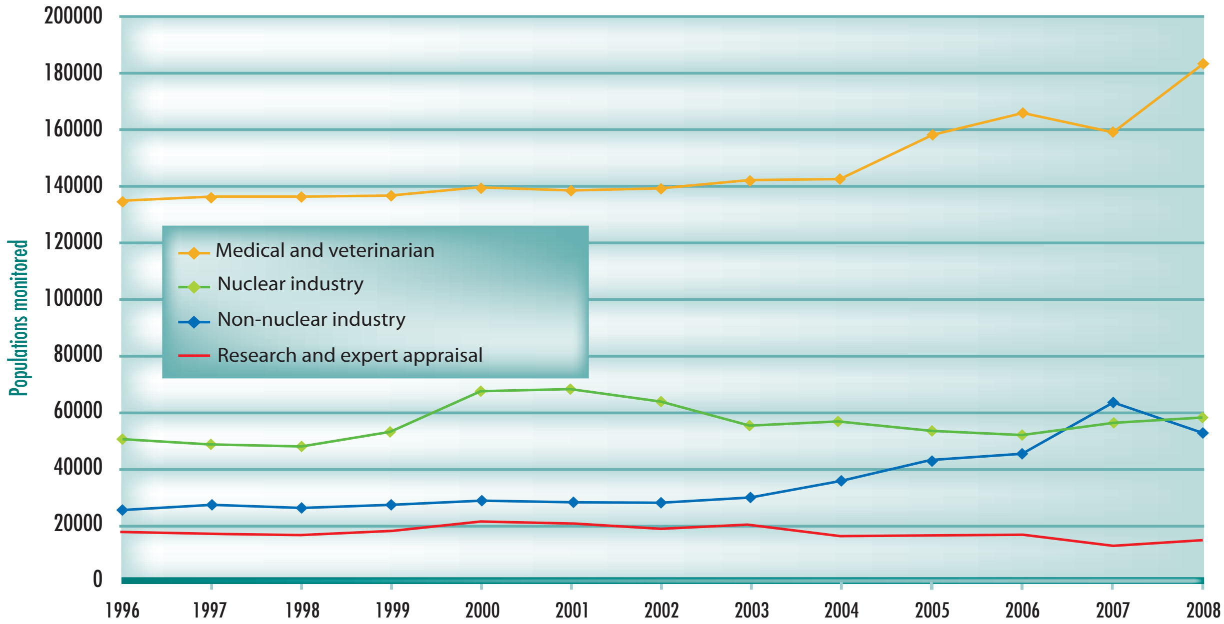
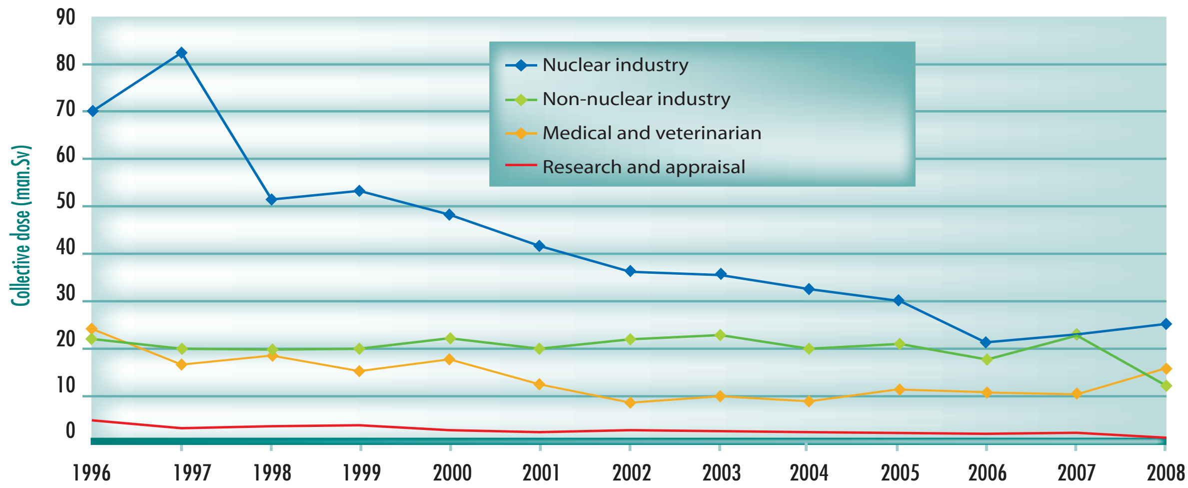


Diagram 4: evolution of collective doses, per area of activity, from 1996 to 2008 (source: IRSN)



during the 1990s is no doubt the explanation for this positive trend (see diagrams 4 and 5).

The number of monitored workers whose annual dose exceeded 20 mSv has also been falling significantly (see diagram 6). Each overdose has to be the subject of a significant event notification to ASN by the nuclear activity licensee and of an individual investigation, jointly with the occupational physician and if necessary with the conventional safety inspectorate, in accordance with the circular of 16 November 2007 concerning coordination of the radiation protection inspectors and the conventional safety inspectors for the prevention of risks associated with ionising radiations.

3 | 2 | 2 Worker exposure to enhanced natural ionising radiations

There is no system for monitoring exposure of individuals working in activities which enhance exposure to

Diagram 5: evolution of number of workers monitored, with an annual dose in excess of 20 mSv, from 1996 to 2008 (source: IRSN)

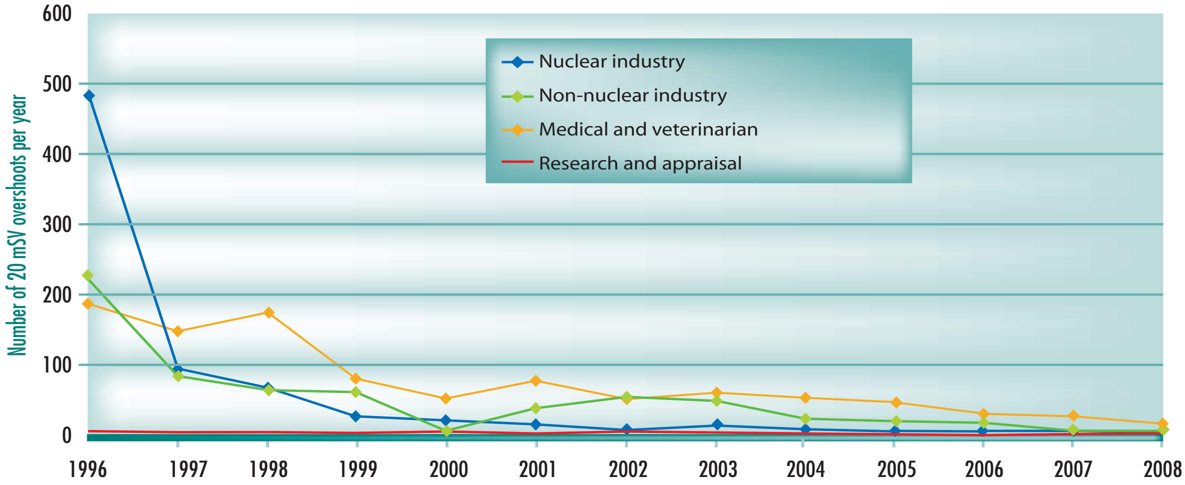
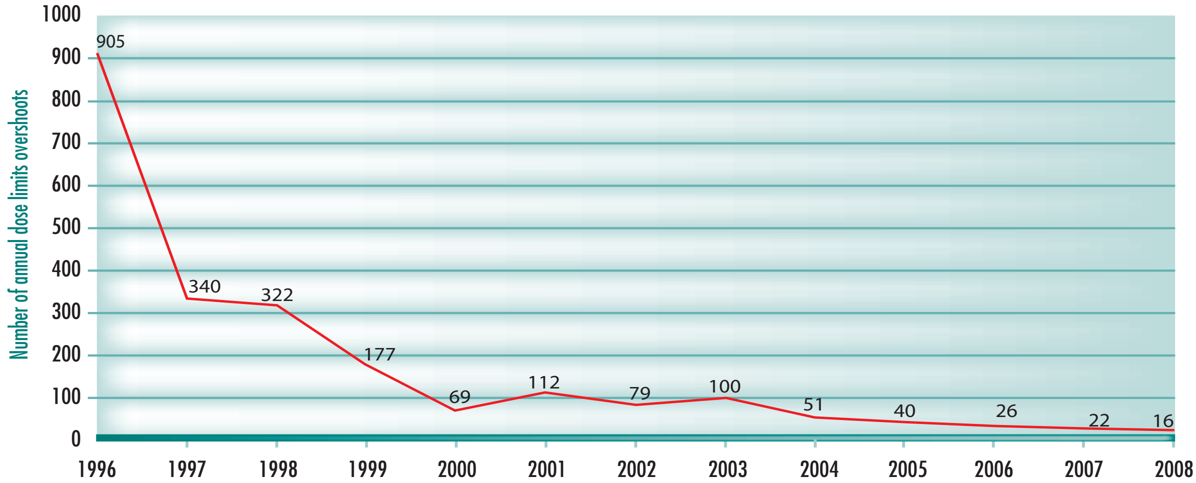


Diagram 6: evolution of number of workers monitored, with an effective annual dose in excess of 20 mSv, from 1996 to 2006 (source: IRSN)



natural ionising radiations. The international studies published however show that exposure can range from a few millisieverts to several tens of millisieverts per year.

Worker exposure to enhanced natural ionising radiations 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, published by ASN in January 2010, show that 83% of the doses received by workers in the industries concerned (see chapter 3) 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

SIEVERT website: www.sievert-system.com/index.html

intensity of cosmic radiation at high altitude. These doses can exceed 1 mSv/year. The mean annual dose for "short-haul" crews was therefore estimated to be from 1 to 2 mSv, from 3 to 5 mSv for "long-haul" crews and up to 10 mSv for certain air mail flight crews.

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

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 take part in evaluating the impact of BNIs.

However, for methodological reasons, 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, it is impossible to directly control compliance with the exposure limit for the population (see chapter 3). 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

Groundwater samples from around the Gravelines nuclear power plant (Nord *département*) – September 2008 is then calculated using models for simulating transfers to the environment. The dosimetric impacts vary, according to the type of installation and the living habits of the reference groups chosen, from a few microsieverts to several tens of microsieverts per year.

These estimates are unknown for nuclear activities other than BNIs. Prior methodological studies are required in order to obtain a better understanding of the impact of these facilities, in particular the impact of discharges containing small quantities of artificial radionuclides originating from the use of unsealed radioactive sources in research or biological laboratories, or in nuclear medicine departments. 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 small contribution to exposure of the population. The average individual effective dose currently being received 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 in 1980 estimated 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).

3 | 4 Doses received by patients

Exposure to ionising radiations of medical origin is on the increase in most countries (source: UNSCEAR).

• Worldwide, the number of radiological examinations rose from 1.6 to 4 billion between 1993 and 2008, i.e. an increase of some 250%. About 17 million nuclear medicine examinations were carried out yearly in the 1970s, a figure which leapt to 35 millions (+200%) in the early years of this millennium.

• In the USA, the average annual effective dose per person rose from 0.53 mSv in 1983 to 3 mSv in 2006.

• A significant percentage of this increase can be attributed to the rise in the use of computed tomography and interventional radiology practices. The percentage due to computed tomography worldwide was 42% of medical exposure in 2008, as opposed to 34% in 2000.

• In the developed countries, the share of computed tomography examinations is 8%, although the associated dose represents 47% of all medical exposure.

• There were 11,050 tomography appliances in Japan in 2000 (or 88 per million inhabitants) with an associated average effective dose of 2.3 mSv. In the USA, there were 3,956 of them in 2006 (13.2 per million inhabitants) with an associated average effective dose of 1.5 mSv. In France, the number of tomography appliances stood at 754 in 2008 (or 11.6 per million inhabitants) but the average dose is not known (IRSN estimate expected in 2010).

The upward trend in the average dose in medical imaging can be attributed to several factors:
– the increase in the level of doses delivered by the equipment (tomography appliances and PET), thereby improving the diagnosis;
– the increase in the number of examinations delivering increasingly high doses (whole body tomography, virtual colonoscopy, heart scan, etc.);
– the increase due to medical practices:
  • medical imaging combined with laboratory analyses for diagnosis of diseases;
  • medical imaging, in association with interventional practices, is becoming a treatment tool in place of surgery (neurology, cardiology, etc.);
  • medical imaging is decisive in guiding the therapeutic strategy (cancerology) and monitoring the effectiveness of treatment.

Medical exposure to ionising radiations (computed tomography, positron emission tomography (PET), interventional

Table 4: number of procedures in France, per sector, using ionising radiations

Type of procedure	Health institution	Private practice
Conventional radiology (including dental)	14.5 to 25 million	40.9 million
Computed tomography	2 to 3.8 million	2.2 million
Nuclear medicine	850,000	n/a*
Interventional radiology	892,000	n/a*
Total	61.3 to 73.6 million	

*n/a = not available

radiology) represents the largest share of 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 multiplying the number of examinations involving high levels of irradiation, on a given individual, could lead to the value of 100 mSv being reached, a value above which studies have shown that there is a significant probability of developing a radiation-induced cancer.

One of ASN's priorities for the coming years must be to monitor application of the justification and optimisation principles in the field of medical imaging.

In France, the four most common conventional radiology examinations are radiography of the lower and upper limbs (32%), the spine (16%), the thorax (12%) and the breast (11%); oral radiography accounts for 85% of dental examinations, while tomography of the head and spine represent 38% and 26% respectively of the total number of examinations by scanner. Based on the estimated dose values per examination (national or, failing which, European data), the estimated average annual effective dose per person is between 0.66 mSv and 0.83 mSv.

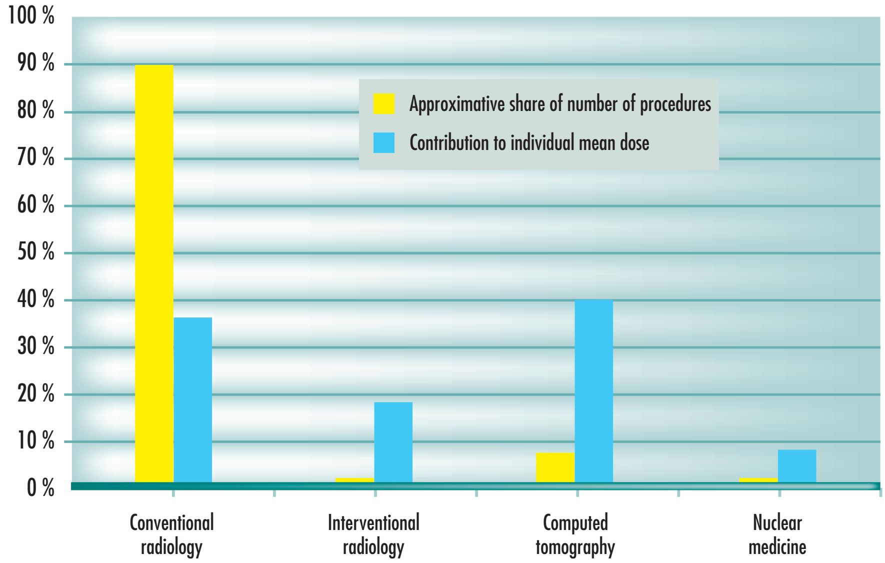
Diagram 7 presents the respective shares of the number of procedures and associated doses, for conventional radiology, computed tomography, nuclear medicine and interventional radiology.

3 | 5 Protection of non-human species

The international radiation protection system was created to protect man against the effects of ionising radiations. 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 seeing greater importance being attached to the impact of ionising radiations on non-human species in the regulations and licensing of nuclear activities. However, scientific data on the effects of ionising radiations on non-human species are limited and ASN considers that further research is needed before being able to propose specific measures for their protection.

Diagram 7: breakdown of number of medical procedures and associated doses



4 OUTLOOK

Exposures monitoring requires a particular effort in order to better identify the population categories or groups which are most exposed. The interest of this is three-fold: this knowledge should lead to better targeting of risk reduction efforts (optimisation), provide reliable indicators for evaluating the effectiveness of public policy and develop epidemiological surveys for an improved approach to the risk. Thus:

– as in previous years, the results of the measurement of the doses received by workers in 2008, published by IRSN, confirm the drop in the number of monitored workers for whom the annual dose exceeded 20 mSv, as well as the drop in the collective dose, which began in 1996. However, these results do not take account of internal dosimetry and dosimetry of the extremities, which are not at present recorded by IRSN. As it is tasked with organising a permanent radiation protection watch, ASN remains particularly attentive to the correct working of the exposure monitoring system set up by IRSN (SISERI), in that the statistics provided constitute valuable national indicators of trends in worker exposure and are useful in assessing the effectiveness of the measures taken by the licensees to apply the optimisation principle;
– exposure of the French population to radon is at present inadequately documented, as the estimates produced by IRSN in 1997 have never been updated and fail to take account of the measurements taken since 1999 in premises open to the public. During its preparation of the new radon risks national action plan, ASN asked that the possible creation of a database containing all available data on the radon exposure of the public and workers be examined, as ASN considers this to be a necessary step in gaining a clearer understanding of the risk involved;
– finally, ASN underlines the interest of the forthcoming work to be done by the national patient exposure observatory, run by InVS and IRSN, which should soon benefit from the new social security classification of medical procedures and thus allow monitoring of a cohort of 600,000 patients treated by the private sector for the past 20 years.

The Versailles International Conference on Modern Radiotherapy, held in December 2009 by ASN, underlined the need to intensify efforts, both locally and internationally, in the field of recording and analysing treatment side-effects and complications and to develop significant event notification systems for analysis and operating experience feedback purposes. Introduction of the system for notifying serious undesirable events by InVS, interfaced with the radiation protection events notification system implemented by ASN, will constitute very real progress once these effects can be analysed from the medical and scientific viewpoints.

In addition to its regulatory duties, ASN closely monitors developments in research and knowledge in the field of health and ionising radiations, as well as in international radiation protection doctrine. The question of hypersensitivity to ionising radiations, examined at the Versailles international conference, should be given particular attention in terms of applied research so that a patient radiation sensitivity test can be developed rapidly.

More precisely, in 2010, ASN:

– will conduct a review of current research programmes, the results of which could have an impact on the radiation protection system and its regulation;
– will examine the conclusions of the expert reviews it requested on the occurrence of child leukaemia around BNIs and on the environmental impact of tritium discharges.