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 substance 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 radiation is used.

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

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 radiation, 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 radiation on persons directly or indirectly exposed, including through environmental contamination.

Responsibility for supervising the safety of nuclear installations and radioactive substance transports lies with the ministers for the Environment and Industry, while responsibility for supervising radiation protection lies with the Minister for Health and the Minister for Labour.

Decree 2002-255 of 22 February 2002, which created the Directorate General for Nuclear Safety and Radiation Protection, also gave this Directorate - under the authority of the ministers for Health, Industry and the Environment - responsibility for defining and implementing nuclear safety and radiation protection policy. The DGSNR together with the regional offices for which it organises and supervises activities in its area of competence, is referred to as the "Nuclear Safety Authority" (ASN).

1 DANGERS AND RISKS OF IONISING RADIATION

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 lesions, the most important concern the DNA of the cells and are not fundamentally different from those caused by certain toxic chemical substances.

When not repaired by the cells themselves, these lesions 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 become apparent once the quantity of radiation absorbed exceeds a certain dose level, depending on the type of tissue exposed; the effects increase proportionally to the dose of radiation received by the tissue.

Cells can also repair the lesions 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 division to new cells. A genetic mutation is still far removed from transformation into a cancerous cell, but the lesion due to ionising radiation may be a first step towards cancerisation.

The suspicion of a causal link between the occurrence of cancer and exposure to ionising radiation dates from the beginning of the 20th century (observation of skin cancer on radiodermatitis). Since then, several types of cancers have been observed in a professional environment, including leukaemia, primitive bronchopulmonary cancers through inhalation of radon and bone sarcomas. Outside the professional sphere, monitoring of a group of about 85,000 people irradiated in Hiroshima and Nagasaki provided detailed data on induction and mortality from cancer after exposure to ionising radiation. Other epidemiological work, in particular in radiotherapy, highlighted a statistically significant rise in secondary cancers among patients treated using radiotherapy and attributable to ionising radiation. We should also mention 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.

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. We then talk of 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.

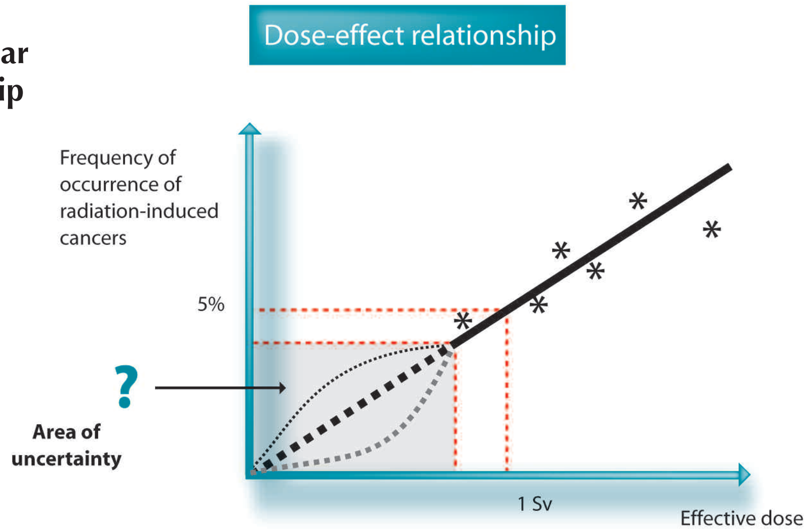
1 | 2

Evaluation of risks linked to ionising radiation

Cancer monitoring in France is based on departmental registers: 10 general registers and 9 specialised registers cover about 15% of the general mainland population and there are also 2 national child cancer registers (hematological malignancy and solid tumours in children), with the aim - as with any monitoring system - of identifying trends in terms of an increase or reduction in the incidence of this disease over a period of time, or of locating clusters of cases in a given region. This intentionally descriptive monitoring method cannot identify radiation-induced cancers, as their form is not specific to ionising radiation.

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 posited 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).

Diagram of the linear relationship without threshold



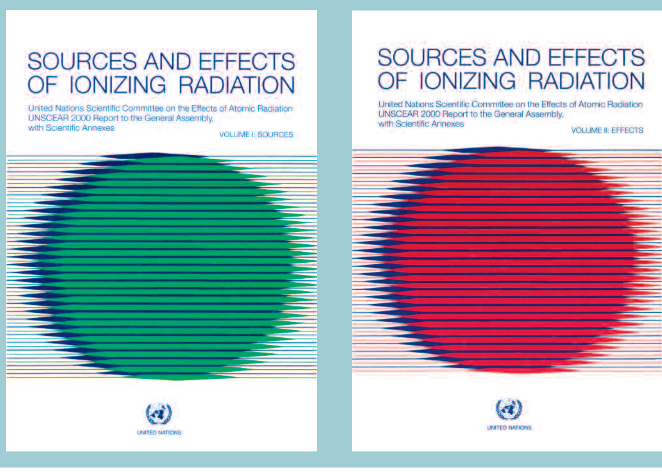
The study from the International Agency for Research on Cancer (IARC), published in the British Medical Journal of 29 June 2005, presents a compilation of the data concerning exposure of workers in the nuclear industries of 15 countries. This study, covering 407,391 workers, is the largest epidemiological study of nuclear workers so far carried out, and shows a calculated rise of 1 to 2 % in the risk of death from cancer. This is the first time that an increase in excess relative risk of cancer has been brought to light by the epidemiology of nuclear workers exposed to low doses of ionising radiation. This result does however confirm the assumption of a linear relationship without threshold with low doses of ionising radiation, on which current radiation protection rules are based.

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. 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 radiation can be calculated, using a linear extrapolation without threshold of the relationship observed at high doses. The legitimacy of these estimates however remains open to debate within the scientific community.

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 radiation on man.

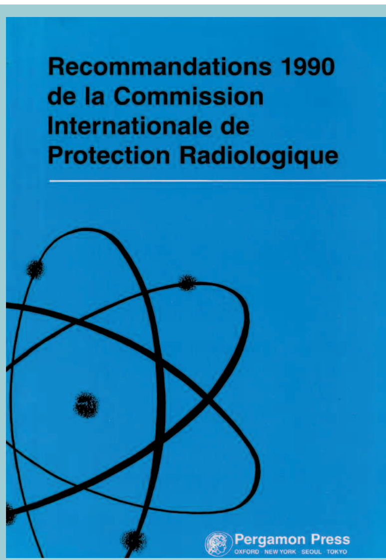
Every 5 years, UNSCEAR publishes a summary of the work conducted internationally in 2 fields: radiation sources (metrology) and the effects of radiation on man (radiobiology, radiotoxicology, etc.) (see next page). The next publication is scheduled for 2006.



UNSCEAR 2000 reports

ICRP

For many decades now, the International Commission on Radiological Protection (ICRP) has been publishing radiation protection recommendations which are usually adopted as the basis for international standards (particularly those issued by the IAEA) and community directives. New recommendations are currently being prepared. After consultation concerning an initial draft in 2004 on its website (www.icpr.org), new proposals were made in 2005 for a publication planned for 2007, following a further consultation. These recommendations will be issued together with fundamental documents concerning the biological and epidemiological bases for risk assessment, the values and units used in radiation protection, characterisation of the reference individual for dose estimates, optimisation of radiation protection and protection of the environment.



CIPR 60

In this context, and on the basis of the scientific work performed by UNSCEAR (see box), the International Commission on Radiological Protection (see ICRP publication 60) published coefficients for the risk of death by cancer due to ionising radiation, identifying a 4% excess risk per sievert for workers and 5% per sievert for the population at large. Use of this model, for example, would lead to an estimate of about 7000 deaths in France every year, as a result of cancer due to natural 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 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 radiation cannot be directly observed through epidemiology; the risk can be calculated if we assume 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 nor zero impact, whether in terms of the doses received by medical or industrial workers, or those associated with releases from BNIs. However, many uncertainties and unknown factors persist and require the ASN to 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.

One can in particular mention six areas of uncertainty:

• *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.

• *Acceptable risk* - Radiation protection does not claim to be able to achieve zero risk for the effects of ionising radiation but simply to keep them below a level felt to be acceptable. The choice of this level is not the result of technical considerations only, but also involves a significant degree of subjectivity: everyone is entitled to have his own view of the acceptable level of risk, and this level can even differ according to the industrial or medical application of the ionising radiation or its natural or artificial origin. The authorities must take account of this social perception when defining public health policy; but to what extent can they differentiate between a dose received by a nuclear worker, and that received by a patient undergoing radiography or a person subject in the home to radon emissions from granite bedrock?

• *Hypersensitivity to ionising radiation* - The effects of ionising radiation on personal health varies from one individual to the next. We have for example known for a long time that the same dose does not have the same effect on a growing child as on an adult, and this has been incorporated into the regulations. However, in addition to these well-known disparities, certain individuals could be hyper-sensitive to radiation owing to deficiencies in their cellular repair mechanisms controlled by the genetic machinery: in any case this is what is indicated by the in-vivo observations made by radiotherapists and the in-vitro observations made by biologists. Delicate ethical questions then legitimately arise, clearly going beyond the framework of radiation protection: for example should one search for the possible hyper-sensitivity of a worker likely to be exposed to ionising radiation? Should the general regulations, for example, provide for specific protection for those concerned by hyper-sensitivity to ionising radiation?

• *Hereditary effect* - 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 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.

• *Dose, dose rate and chronic contamination* - The epidemiological surveys performed on persons 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, 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.

• *Environment* - The purpose of radiation protection is to prevent or reduce the direct or indirect harmful effects of ionising radiation on humans, including through damage to the environment: human protection entails protection of the environment, as illustrated by the impact assessments submitted to the public inquiries prior to granting of BNI discharge licences. 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. On this subject, even more so than those mentioned earlier, defining an acceptable level will be a delicate business. The ASN will therefore closely monitor the work being done on this subject by the ICRP, the results of which could have important repercussions in the regulatory field.

2 Fields of activity involving radiological risks

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 materials for civilian use;
- production and use of ionising radiation;
- radioactive waste and contaminated sites;
- TENORM activities.

2 | 1

Basic nuclear installations

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 permanent nuclear installations, called “Basic Nuclear Installations” (BNIs) are defined by decree 63-1228 of 11 December 1963 which sets the categories:

- nuclear reactors, with the exception of those equipping a means of transport;
- particle accelerators;
- plants for the separation, manufacture or transformation of radioactive substances, 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 substances, 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 substances 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 2005 is given in appendix B.

2 | 1 | 2

The safety of basic nuclear installations

The fundamental principle underpinning the organisational system and the specific regulations applicable to nuclear safety is that of the prime responsibility of the operator. The public authorities see to it that this responsibility is fully assumed, in compliance with the regulatory requirements.
The respective roles of the public authorities and the operator can be summarised as follows:

- the public authorities define the general safety objectives;
- the operator proposes technical procedures for attaining them, and justifies them;
- the public authorities ensure that these procedures are consistent with the goals set;
- the operator implements the approved measures;

– during their inspections, the public authorities check correct implementation of these measures and draw the corresponding conclusions.

2 | 1 | 3

Radiation protection in basic nuclear installations

BNIs are "nuclear activities", as defined by the Public Health Code, but are subject to specific regulation and supervision, owing to the significant risks of exposure to ionising radiation.

The operator is required to take all necessary steps to protect the workers against the hazards of ionising radiation, and more particularly to follow the same general rules as those applicable to all workers exposed to ionising radiation (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.). The operator must also take the steps necessary to attain and maintain an optimum level of protection of the population, in particular by checking the effectiveness of the technical systems implemented for this purpose.

2 | 1 | 4

The environmental impact of basic nuclear installations

Under normal operating conditions, nuclear facilities discharge liquid and gaseous effluent, which may or may not be radioactive. The environmental and health impact of these discharges must be strictly limited.

The facilities must therefore be designed, operated and maintained in such a way as to limit the production of such effluent. It 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, which are the one truly specific aspect of nuclear facilities.

Radiological monitoring of the environment around a BNI

2 | 2

Transport of radioactive and fissile material for civilian 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

Transport of radioactive materials

and must be able to withstand all foreseeable transport conditions;
- the transport medium 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 prime responsibility for implementing these lines of defence lies with the shipper.

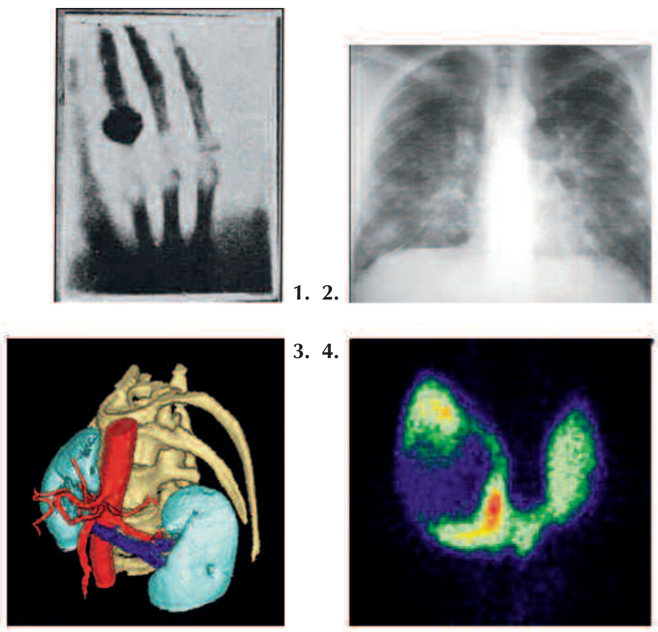
2 | 3

Production and use of ionising radiation

Ionising radiation, whether generated by radionuclides or by electrical equipment (X-rays), is 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 - also considered to be nuclear activities - are the subject of a general system of licences or, as applicable, a special system of licences (case of BNIs, ICPEs and installations subject to the Mining Code) in which, on the basis of information forwarded by the licensee, the various radiation protection related aspects are examined, with regard to protection of both the workers and the population at large. Environmental protection is also taken into account through requirements applied to discharges of liquid and gaseous effluent. In the case of use for medical purposes, patient protection issues are also examined.

For activities other than those subject to the special systems mentioned above, the licences are issued to the persons responsible for use of the ionising radiation. 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 physics expert), technical (premises and equipment conforming to current standards) organisational, or measurements (dosimetry). Some activities (e.g.: radiology facilities) are simply subject to notification.



1. 2.

3. 4.

1. First X-ray produced in 1895 by Wilhelm Conrad Röntgen, reproducing his wife's left hand.
2. Lung radiography.
3. 3D reconstitution of the kidneys, their blood supply and the bones in this region (spine and ribs).
4. Thyroid gland scintigraphy produced after injecting the patient with a radioactive tracer.

2 | 4

Radioactive waste


Radioactive waste packaging

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

For very low level 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 regulatory supervision 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 management channels;
- ensure mastery 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 (interim storage, transport, disposal).

2 | 5

Contaminated sites

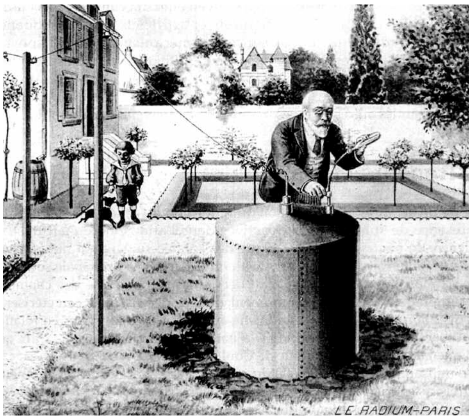
Management of sites contaminated by residual radioactivity resulting either from a past nuclear activity, or an activity which generated deposits of natural radioelements, warrants specific radiation protection actions, in particular if rehabilitation is envisaged. In the light of the current or future uses of the site, decontamination targets must be set and disposal of the waste produced during clean-up of the premises and the contaminated soils must be controlled, from the site up to the storage or disposal location.

2 | 6

Technologically enhanced naturally occuring radioactive materials (TENORM)

TENORM activities justify supervision, and even risk evaluation and management, if likely to generate a risk for exposed workers and, as applicable, the population in general.

Some professional activities which cannot be defined as “nuclear activities” can indeed lead to significant exposure to ionising radiation of the workers and, to a lesser extent, of the populations in the



Ancestor of radon flux measurement in the soil using an accumulation chamber

vicinity of the places where these activities are carried out. This is in particular the case with activities which use materials (raw materials, construction materials, industrial residues) containing natural radioelements not used for their radioactive, fissile or fertile properties. The natural families of uranium and thorium are the main radioelements encountered.

Among the industries concerned, we could mention 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 a precise identification of the activities, estimation of the impact of the exposure on the persons concerned, taking of corrective action to reduce this exposure if necessary, and monitoring.

Targeted on the risk to the population as a whole, but also to workers, monitoring of human exposure to radon in premises open to the public is also a radiation protection priority in geographical areas with a high potential of radon exhalation owing to the geological properties of the site. A strategy to reduce this exposure is necessary if the measurements taken exceed the regulatory action levels defined on the basis of work done internationally. Teaching establishments, health and social care establishments, thermal establishments and penitentiary establishments are primarily concerned by the radon monitoring measures.

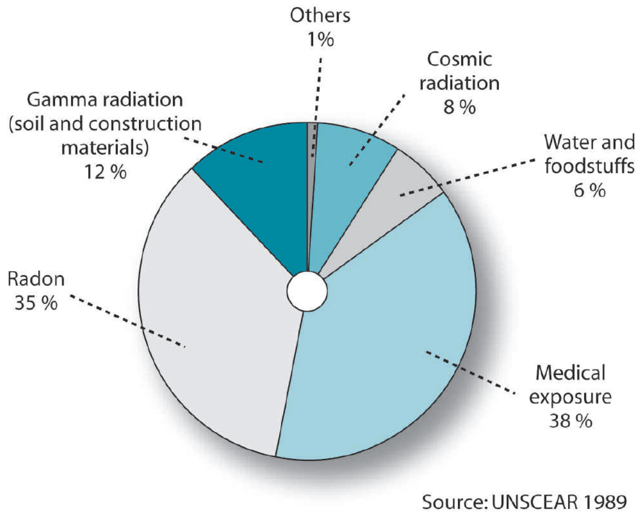
Finally the exposure of aircrews to cosmic radiation, aggravated by prolonged periods at altitude, also warrants dosimetric monitoring.

3 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 recreate the radiation dose to which the persons 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 radiation 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 radiation of natural origin and to radiation created by human activities. The average exposure of the French population is estimated, per inhabitant, at 4 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: National health and environment plan, report by the National Orientation Committee - February 2004). The following diagram represents an estimate of the respective contributions of the various sources of French population exposure to ionising radiation.

These data are mainly extracted from international literature and are too imprecise to allow identification - in each category of exposure sources - of the categories or groups of persons most exposed.



Sources of exposure to radiation for the French population (annual averages)

3 | 1

Exposure of the population to NORM

Exposure of the population to naturally-occuring ionining radiation (NORM) is the result of 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 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 however extremely variable. The highest external exposure dose rates in the open air range in France, depending on the regions, between a few nGy h^{-1} and 300 nGy h^{-1}. The average highest values are observed in the Limousin region (120 nGy h^{-1}), with the lowest in the sedimentary basins (20 nGy h^{-1} in the Bouches-du-Rhône area).

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 (80 and 20% respectively), the average annual effective dose due to external exposure to gamma radiation of terrestrial origin is estimated at about 500 µSv (UNSCEAR, 1993).

The internal exposure through inhalation, owing to air suspension of particles of soil, is estimated at 2 µSv per year, while that due to the long-lived descendents of radon is estimated at about 10 µSv 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 (1993), the average dose per individual is about 50 µSv 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 17 µSv/per year.

Water 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 descendants of uranium and thorium, but also of potassium 40, varies according to the department given 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.

Natural radioactivity of mains water

The new programmes for radiological monitoring of public mains water and non-mineral bottled waters (see chapters 3 and 5) will eventually allow production of a complete balance of the radiological quality of water intended for human consumption, primarily on the basis of total alpha and beta radioactivity measurements. The corresponding information is incorporated into the DDASS health/environment information system (SISE-Eau) and will shortly enable an inventory of the natural radioactivity of mains water to be produced.

Exposure to radon

Exposure to "domestic" radon (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/m^3, with about half the results being below 50 Bq/m^3, 9% above 200 Bq/m^3 and 2.3% above 400 Bq/m^3. These measurements led to a classification of the departments 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 of the doses linked to the actual exposure of the individuals. If we assume a home occupancy ratio of 90%, these values give an average annual dose of 1.5 mSv.

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. The summary of these measurements, published by the ASN in 2003, show that of about 13,000 establishments checked between 1999 and 2001, 12% showed concentrations of more than 400 Bq/m^3 and 4% more than 1000 Bq/m^3. Given the diversity of the length of time for which the premises are occupied, no conclusions could be drawn in terms of exposure.

Measurement of radon in the home

The ASN is taking part in building a new information system designed to collate data on the main pollutants in the home (SISE-Habitat project coordinated by the Directorate General for Health). This project should centralise the radon measurement results for premises open to the public and the information system should come on stream in around 2007.

In order to gain a clearer understanding of the radon doses to which the population as a whole is exposed, a study into the feasibility of incorporating radon measurement into the residential health file required in the event of sale or rental of a property, to ensure fuller information of the purchaser or future tenant, is provided for in the national health and environment plan - PNSE). This study, coordinated by the ASN and the IRSN, should be starting in 2006.

1. IPSN, 1985

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.

If we assume the average time spent inside the home (which itself attenuates the ionic component of the cosmic radiation), the individual effective dose in a locality at sea level in France is 267 µSv per year, whereas it could exceed 1100 µSv per year in a mountain locality such as Cervières at 2,836m altitude. The average annual effective dose per individual in France is 331 µSv per year.

3 | 2

Doses received by workers

3 | 2 | 1

Exposure of nuclear workers

The system of monitoring of external exposure of persons working in facilities where ionising radiation is 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 the 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 exposure doses and the dosimetric results of any internal contamination.

2004 statistics

Results of dosimetric monitoring of worker external exposure in 2004 (source: IRSN)

Total population monitored: 255,321 workers

Monitored population with a recorded dose below the detection threshold: 227,942, or about 89 %

Monitored population with a recorded dose of between the detection threshold and 1 mSv: 15,545, or about 6.1 %

Monitored population with a recorded dose of between 1 mSv and 20 mSv: 11,783, or about 4.6 %

Monitored population which exceeded the annual dose of 20 mSv: 64 including 13 above 50 mSv

Collective dose (sum of individual doses): 63.7 Man.Sv

Annual average individual dose in the population which recorded a non-nil dose: 2.3 mSv

The results of dosimetric monitoring of worker external exposure in 2004 on the whole shows that the prevention system put in place in facilities where sources of ionising radiation are used is effective, because for more than 95% of the population monitored, the annual dose remained lower than 1 mSv (dose limit for the public). However, these statistics do not accurately 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 likely that some workers do indeed fail to wear their dosimeters.

For each field of activity, the following two tables give the breakdown of 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 sector, which accounts for a significant proportion of the population monitored (nearly 45%) only accounts for about 15% of the collective dose. However, it does comprise 32 (out of 51) occasions of

BNI worker dosimetry (year 2004-source: IRSN)

	Number of persons monitored	Sum of doses (Man.Sv)	Doses > 20 mSv
EDF	19,406	9.50	0
COGEMA + MELOX	7,201	1.77	0
CEA	6,600	1.17	0
IPN Orsay	3,132	0.02	0
Outside contractors	31,174	21.63	4

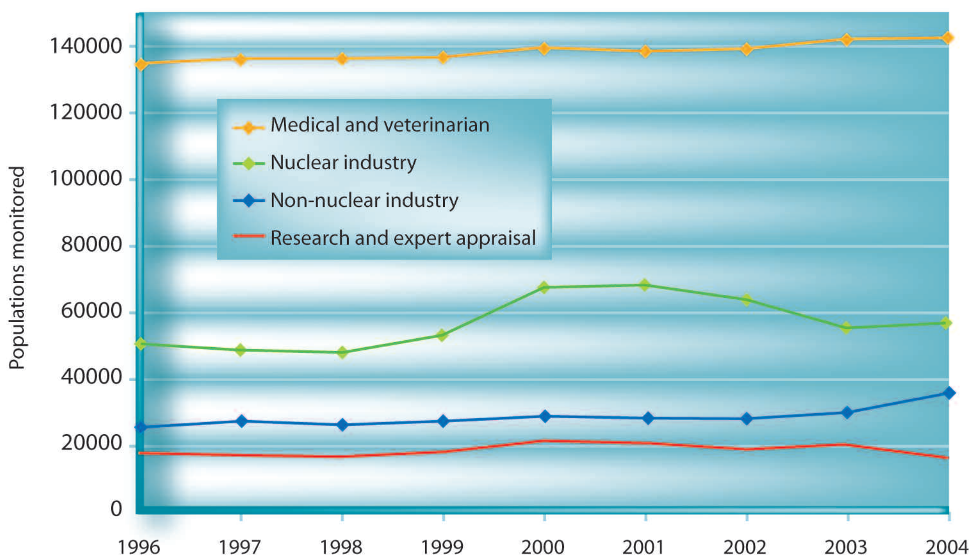
Dosimetry of workers in nuclear-related activities (year 2004-source IRSN)

	Number of persons monitored	Sum of doses (Man.Sv)	Doses > 20 mSv
Medicine	115,578	8.43	32
Dental	23,773	0.49	2
Veterinarians	6,915	0.56	4
Conventional industries	29,174	20.02	9
Research	70,211	0.04	0
Misc.	7,613	0.26	1

the annual limit being exceeded, including 7 (out of 13) above 50 mSv. As a comparison, the collective dose at EDF is of the same order of magnitude, but with a smaller monitored population (7 times smaller), but no occasion on which the annual limit was exceeded.

Evolution from 1996 to 2004

Diagram 1: evolution of populations monitored, per field of activity, from 1996 to 2004



The latest statistics published by the IRSN in December 2005 show relative stability of the populations subject to dosimetric monitoring since 2000 (see diagram 1). However, the collective dose, consisting of the sum of the individual doses, has been falling (about -50%) since 1996 at a time when the populations monitored have grown by about 13%. The optimisation approach implemented by the nuclear operators during the 1990s is no doubt the explanation for this positive trend (see diagrams 2 and 3).

Diagram 2: evolution of the populations monitored and of collective doses, from 1996 to 2004

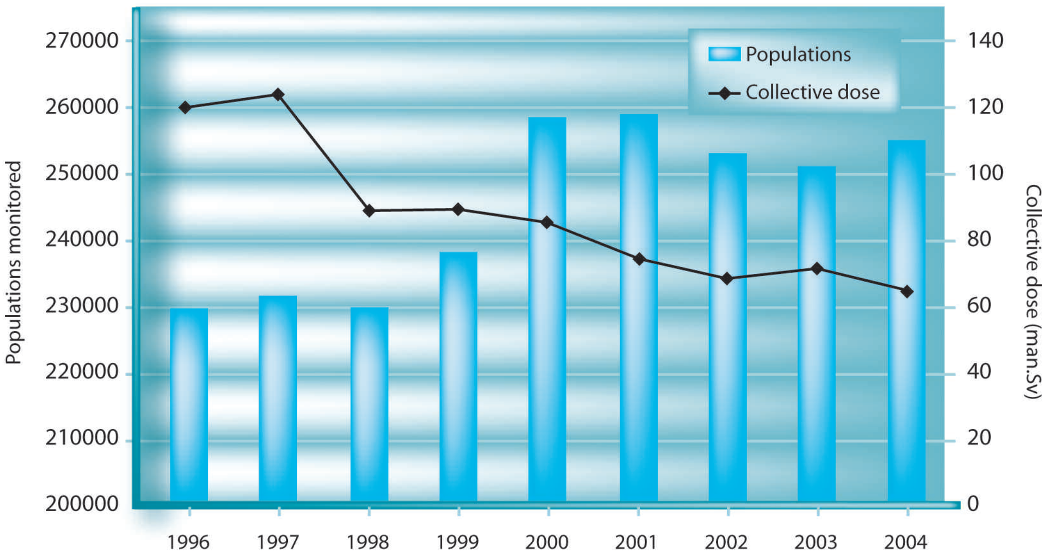
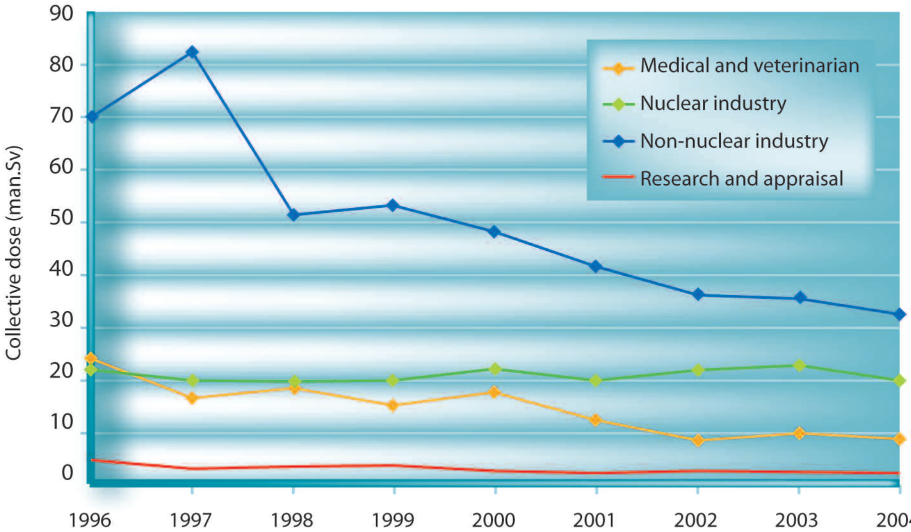
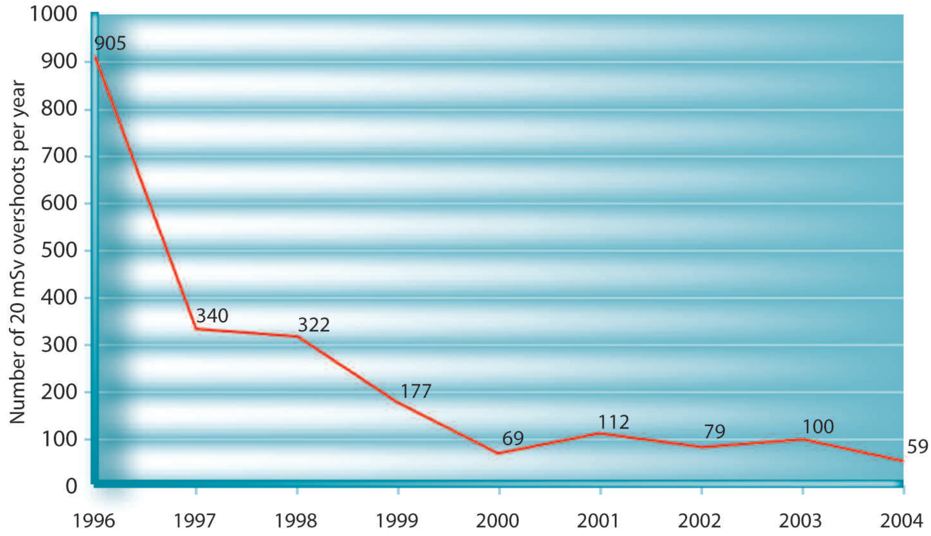


Diagram 3: evolution of collective doses, per field of activity, from 1996 to 2004



The number of monitored workers whose annual dose exceeded 20 mSv has also been falling significantly (see diagram 4). Even though each overshoot leads to a special investigation, jointly with the occupational physician, the variations observed since 2000 are considered to be statistical fluctuations.

Diagram 4: evolution of number of workers monitored for whom the annual dose is higher than 20 mSv, from 1996 to 2004



The ASN is particularly attentive to the correct working of SISERI in that the statistics provided by the IRSN constitute national indicators of choice concerning the evolution of worker exposure and assessment of the effectiveness of the steps taken by the operator to apply the principle of optimisation.

3 | 2 | 2

Worker exposure to TENORM

There is no system for monitoring exposure of persons working in activities which enhance exposure to NORM. The studies so far published show that exposure can range from a few millisieverts to several tens of millisieverts per year. Worker exposure to technologically-enhanced naturally occuring ionising radiation (TENORM) 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). Thus, for example:

• industries handling raw materials that are naturally rich in radionuclides (phosphates, foundry ore, zirconium silicates, dye pigments, rare earths) can lead to annual worker exposure of several millisieverts;

• extraction of oil and natural gas can also lead to annual doses of several millisieverts through irradiation due to the particularly radioelement-rich scale that forms in the pipelines;

• in spas, the high radon content of the water and the poor ventilation indicate that there would be significant doses, both for the personnel and the public coming to take the waters (a bibliographical study by the IRSN of foreign spas shows that annual doses of 10 to 100 mSv are common for the personnel and from 1 to 4 mSv for the members of the public).

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. We therefore estimate that the mean annual dose for "short-haul" crews would 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.

In order to collect data about this natural exposure, an observation system named SIEVERT was set up by the Directorate General for Civil Aviation, the IRSN, the Paris Observatory and Paul-Émile Victor French institute for polar research (www.sievert-system.com).

3 | 3

Doses received by the population as a result of nuclear activities

The automatic monitoring networks managed nationwide by the 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 substances, 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, radioactive effluent discharges are precisely accounted for and radiological monitoring of the environment surrounding the installations is in place. On the basis of the data collected, the dosimetric impact of these discharges on the populations living 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 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 clear knowledge 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. These are in progress within the IRSN at the request of the ASN.

3 | 4

Doses received by patients

We have no system for monitoring patient exposure, in particular because this exposure is not subject to any strict limitation, owing to its medical benefits. It is hard to accurately identify the overall exposure of medical origin, as we do not know the numbers of each type of examination practiced and the doses delivered for the same examination can vary widely. However, global statistics (UNSCEAR 2000 report, volume 1, p. 401) drawn up for 1.53 billion inhabitants of the developed countries (1991-1996 data) indicate an annual effective dose rate per inhabitant of 1.2 mSv for radiology, 0.01 mSv for dentistry and 0.08 mSv for nuclear medicine. In western Europe, for diagnostic radiological imaging, the annual effective dose per inhabitant in France was assessed at 0.7/0.8 mSv, whereas it is 0.33 mSv for the United Kingdom and 1.9 mSv for Germany.

Action plan for monitoring exposure of patients to ionising radiation

Based on recommendations published in 2002 by the InVS, the ASN produced an Action plan at the end of 2003 designed to set up and develop monitoring of exposure of patients to ionising radiation of medical origin (PASEPRI). The multi-year plan was drafted in close collaboration with the relevant departments of the IRSN and the InVS, then submitted to the various institutional partners involved for approval. Implementation of this plan began in 2004.

It is regularly monitored by a committee chaired by the Director General of the ASN.

One of the actions included in the PASEPRI is to have the IRSN and the InVS set up an observatory of medical exposure to ionising radiation, from which the following lessons can be learned (CNAM 2002 data):
– the annual number of radiological examinations (conventional and dental radiology) would seem to stand somewhere between 55 and 66 million, of which 67 % is with conventional radiology;
– the 4 most common conventional radiological 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;
– scanner examinations of the head and spine represent 38 % and 26 % respectively of the total number of scanner examinations;
– the total annual number of conventional radiography examinations (excluding dental) and scanner examinations is between 60 and 72 million, of which 92 % is for conventional radiography alone;
– if we include nuclear medicine and surgical radiology examinations, the total number of examinations (excluding dental) would be somewhere between 61 and 74 million, for an average annual effective dose of between 0.66 and 0.83 mSv.

4 OUTLOOK

In addition to its regulatory and supervisory duties, the ASN closely monitors developments in research and knowledge in the field of health and ionising radiation, as well as in international radiation protection doctrine. More precisely:

a) Implementing a true scientific watch in the field of ionising radiation, in accordance with the recommendations of the Vrousos commission and the national health and environment plan, implies the provision of considerable resources, which are not currently available. In the meantime, the IRSN is required periodically to publish summaries on the research topics on which it is working.

b) Close attention must continue to be paid to the work of the ICRP, which is updating its recommendations published in 1990. New recommendation proposals are expected in 2006. The ASN will therefore closely monitor this work, particularly as the IAEA and the European Commission have announced their intention to conduct a joint updating of the international “basic standards” which underpin community directives and European regulations concerning radiation protection.

c) Exposure 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. Monitoring patient exposure and domestic radon are two priority areas for the ASN:

• thus, the national action plan to identify exposure to ionising radiation of medical origin (PASEPRI) set up by the ASN in 2004, jointly with the IRSN and the InVS, began in 2005 to contribute new and more precise data concerning estimates of the doses delivered to patients. It will continue in 2006, in association with the learned societies concerned;

• furthermore, the ASN is continuing with implementation of the action plan concerning the risks linked to radon in the home. This plan is leading to preparation of the measures necessary for including radon measurement in the residential health file required for real estate transactions. It should eventually contribute to improving understanding of radon exposure in those departments most concerned by this radioactive gas.