Safety and Radiation Protection at Nuclear Power Plants in France in 2015

IRSN’S POSITION
IRSN is a public authority with industrial and commercial activities set up in 2001. Its activities are defined in Law 2015-992 of 17 August 2015 on green growth energy transition. It is supervised jointly by the Ministers of Ecology, Research, Industry, Health and Defence.

As a public expert on nuclear and radiological risks, IRSN, through its research, assessment and monitoring activities, evaluates the scientific and technical issues relating to such risks. The scope of its activities both in France and abroad is wide and varied, and includes the safety of nuclear facilities, transport and radioactive waste, monitoring the environment and the health of workers and patients, advice and response in the event of a radiological risk, and human radiation protection in normal and accident situations. Its expertise also comes into play in similar defence-related activities.

IRSN contributes directly to national policy in the field of nuclear safety, human and environmental protection against ionising radiation, and the protection of nuclear materials, facilities, and transport of radioactive materials against the risks of malicious acts. In this area, it interacts with all the stakeholders concerned by these risks: public authorities, particularly nuclear safety and security regulators, local authorities, businesses, research organisations, associations, and civil society stakeholders and representatives.

Another of its concerns is to keep the public informed by publishing the findings of its work. Through its activities, IRSN is also involved in major public policies in other areas such as research and innovation and occupational and environmental health.

IRSN has a workforce of some 1,800 employees including many engineers, doctors, agronomists, veterinarians, technicians, experts and researchers.

To carry out its work effectively, IRSN has a budget of some €300 million.
Safety and radiation protection require continuous vigilance on the part of all those involved and can never be taken for granted. They must remain an absolute priority to ensure continuous improvement.

For IRSN, achieving this goal implies constantly expanding knowledge gained from two complementary sources, namely research and careful analysis of national and international operating experience feedback. Constantly improving knowledge in this way is essential for performing state-of-the-art nuclear and radiological risk assessments that accurately reflect realities in the field.

As part of its activities, the French Institute for Radiological Protection and Nuclear Safety (IRSN) carries out a continuous technical watch on safety and radiation protection for civil basic nuclear installations and transport of radioactive materials for civilian use in France.

This work involves analysing significant events concerning these installations and transport activities that are reported by licensees to ASN, the French Nuclear Safety Authority. The purpose of this analysis is to draw lessons to provide IRSN with additional feedback. IRSN carries out in-depth analysis of the most important events. It also performs a more general examination of these events to highlight overall lessons and trends and to identify areas for improvement that call for particularly close attention on the part of licensees. The results of these overall analyses are presented in three mission reports:

“IRSN's Position on Safety and Radiation Protection at Nuclear Power Plants in France”, a report published every year since 2008, concerns the 58 nuclear pressurised-water reactors currently operated by EDF.

“Safety at Basic Nuclear Installations other than Nuclear Power Plants: Lessons Learned from Significant Events”, a report published every two years since 2009, concerns nuclear fuel cycle facilities, research laboratories and reactors, radioactive waste treatment, storage or disposal facilities, as well as facilities that have been shut down and are currently undergoing clean-up or dismantling operations.

“Safety of the Transport of Radioactive Materials for Civilian Use in France - Lessons Learned by IRSN from Analysis of Significant Events”, a report published every two years since 2008, concerns the transport of radioactive materials for civil use in France.

As risks relating to nuclear activities are a major concern for the French public, as reflected in the annual IRSN Barometer on the perception of risks and safety, these reports are intended to inform stakeholders and the general public to improve their understanding of concrete issues in safety and radiation protection. With this in mind, the reports also address “general” or “cross-cutting” topics where IRSN’s expertise has helped to enhance safety and radiation protection.
Key events 2015

Main trends in 2015...

As part of its assessment activities, IRSN makes use of the lessons learned from significant safety-related or radiation protection events, particularly based on the reports sent by EDF to the ASN within two months of the event.

Reduction in the number of significant safety events reported in 2015

The reduction in the number of significant safety events (Figure A) already observed in 2013 and 2014 continued in 2015 (down 7% compared to 2014). The strategy used by EDF of analysing each significant safety event in detail in order to learn lessons in terms of identifying the causes and defining the associated corrective actions, seems to be bearing fruit in the long term. However, this hypothesis needs to be confirmed in the coming years if other hypotheses, such as poorer detection of deviations, are to be discounted. Of the 604 significant safety events identified in 2015, 70 were classified as Level 1 on the INES scale and, for the third year running, there were no events at Level 2 or above.

IRSN’s analysis identified the following key points:

- since 2007, the conditions for conducting periodic tests have been defined as part of the project to standardise operating practices and procedures. This led to a reduction in the number of significant safety events between 2010 and 2013 and stability between 2013 and 2014; the figure rose again in 2015 because of errors in the setting up of periodic test conditions. IRSN believes that the benefits of this approach have now reached their limit. In addition, in 2015 the number of significant safety events resulting from failure to carry out periodic tests at the correct frequency continued to increase: this could be due to a lack of care when scheduling periodic tests, tens of thousands of which must be carried out on each reactor every year;

- a slight increase was observed in 2015 in the number of events associated with maintenance non-quality; only a quarter of which were detected as part of maintenance activities. The detection times of these maintenance non-quality events are often too long;

- an increase in the number of system alignment errors was also observed in 2015; these errors could have caused safety-related systems to be unavailable. The most common errors concern the choice of valve to operate, failure to set the valve correctly and operations that do not comply with the operating documents.

Licensees of basic nuclear installations must report to ASN, the French Nuclear Safety Authority, any significant safety or radiation protection events within 48 hours of detection. Significant safety events can considerably affect facility safety. Significant radiation protection events are liable to impair human health through exposure to ionising radiation.

The number of significant safety events each year fell 7% in 2015 compared to 2014.
Some key events in 2015...

IRSN has identified two events that highlight the need to ensure optimum operating conditions for reactors. A brief summary of these events is given below.

Deviation from compliance at CPY-series 900 MW reactors

At the end of 2014, EDF reported a deviation from compliance involving the design of the CCWS1 used for cooling some of the equipment in CPY-series 900 MW reactors. As a result, an earthquake could cause some of the brackets supporting the CCWS pipes to fail, rupturing the pipes.

To prevent the deterioration of the reactor coolant seals2, creating a break in the reactor coolant system, at least one of the following two systems is needed: thermal barriers (devices requiring the availability of the CCWS for cooling the seals) or the injection of cold water into the seals.

In the event of an earthquake, the resulting partial loss of the CCWS would lead to the loss of the CCWS section supplying the auxiliary systems, causing the two systems to shut down and therefore a break in the reactor coolant system. The loss of the CCWS would also lead to a loss of coolant in the spent fuel pool. However, the CCWS trains feeding the engineered safeguard systems would not be damaged and would still be available.

EDF is planning to reinforce the brackets in question; the work should be completed in 2018. In the meantime, EDF must make sure that shutdown of the reactor and the spent fuel pool to a safe state3 is possible in case of an earthquake. The achievement of shutdown requires a means of providing the safety functions: control of core reactivity, removal of the heat produced and containment of the radioactive materials (see Chapter 1 of this report).

1. The CCWS is the component cooling water system (see Chapter 1 of this report).
2. There are three seals that ensure there are no leaks between the reactor coolant pump and the rotating shaft (see description of the three seals – page 41 of the P public report on PWRs for 2012).
3. Safe state: state in which the safety functions are assured in the long term.
To control core reactivity, EDF considers that the injection of borated water from the safety injection system accumulators is adequate. To remove the residual heat from the reactor, EDF plans to restore the water supply to the steam generators using mobile pumping equipment not used in current procedures for abnormal or emergency operation (Figure C).

To manage the spent fuel pool, EDF plans to use the Nuclear Emergency Response Team (NERT) set up as part of post-Fukushima actions.

IRSN took the view that shutdown as envisaged by EDF was possible, but that the demonstration that reactivity could be controlled needed to be substantiated and that the mobile equipment to be used for restoring the supply to the steam generators and its implementation did not meet all the necessary requirements. In addition to consolidation of the above measures, IRSN felt that EDF should be able to guarantee that one CVCS pump* would work properly; these pumps can be lost if the water they are drawing in is no longer cooled by the CCWS. This would provide an additional means of boration and high pressure injection into the reactor coolant system.

In response, EDF submitted a new file (currently being examined by IRSN) in which it asserts that, in an earthquake, the functionality of the automatic control systems not qualified to withstand an earthquake is guaranteed, which would preserve the CVCS pumps.

**Bugey 5 containment leak test**

The leak test carried out on the containment of reactor 5 at Bugey nuclear power plant in 2011, during the third ten-yearly reactor safety review, revealed a higher leakage rate than previous tests. Although the leakage rate observed during the test meets regulatory criteria, the increase indicates that the containment is changing over time. ASN therefore laid down a requirement that the containment should be leak tested again within five years, rather than waiting until the next ten-yearly leak test.

Pressure tests were carried out during the reactor outage for scheduled maintenance and refuelling, which began at the end of August 2015. These tests, which took place in October 2015, revealed that the containment’s impermeability had deteriorated compared with the 2011 test.
The 58 reactors operated by EDF in France are highly standardised: they have the same reactor system (they are all pressurised water reactors or PWRs), their nuclear steam supply system is built by the same constructor; and they have the same industrial architect, which is also a licensee. The PWRs, split into three series (Figure E), therefore share the same design and operating basis.

Chapter 4 of this report presents three important themes, which IRSN assessed in 2015 and presented to the Advisory Committee for Reactors:

- Guidelines for the studies to be carried out for the fourth ten-yearly reactor safety reviews of 900 MW reactors: the examination looked at the programme of action for the fourth ten-yearly periodic safety reviews of thirty-four 900 MW reactors, the first of which will take place in mid-2019;
- Optimising the radiation protection of workers at EDF's power plants: IRSN analysed the appropriateness and adequacy of the organisational measures proposed by EDF as part of its strategy to improve the radiation protection of workers;
- Controlling the activities subcontracted by EDF at PWRs in operation: IRSN’s analysis looked at the measures taken by EDF to control the risks associated with the maintenance of its reactors carried out by subcontractors.

A periodic review consists of:
- an examination to check that the condition of the facility complies with the safety baseline and the regulations in force; this examination is used to deal with any compliance gaps detected;
- a safety review intended to bring the safety level of existing reactors up to that of the most recent ones where possible; the safety review may prompt EDF to revise its reference documents;
- the deployment of improvements resulting from the safety review.

The aim of the periodic safety reviews that have been carried out on power reactors in France for several decades is to guarantee the highest standards of safety at facilities.

Continuous improvement of reactors...

This increase in the leakage rate is thought to be caused by localised deterioration of the metal liner of the containment, which is approximately 6 mm thick. On the basis of the tests and investigations carried out, EDF believes that a likely source of leaks is the area at the bottom of the reactor building, where the base slab of the internal structures meets the truncated part of the containment cylinder (Figure D). This joint, which is approximately two centimetres thick and one metre deep, is filled with a petroleum wax enclosed by sealant and covered with a protective metal plate.

The removal of the petroleum wax enabled almost all of the metal liner around the joint to be examined using an endoscope camera, but this did not reveal any defects or holes in the liner. These inspections are complicated and imprecise because they are carried out in a tight space; the images obtained are sometimes difficult to interpret because of the petroleum wax residues.

At the stage the investigations had reached by the end of 2015, EDF was questioning whether the joint should be filled with petroleum wax, which would not totally prevent the corrosion of the metal liner. EDF concluded that it was necessary to replace the wax with a more fluid product that could be topped up, and would more effectively prevent air and water ingress and therefore the risk of corrosion. In 2016 IRSN will assess the new technical solution proposed by EDF, particularly its ability to restore the containment’s impermeability in an effective and durable way.

Figure E
Three power levels
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The nuclear power plants currently in operation in France comprise a total of 58 pressurised water reactors (PWRs), referred to as “second generation”, by comparison with the European Pressurised Water Reactor (EPR), which is currently under construction and part of the “third generation”.

One specific feature of the French NPP fleet is its standardisation, with many technically similar reactors spread over 19 nuclear sites (Figure 1.1). Each site includes two to six PWRs. The nuclear reactor fleet is divided into three series according to electrical power output:

- The 34 reactors in the 900 MW series include six in the CP0 series (two at Fessenheim and four at Bugey) and 28 in the CPY series (four at Tricastin, six at Gravelines, four at Dampierre-en-Burly, four at Le Blayais, four at Chooz, four at Cruas, and two at Saint-Laurent-des-Eaux).
- The 20 reactors in the 1300 MW series are subdivided into two trains, those in the P4 train (four at Paluel, two at Saint-Alban and two at Flamanville) and those in the P’4 train (two at Belleville-sur-Loire, four at Cattenom, two at Golfech, two at Nogent-sur-Seine, and two at Penly).
- The four reactors in the 1450 MW series, also referred to as the N4 series (two at Chooz and two at Civaux).

The rest of this chapter provides a relatively general and simplified description of the main components of the PWRs operating in France to provide a basis for understanding this report.
General layout

Broadly speaking, a nuclear reactor consists of two parts (Figure 1.2): the “nuclear island”, where nuclear fission produces heat, and the “conventional island”, where that heat is transformed into electric current, and where the facility cooling system is also located.

Nuclear island

In 1300 MW reactors, the nuclear island primarily includes:

- the reactor building (RB) which houses the actual reactor and the entire reactor coolant system, as well as some of the systems that ensure reactor operation and safety;
- the fuel building (FB), which houses, in particular, the facilities for storing and handling fresh fuel (until it is loaded into the reactor) and spent fuel (until it is transferred to the reprocessing plant);
- the safeguard auxiliary building and electrical equipment rooms (SAB/BL), with the main engineered safeguard systems located on the lower level of the building and the electrical equipment rooms (control room and operations facilities, electrical power supplies, and the I&C system of the reactor) on the upper level;
- the nuclear auxiliary building (NAB), which houses the auxiliary systems required for normal reactor operation;
- two physically separate buildings, each housing a diesel generator (backup electrical power supplies);
- an operations building.

Conventional island

- The conventional island equipment converts the steam generated by the nuclear island into electricity and supplies this electricity to the transmission system. The main parts of the conventional island are:
  - the turbine hall, which houses the turbine generator (this converts the steam generated by the nuclear island into electricity) and its auxiliary systems;
  - the pumping station, which cools the facility through the heat sink (river or sea) - this is known as once-through cooling;
  - a cooling tower, if a closed-loop cooling system is used.

Figure 1.2
General diagram of a pressurised water reactor (1300 MW or 1450 MW) and its main systems
Description of a pressurised water reactor

Reactor core

The reactor core is made up of fuel assemblies. Each fuel assembly includes 264 fuel rods, 24 tubes that may contain rods from a control rod assembly and an instrumentation tube. The fuel rods, which are approximately four metres high (this depends on reactor power), are made of zirconium alloy tubes, also called cladding. Pellets measuring 8.2 mm in diameter, and made of uranium dioxide (UO2) or a mix of uranium and plutonium oxides \((\text{U,Pu})\text{O}_2\) are stacked inside the rods, and make up the nuclear fuel. The fuel assemblies are partially renewed during scheduled reactor outages, which occur every 12 to 18 months. The core is placed inside a carbon steel reactor vessel (Figure 1.3) which has a stainless steel liner and a head that is removed for refuelling operations.

Reactor coolant system and secondary systems (Figure 1.4)

The reactor coolant system removes the heat released in the reactor core through pressurised water circulating in the coolant loops. Each loop is connected to the reactor vessel and equipped with a pump (reactor coolant pump), which circulates the heated water in contact with the fuel assemblies towards heat exchangers (steam generators), where the reactor coolant transfers some of its energy to the secondary systems before it is returned to the core. A tank (pressuriser) connected to a coolant loop allows the water to expand, due to its dilation, and controls the pressure (normal operating pressure = 155 bar) to maintain the heated water (in liquid form) at a temperature of more than 300°C in the reactor coolant system.

The secondary systems convert the thermal energy produced by the core into electricity. The (radioactive) water in the reactor coolant system transmits some of its heat to the (non-radioactive) water in the secondary systems in the steam generators; this forms steam, called secondary steam, which expands in a turbine coupled to a generator. On leaving the turbine, the steam is cooled in a condenser. The condenser tubes are cooled either using water drawn from a river or the sea (once-through cooling), or via a tertiary loop where water is cooled by air in cooling towers (closed loop).
The containment building (or reactor building) houses the reactor coolant system, part of the secondary systems, including the steam generators, and a number of safety and operations auxiliary systems.

The reactor building is composed essentially of a concrete cylinder, topped with a concrete dome (the roof of the building), forming a strong barrier built to leaktightness specifications. It prevents radioactive materials from escaping into the outside environment and protects the reactor against external hazards. It is designed to withstand pressures reached during design-basis accidents (4 to 5 bar absolute) and remain leaktight under these conditions. The concrete walls rest on a concrete foundation raft which forms the base of the building.

Main auxiliary systems and engineered safeguard systems (Figure 1.5)

The auxiliary systems contribute to basic safety functions (controlling core neutron reactivity, removing heat from the reactor coolant system, containing radioactive materials and protecting people and the environment from ionising radiation) both during normal operation at power and when the reactor is shut down or restarted.

The main systems concerned are:

- the chemical and volume control system (CVCS), which:
  - adjusts the boron concentration in the water in the reactor coolant system by adding demineralised or borated water according to variations in reactor power;
  - adjusts the water inventory in the reactor coolant system according to temperature variations;
  - maintains the water quality in the reactor coolant system by injecting chemical substances to reduce the corrosion product content of the water;
- the residual heat removal system (RHRS), which, during reactor shutdown, removes the residual heat produced by the fuel assemblies in the reactor vessel and prevents the temperature of the water in the reactor coolant system from rising.
- the safety injection system (SIS), which injects borated water into the reactor core, in particular in the event of a loss of coolant accident, to halt nuclear reactions and maintain an adequate water inventory in the reactor coolant system;
- the containment spray system (CSS) which, in the event of an accident leading to a significant increase in pressure in the reactor building, reduces the pressure and thus maintains containment integrity. The system is also used to remove radioactive aerosols that may be released into this containment;
- the steam generator emergency feedwater system (EFWS), which cools the water in the reactor coolant system if the main feedwater system (MFWS) is unavailable.

Other systems

Other reactor safety-related systems include:

- the component cooling water system (CCWS), which cools some of the safety-related equipment in the CVCS, SIS, CSS and RHRS and ventilation systems;
- the essential service water system (ESWS), which cools the CCWS via the heat sink;
- the fuel pool cooling and purification system (FPCPS), the functions of which include removing the residual heat from the fuel assemblies stored in the spent fuel pool;
- the ventilation systems, which play a critical role in the containment of radioactive materials by placing the rooms under varying degrees of negative pressure and filtering aerosols prior to release;
- fire protection systems;
- the instrumentation and control system and electronic systems.
Overall assessment of safety and radiation protection performance of nuclear power plants in operation

Information related to event reporting

Operating safety: main trends
Radiation protection: main trends

The safety of a nuclear reactor is based on its design and the quality of its construction; the conditions under which it is operated constitute a determining factor in ensuring a continuous satisfactory level of safety and of radiation protection.

IRSN assessment of safety and radiation protection performance at EDF’s nuclear power plants (NPPs) is based on analysis of a large amount of data obtained through continuous monitoring of reactor operation. Data relative to events and incidents affecting foreign as well as French nuclear facilities form one of the key sources of experience feedback from which lessons can be learned.

For an overall perspective on operating safety and radiation protection at EDF NPPs, IRSN has developed tools and methods for analysing operational experience feedback, including indicators it has established itself (refer to the 2007 IRSN public report, page 10). These tools contribute to the identification of both general and reactor-specific trends and any deviations in safety and radiation protection performance.

After some information related to event reporting, the next two sections present the main lessons to be drawn from IRSN’s overall assessment of safety and radiation protection performance for 2015.
Information related to event reporting

Significant events and events of interest

The operator of a basic nuclear facility is required to report any incident occurring in its facility to ASN, the French Nuclear Safety Authority, whether it resulted in radiological impact or not, if it meets the reporting criteria defined in the ASN guide dated 21 October 2005, applicable since 1 January 2006.

Events meeting any of the ASN guide reporting criteria are considered significant in the areas of safety of facilities, radiation protection of workers and members of the public, or the environment; some events may be classified as significant according to criteria defined for one or more of these areas. The term “significant safety event” (SSE) refers to events with a potentially significant impact on NPP safety. The term “significant radiation protection events” (SRPE) refers to ionising radiation exposure events posing a potential threat to the health of exposed persons.

Dealing with events of interest

Events outside the scope of the reporting criteria are recorded by the facility operator as part of experience feedback. These events of interest are not of sufficient immediate importance to justify individual analysis, but their recurrence may be a sign of a problem necessitating in-depth analysis. The information related to these events is available on ASN request to basic nuclear facility inspectors and to IRSN. For each of the areas of safety, radiation protection and environment, the facility operator defines its own criteria for identifying events of interest.

Events of interest may be requalified as significant events after analysis.

INES scale

The International Nuclear and Radiological Event Scale (INES), applied internationally since 1991, was originally used to rate events occurring in nuclear power plants; it has since been extended and adapted to cover all nuclear and radiological events occurring in civil nuclear facilities.

This scale, adopted by more than 70 countries, is intended to help the media and the general public understand the significance of nuclear incidents and accidents in terms of safety. It has seven levels (Figure 2.0).

Events related below scale/level 0 concern deviations from normal operation of the facilities; they have no safety significance.

- Major accident
- Serious accident
- Accident with wider consequences
- Accident with local consequences
- Serious incident
- Incident
- Anomaly

Figure 2.0
The INES scale severity levels

BELOW SCALE/LEVEL 0
NO SAFETY SIGNIFICANCE
The overall assessment conducted by IRSN

Significant events are analysed as part of the general review of experience feedback from NPPs. Each significant event is reviewed by IRSN and discussed at technical level between EDF and IRSN in order to identify lessons at national and even international level.

The overall assessment of experience feedback by IRSN takes account of all significant safety-related and radiation protection events reported by EDF, as well as all reports on the inspections conducted by ASN with IRSN support in nuclear power plants, and the information obtained from EDF reactor operation monitoring and from certain events of interest for safety and radiation protection.

The assessment is based on experience feedback tools and analysis methods developed by IRSN, including indicators intended for overall assessment of changes in factors contributing to facility safety and worker radiation protection; these indicators cannot determine the causes of the changes, but they throw light at macroscopic level on the trends that are identified and highlight the areas that would merit more thorough review by EDF.

For 2015, the IRSN position on the safety and radiation protection trends of the operating NPPs was the subject of a notice to ASN – no. 2016-00271.

Operating safety: main trends

The annual number of significant safety events concerning EDF reactors fell by 7% in 2015. In 2015 again, half of these significant events involved non-compliance with the operating technical specifications. Furthermore, the quality of the maintenance activities was not at the required level, one reason being often-incomplete risk analysis. Improved control of these activities consequently remains a major objective for EDF. Inspections in 2015 also showed a habituation to deviation which necessitates a firm reaction by the plant operators in order to maintain the conformity of the facilities.

The reduction of the number of SSEs observed since 2013 continued in 2015

In 2015, 604 significant safety events (SSE) were reported by EDF (Figure 2.1); thus, on average about 10 SSEs were reported for each reactor, compared with a little more than 11 in 2014, 12 in 2013 and 12.5 in 2012. The method deployed by EDF for in-depth analysis of each SSE, in order to draw lessons from them in terms of identification of causes and definition of the associated corrective actions seems to be bearing fruit lastingly. However, this assumption will have to be confirmed over the coming years, if only to set aside other possibilities such as less effective detection of deviations.

Of the 604 SSEs reported in 2015, 70 were rated at level 1 on the INES scale and, for the third consecutive year, no event was rated at level 2 or higher.
For IRSN, the number of event reports can be indicative of issues that need to be understood and analysed as warning signals in order to identify relevant preventive actions contributing to improvement of plant safety. The number of significant events cannot on its own serve as a quantifying measure of good operating practice applied to the operating NPPs. Variations in this number cannot be linked directly with a variation in safety level.

Breakdown of the number of SSEs in 2015 by reporting criterion (Figure 2.2) shows that half of the SSEs involved non-compliance with the operating technical specifications (criterion 3). Criterion 10 was the second criterion most used by the plant operators (28% of the SSEs). The events defined by the other eight criteria accounted for 22% of the total number of reported SSEs.

Trend analysis of the safety indicators by IRSN in 2015 highlights a certain typology described in detail below.

**Increase in the number of SSEs related to periodic tests**

The definition of the periodic test schedule (including the periodicity and conditions of each periodic test) and compliance with the criteria set out in the general operating rules are crucial. Since 2007, the periodic test conditions have been drawn up as part of the operating practices and procedures standardisation project (\[1\] refer to the 2013 IRSN public report, page 28). After a trial period, this new approach led to a reduction in the number of events between 2010 and 2013 and stability between 2013 and 2014; an increase was observed in 2015, due to errors in the conditions for performing periodic tests (13 in 2014 and 19 in 2015) (Figure 2.3). IRSN considers that the benefit of the new approach seems to be

![Figure 2.2](image-url)

**The ten criteria for reporting significant safety events (SSE)**

| SSE 1 | Automatic reactor trip |
| SSE 2 | Activation of an engineered safeguard system |
| SSE 3 | Non-compliance with operating technical specifications |
| SSE 4 | Internal or external hazard |
| SSE 5 | Malicious act (or attempt) potentially affecting facility safety |
| SSE 6 | Transition to fallback state in accordance with operating technical specifications or emergency operating procedures in response to unexpected plant behaviour |
| SSE 7 | Event that caused or could cause multiple failures |
| SSE 8 | Event or anomaly specific to the main primary or main secondary cooling system, or pressure vessels in systems connected to them, resulting or potentially resulting in an operating condition that was not considered during design or is not covered by existing operating procedures |
| SSE 9 | Design, manufacturing, installation or operating fault concerning functional systems and equipment not covered by criterion 8, resulting or possibly resulting in an operating condition that was not considered at the design stage and is not covered by design basis conditions and existing operating procedures |
| SSE 10 | Any other event likely to affect the safety of the facility and considered significant by the licensee or ASN |

The reduction of the number of SSEs observed in 2013 and 2014 continued in 2015.
Overall assessment of safety and radiation protection performance of nuclear power plants in operation

Safety and radiation protection of the French nuclear power plant fleet in 2015

Reaching its limits; EDF must be vigilant on this point.

Also in 2015, the number of SSEs due to non-compliance with periodic testing continued to increase (29 in 2015, 27 in 2014, compared with 20 in 2013). (Figure 2.3): this may result from a decrease in vigilance in periodic test planning. However, this conclusion must be tempered by the large number of periodic tests that must be performed on a reactor (several tens of thousands per year). Nevertheless, it is important that the periodic tests be carried out in accordance with their schedule, in order to ensure compliance with the safety demonstration. According to IRSN, plant operators must check the scheduling of the periodic tests and identify and implement the measures preventing scheduling errors.

Weak signals: information that announces a change in trend and which must trigger an analysis of additional information in order to confirm it and enable introduction of corrective actions.

The number of maintenance non-quality remains high, and EDF must continue its actions intended to reduce the number of observed deviations.

Maintenance non-quality (MNQ) concerns errors committed during equipment maintenance work (insufficient torqueing, inappropriate spare part, part fitted the wrong way round, etc.). This indicator records the number of events for which subsequent analysis by the plant operator revealed an error of application of the operating documents or non-compliance with good practice in a maintenance operation. This error is the source of an anomaly in the facility.

Inappropriate maintenance or equipment modification actions

After a fall in the number of maintenance-related events observed in 2014 (88 events), a small rebound was observed in 2015 in the number of events related to maintenance non-quality (MNQ) (93 events) (Figure 2.4). EDF must consequently continue its actions intended to reduce the number of deviations observed.

Maintenance non-quality detection times too long

An important aspect of the MNQs analysed by IRSN concerns the times to detection of anomalies by EDF: 50% of MNQs are detected within one month, 22% of MNQs have a latency between one and six months and 8% of anomalies are still present after three years (Figure 2.5). For IRSN, the detection time is still too long.

In addition, only a quarter of MNQs are detected during maintenance operations, mainly during requalifications; the remaining three-quarters are detected by chance, i.e. not during maintenance operations, for example during normal control operations.

For IRSN, the increase in the number of MNQs and the low detection rate of MNQs by maintenance activities reveal deficiencies in taking account of weak signals.

In view of the safety issues associated with MNQs, for several years EDF has been undertaking actions intended to improve the reliability of maintenance operations, during both preparation and execution. Nevertheless, the results are not yet at the required level, in particular because too many such events originate in an often-incomplete risk analysis.

Stability of the number of deviations from the authorised operating domain

In 2015, the number of deviations from the authorised operating domain returned to its 2012 level: only just over thirty events involved unintentional deviation beyond the limits assigned to physical parameters in the authorised operating domain (Figure 2.6).

This gives an average of 0.5 SSE per reactor per year. It should be noted that, over the last two years, the durations of deviations from the authorised operating domain have remained short: such events are detected and corrected in less...
The water spray valves in the pressuriser are controlled by the pressuriser pressure control system in order to maintain the pressure in the reactor coolant system at a pre-set value. They are never fully closed: a stop ensures a continuous spray flow rate.

A periodic test by the operations department makes sure that, when the valve is on its stop, the flow rate is sufficient to supply water spray in the pressuriser.

Deviations from the authorised operating domain are detected and corrected in less than five minutes on average over the NPP fleet.

The authorised operating domain includes various operating modes ranging from reactor shutdown to power operation. Each operating mode is associated with technical operating specifications that define all the operating requirements and limits to be observed (pressure, temperature, boron concentration, water level, etc.) and all the essential equipment required to maintain the reactor in a safe state in accordance with safety demonstration criteria.

It is strictly forbidden for operators to deliberately deviate from a reactor’s current authorised operating mode without meeting the applicable requirements for changing the reactor state. In the event of inadvertent deviation from an operating mode, the operator must take all necessary measures to return the reactor to its initial state or to return to a correct situation as soon as possible.

Example of a deviation from authorised operating domain

One such event in 2015 was particularly notable. It occurred at the Dampierre-en-Burly nuclear power plant, following a maintenance non-quality, leading to deviations from the domain and necessitating fallback of reactor 2.

On 20 May 2015, during restart of reactor 2, the periodic test of Operations was unsatisfactory, necessitating readjustment of the stops of the water spray valves in the pressuriser.

On 4 June 2015, a periodic test of the spray valves, consisting in opening then closing both of the valves, was carried out. Following this test, the spray valves did not close fully, resulting in a decrease in reactor coolant system pressure and deviation from the authorised domain (pressure below the low limit). Investigations incriminated the spray valves. Fallback was initiated in application of the procedure to be followed stipulated by the operating technical specification.

The team running the test, which had never carried out this operation, made a mistake when adjusting the stop, even though the operation file was adequate: the consequence of this error was that the spray valve could not close fully after its actuation. After debriefing with the team leader, the periodic test of Operations was declared satisfactory.

Deviations from the authorised operating domain

than five minutes on average over the operating NPPs. In most cases, deviations from the authorised operating domain involve overshoot/undershoot of primary coolant pressure and temperature limits. The main causes are related to human error during sensitive phases of manual control of the reactor from the control room.
System alignment consists, for example, in opening or closing valves and switching equipment on or off to create a circuit suitable for performing the functions required in a specific operating state. System alignment may be necessary in order to perform maintenance work, test a system to ensure its availability, or change the reactor state. It is carried out tens of thousands of times each year at facilities in France.

Administrative lockouts are physical lockouts, i.e., padlocks and chains installed on the equipment.

Fallback initiation

Any failure or sign of malfunction affecting safety-related equipment is detected by monitoring carried out while the reactor is in operation. The operating technical specifications require the plant operator to return the reactor to a safer state (fallback state) than when the anomaly was detected, depending on the seriousness of the situation. Fallback initiation is the first of the operations designed to bring the reactor to the fallback state. It is preceded by a period called the “initiation period” which enables the plant operator to either resolve the anomaly or implement palliative measures to maintain the reactor in its initial state, or prepare fallback if the anomaly cannot be resolved or compensated for within this period.

Several deviations from the domain occurred during the reactor fallback. The shift crew considered that the normal operating procedures would not enable compliance with reactor coolant system pressure limits and decided to apply the abnormal operating procedures. At noon the next day, the reactor had reached the fallback state and the crews resumed the normal operating procedures. This event was rated Level 1 on the International Nuclear Event Scale.

The management of the Dampierre-en-Burly NPP has implemented actions to prevent recurrence of this event, in particular training courses for the personnel involved. The operation file and the diagrams have been improved, and an operational experience feedback analysis sheet describing the adjustment of the valve stops for future operations has been drafted.

Increase in the number of alignment errors

Despite several local and national action plans, the number of SSEs reported following alignment errors increased by almost 30% between 2013 and 2015, from 36 in 2013 to 46 in 2015. These events could have resulted in unavailability of the reactor systems, including safeguard systems.

The most common errors include errors in the choice of valve to operate, failure to set the valve correctly and operations that do not comply with the operating documents. One of the difficulties in system alignment tasks is that the representation of the state of the facility available to the technicians assigned to the tasks is fragmented and is not updated in real time.

The preparation of an alignment operation and constant communication between the technicians and the control operators play a determining role in successful completion of alignment tasks. However, the large majority of system alignment tasks must be performed by technicians in the rooms containing the equipment, which makes it difficult for the operators in the control room to monitor and immediately test their actions. In view of this situation, EDF has implemented action plans, without any real progress observable at present.

2015 saw a significant decrease in the number of alignment failures managed by administrative lockouts, from around twenty events to less than fifteen events for 2015. The downward trend is a positive point, as administrative lockouts are a strong line of defence during operation of an NPP: any omission or error in the application or removal of an administrative lockout generates risks, as some systems or protections might not be able to fulfil their function.

Reduction of the number of fallback initiations not performed

The annual number of fallback initiations (Figure 2.7) demonstrates the impact of operation contingencies that require reactor fallback in application of the operating technical specifications (OTS) in order to maintain satisfactory safety levels.

A fallback initiation that is not performed is a noncompliance with the OTS, and may be due to various reasons: incorrect diagnosis of the detected deviation, time allowed for restoring compliance elapsed, or conflict between facility safety and availability.

The annual number of reactor fallback initiations not performed decreased, four in 2015 compared with eight in 2014. Three of the four fallback initiations not performed in 2015 were identified as events of particular interest from the IRSN point of view:

- two for the organisational aspect: a large number of organisational lines of defence did not operate;
- one related to a safeguard function: unavailability of automatic
isolation of the water reserve (RWST of the reactor building and fuel building fuel pool cooling and purification system) on a safety injection signal in recirculation phase.

**Notable events for IRSN²**

Two events in 2015, were particularly revealing of problems in the management of technical contingencies during reactor shutdown or restart. The events occurred in the Flamanville and Gravelines NPPs.

The Flamanville NPP has experienced a high number of equipment failures affecting reactor 2. Among these failures, an unexpected problem on the auxiliary transformer was the starting point for four consecutive significant events over the period from October to December 2015. In order to stop the repeated failures of the auxiliary transformer, EDF decided to replace it in January 2016. These events highlight a lack of organisation of the plant regarding the management and fitting of replacement parts and the control of subcontracted maintenance activities.

The second notable event in 2015 concerned reactor 2 of the Gravelines NPP. During a refuelling outage, components of the two steam inlet valves of the steam generator emergency feedwater system turbine-driven auxiliary pump were replaced. During the periodic test of the reactor protection system when the reactor was being restarted, these two valves were not actuated. The analysis of the causes of this event provided evidence of inadequate preparation and control of the maintenance operations carried out and revealed the risks related to work on “redundant” equipment (poor scheduling of maintenance work on these valves leading to a common mode failure). To avoid recurrence of this event, the plant operator has decided to alternate work on identical equipment from one outage to another.

**Non-compliance with fire risk management requirements**

Three events that occurred in 2015 were particularly rich sources of information concerning taking into account fire-related risks during maintenance activities.

The first event occurred in October 2015 at the Chinon B NPP: it concerned a fire outbreak in an electrical cabinet of the AC generator exciter in the turbine hall, initiated following replacement of electronic modules to remedy connection faults. When the cabinet was powered up again, a major fire started, attended by 31 fire brigade personnel. A reactive inspection conducted by ASN with IRSN support provided evidence that similar events had occurred in 2006. One of the main conclusions of this inspection concerned the sensitivity of the switchgear involved to fire. The inspection identified deficiencies in the assimilation of the 2006 experience feedback, which would have enabled the plant operator to identify the activity as sensitive and to define appropriate countermeasures preventing the occurrence of this event.

The second event occurred in July 2015 on reactor 2 of the Paluel NPP, and concerned a titanium fire in the condenser located in the turbine hall. The condenser was undergoing a major renovation of its tube bundle, consisting of thousands of titanium tubes. When the tubes were being cut using a plasma torch, titanium dust ignited; a fire started and propagated to the condenser tubes, resulting in the first metal fire recorded in the EDF NPP fleet. A reactive inspection identified deficiencies in the risk analysis of this complex condenser renovation work, along with inadequate allowance made for work by other contractors and interactions between the different work programmes over an extended period.

The third event occurred in September 2015 on reactors 4 and 5 of the Bugey NPP. This event showed that new organisational practices of hot-work permit verification and fire detection system management may be detrimental to safety. Hot-work permits and fire detector inhibitions and returns to service were managed by a person who was not a member of the Operations department.
In practice, during working hours, the control room operators no longer checked the hot-work permits or inhibited the detectors from the fire control centre electronic supervision unit. However, the inhibitions of certain fire detectors in a given area are processed in the context of the operating technical specifications, which require a human presence in order to detect any fire outbreak in that area.

The organisation in place at Bugey did not enable the shift crew to ensure proper application of the operating technical specifications: on three occasions, the generated inhibitions were not identified by the operators in the control room. The stipulated procedure to be followed (specific monitoring rounds) was not complied with.

For IRSN, EDF must make sure that the various hot-work permit verification and fire detection system management practices remain activities restricted to the EDF shift crews and must not be delegated to contractor personnel who have not necessarily received the appropriate training.

Deviation management

Deviation management is described in the INB order of 7 February 2012: Articles 2.6.2 and 2.6.3 cover the investigation and processing of deviations. They define a deviation as follows: “non-compliance with a defined requirement (in the regulations applicable to basic nuclear facilities), or non-compliance with a requirement defined by the integrated management system of the plant operator potentially affecting the provisions cited in the second paragraph of Article L. 593-7 of the French environmental code (demonstration of protection of interests)”. 

Inhibitions: inhibitions of automatic fire detectors, necessary during maintenance work involving welding or grinding operations, prevent inadvertent actuation of the detectors by smoke or dust generated by the work. Fire watch in the rooms concerned is then carried out by the personnel.

The inspections in 2015 highlighted a process of habituation to deviation: justifications were generally given preference to the detriment of immediate restoration of the compliance of the facility.

Independent Safety Review Team (FIS):

The FIS brings together all the safety engineers of the site, who must in particular:

- verify the state of safety of the facilities in real time and off-line;
- perform analyses of observed malfunctions or of deviations and incidents related to the safety of the facilities, independent of the analyses performed by the site operational departments.

Deviation management

Inspections conducted by ASN with IRSN support in 2015 have provided evidence of a number of deficiencies in the management of deviations by the plant operators. These deficiencies prevent the plant operator from obtaining a complete view of the deviations in its facilities and of the state of progress of their processing. Consequently, this situation could result in an incorrect assessment of the state of safety of the facilities.

Furthermore, the inspections in 2015 on the compliance gaps highlighted a process of habituation to deviation: justifications were generally given preference to the detriment of immediate restoration of the compliance of the facility. For this reason, IRSN considers it necessary that, in the short term, EDF conduct an audit of deviation management on each site by the Independent Safety Review (FIS) team or the EDF Nuclear Inspectorate (for further information, refer to notice IRSN-2016-00271).
Radiation protection: main trends

The annual number of significant radiation protection events concerning workers at EDF reactors fell by 5% in 2015. IRSN noted a reduction of the number of events related to orange and red regulated area access conditions: the actions implemented by EDF, which seem to have had a positive effect, must nevertheless be continued. An increasing number of events were related to inadequate application of the basic rules of radiation protection: forgetting to wear a dosimeter, non-application of the procedure to be followed when a dosimeter alarm limit is reached, etc. IRSN also stresses that, as in 2014, skin contamination events have resulted in the statutory limits for equivalent dose to the skin being exceeded.

Decrease in the total number of SRPEs reported in 2015

Over the period considered, the number of significant radiation protection events (SRPE) reported by EDF (Figure 2.8) has decreased (104* SRPEs in 2015, compared with 110 in 2014, 119 in 2013 and 112 in 2012).

Most of this decrease in 2015 was observed in the following categories (SRPE types ringed with green in Figure 2.11):

- reduction of the number of events related to exceeding the intervals between statutory mapping operations or between checks on individual (radiometers or dosimeters) or collective (radiation monitors) monitoring devices.

In contrast, 2015 also saw an increase in the number of deviations related to personnel dosimetry, concerning in particular failure to wear an operational or passive dosimeter (SRPE type ringed in red in Figure 2.11), already stressed by IRSN in the report for 2014 (P refer to the 2014 IRSN public report, page 24).

Three SRPEs were rated at level 1 or 2 on the INES scale in 2015. All three of these SRPEs concerned skin contaminations resulting in exceeding of the statutory limit on dose to the skin (one SRPE at level 2, described in chapter 3 of this report) or in exceeding one-quarter of this limit (two SRPEs at level 1).

Radiologically-controlled area: An area that is subject to special regulations to ensure protection against ionising radiation and containment of radioactive contamination. Access to the area is controlled. Dosimeters must be worn inside the area.

6. IRSN data
In 2015, a decrease in the number of events related to non-compliance with the conditions of access to orange or red regulated-access areas was observed. EDF analysed the circumstances and the causes of each of the reported events, together with their actual and potential radiological consequences. EDF then identified and implemented corrective measures to prevent such events recurring.

**SRPE breakdown by reporting criterion**

The regulations on worker protection against the hazards of ionizing radiation require basic nuclear facility operators to report significant radiation protection events (SRPE) to ASN. Such events are reported according to the reporting criteria defined by ASN.

In 2015, 1047 SRPEs were reported by EDF. Most of the event reports in 2015 according to the ASN criteria (Figure 2.10) concerned various significant non-compliance (criterion 10) and non-compliance with controlled area access conditions (criterion 7), which accounted for 46% and 30% of the SRPEs, respectively. The events defined by the other eight criteria accounted for 24% of the total number of reported SRPEs.

**Typology of the reported events**

For its trend analysis, IRSN reviewed the SRPEs and grouped them by type (Figure 2.11). In particular, IRSN analysed the causes and corrective measures related to the types of event that occurred in the highest numbers or that resulted in the most serious actual or potential consequences.

In 2015, a decrease in the number of events related to non-compliance with the conditions of access to orange or red regulated-access areas was observed. Implementation by EDF of operational action plans related to making of and access to orange regulated-access areas (Figure 2.9) seems to have had a positive effect on the trend in the number of events of this type.

**The ten criteria for reporting significant radiation protection events (SRPE)**

<table>
<thead>
<tr>
<th>SRPE</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRPE 1</td>
<td>Non-compliance with regulatory annual individual dose limit requirements, or unexpected situation with potential to cause such non-compliance under plausible representative conditions, regardless of exposure type (including body contamination)</td>
</tr>
<tr>
<td>SRPE 2</td>
<td>Unforeseen situation leading to a 25% overshoot of a regulatory annual individual dose limit value, regardless of exposure type (including body contamination)</td>
</tr>
<tr>
<td>SRPE 3</td>
<td>Any significant non-compliance with radiological cleanliness standards, in particular the presence of contamination sources exceeding 1 MBq, outside radiologically controlled areas, or detection of contaminated clothing (&gt; 10 kBq) by C3 monitors or during whole-body radiation dosimetry</td>
</tr>
<tr>
<td>SRPE 4</td>
<td>Any significant activity (operation, task, modification, inspection, etc.) posing a radiological risk, conducted without radiation protection assessment (justification, optimisation, mitigation) or exhaustive consideration of such assessment</td>
</tr>
<tr>
<td>SRPE 5</td>
<td>A malicious act or attempt liable to impact the protection of workers or members of the public from ionising radiation</td>
</tr>
<tr>
<td>SRPE 6</td>
<td>An abnormal situation affecting a sealed or unsealed source with an activity level higher than the exemption limits</td>
</tr>
</tbody>
</table>
| SRPE 7 | Signage error or failure to comply with technical conditions for access to or spending time in an area subject to special regulations or prohibited area (orange and red areas or gamma radiography inspection areas)  
7a Inadequate marking or signalling  
7b Other non-compliances |
| SRPE 8 | Uncompensated failure of collective radiological monitoring systems |
| SRPE 9 | Inspection of a fixed collective radiation monitor more than a month late (regulatory inspection frequency of one month for fixed systems) or more than three months late for other types of monitor (when the inspection frequency defined in the general operating rules is between 12 and 60 months) |
| SRPE 10| Any other deviation of significance to ASN or the licensee |
however, these actions must be continued, as there are still too many such events.

**Inadequate application of the basic radiation protection rules**

The regulations require the wearing of passive and operational dosimeters (Figure 2.12) by workers entering controlled areas: an increasing number of events show inadequacies in the application of the basic radiation protection rules (forgetting to wear dosimeters, non-application of the procedure to be followed when a dosimeter alarm limit is reached, etc.).

In 2013 and 2014, half the events related to failure to wear dosimeters concerned responses to emergency situations (responses by gendarmes or fire brigade personnel).

In contrast, in 2015 only 2 out of 22 events were attributable to such emergency responses; most of the other 20 involved leaving the dosimeter in the hot changing room when changing into in standard suits, and more than half of these were detected by personnel external to the work (risk prevention department personnel, changing room attendant, etc.). In some cases the workers concerned worked without noticing their omission for longer than an hour on one of the activities identified as having the highest radiological exposures (installing heat insulation, waste sorting, work on valves, etc.).

The main causes identified in the event reports drafted by the plant operators were:

- the ergonomics of the changing room or the difficulty accessing the “t’as tout?” (Got everything?) board when the changing room is very busy (low visibility of the “t’as tout?” notice board). The “t’as tout?” board has a checking mirror prompting the workers to check that they have not forgotten anything before they enter a controlled area (Figure 2.13);

Inadequate risk analysis
Contamination outside controlled area
Radiation-contaminated clothing
Radioactive source management error
Personnel dosimetry
Radiological cleanliness/worker contamination
Radiological monitoring
Gamma radiography inspection
Training/certification

**Figure 2.11**

**Variation in the number of SRPEs by type**

**Personal dosimetry**

Personal dosimetry comprises external and internal dosimetry. **External dosimetry** involves measuring the doses received by a person exposed to a field of radiation generated by a source outside the individual in question. The dosimeters worn by workers are designed to show the dose to the whole body, either by having the dose read at an approved laboratory at a later date (passive dosimetry), or in real time (operational dosimetry). Operational dosimeters have an audible and visual alarm that alerts workers if they are in a field of radiation that exceeds certain thresholds preset to detect abnormal situations. **Internal dosimetry** measures the dose received as a result of incorporating (inhaling or ingesting) radioactive materials. This type of dosimetry involves whole-body radiation measurements (direct measurement of internal contamination) and radiotoxicological tests.

**Figure 2.12**

Operational dosimeter
**Overall assessment of safety and radiation protection performance of nuclear power plants in operation**

**Safety and radiation protection of the French nuclear power plant fleet in 2015**

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A permanent reminder of the controlled area access requirements is necessary in order to maintain the vigilance of the workers and prevent trivialisation of the risk.

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### Effective and equivalent doses

The effective dose is used to estimate whole-body radiation exposure. It factors in the sensitivity of the different types of body tissue as well as the specific type of radiation (alpha, beta, gamma, neutron). The radiation exposure of individual organs is called the equivalent dose. These doses are expressed in sieverts (Sv).

**REGULATORY DOSE LIMITS:**

- For members of the public, the effective dose limit is 1 mSv/year (excluding natural and medical radiation exposure).
- For the workers most exposed, the statutory dose limits over a period of 12 consecutive months are:

<table>
<thead>
<tr>
<th>Organ</th>
<th>Effective Dose Limit (Sv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole body</td>
<td>20 mSv</td>
</tr>
<tr>
<td>Extremities (hands, forearms, feet and ankles)</td>
<td>500 mSv</td>
</tr>
<tr>
<td>Skin</td>
<td>500 mSv</td>
</tr>
<tr>
<td>Crystalline lens</td>
<td>150 mSv</td>
</tr>
</tbody>
</table>

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### Worker contaminations reaching the statutory exposure limits

Since 2012, on average two skin contamination events per year exceed a quarter of the statutory dose limit or even the limit itself.

Over the last five years, most of these contaminations are the consequence of work on equipment at the bottom of reactor building pools or of heat exchanger brushing operations. These areas and activities have a high risk of contamination by strongly-irradiating particles. In general, these contamination events are detected by monitoring at the controlled area exit C1 radiation portal monitor. In chapter 3 of this report, an event is described involving an incident of radio contamination of a worker that occurred on 18 August 2015, during work on a heat exchanger of reactor 4 at the Blayais NPP; the event was rated level 2 on the INES scale. The skin contamination was attributed to transfer of the contamination from the suit to the skin when removing a ventilated leak-tight suit (Figure 2.14).

IRSN considers that, during work preparation, the workers should be made more aware of the skin contamination risk arising from their activity.

Analysis of these SRPEs provides evidence that worksite exit monitoring by a contamination meter (MIP 10 for example) is not carried out in all cases by the workers, who often forget it. In some cases, this is due to malfunctions of the contamination meter or to its location away from the worksite exit. According to IRSN, EDF should continue the actions to improve the conditions for monitoring workers exiting from worksites with contamination risks, particularly in areas with high dose rates. In addition, organisational measures may reduce skin contamination risks when removing protective clothing.

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**Figure 2.13**

"T’as tout" self-checking mirror

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**Figure 2.14**

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Overall assessment of safety and radiation protection performance of nuclear power plants in operation

Safety and radiation protection of the French nuclear power plant fleet in 2015

An increase in the number of events during gamma radiography inspections

Gamma radiography is a non-destructive inspection technique based on gamma-emitting radio-elements, using a portable device (Figure 2.15) to assess homogeneity defects in metals or component welds. This technique is used frequently in EDF NPPs. An event occurring during gamma radiography inspection can have major consequences in terms of worker exposure, as dose rates close to the source reach several hundred milligrays per hour.

Of the 12 SRPEs that occurred during gamma radiography inspections in 2015, half involved marking faults (incorrect marker positioning, omission of marking at the access to the operation area, etc.) and three involved non-compliance with the basic radiation protection rules by the radiologists:

Worksite exit monitoring by a contamination meter (MIP 10 for example) is not carried out in all cases.

Figure 2.14
Worker in a ventilated leak-tight suit

Figure 2.15
Gamma radiography projector (GAM80) containing a radioactive source
without noticing it, a worker allows his dosimeter to fall on the floor during an operation on a pipe of reactor 1 of the Chinon B NPP and consequently carries out the work without his operational dosimeter;

after a gamma radiography inspection at the Fessenheim NPP, the radiation protection department technician went to the inspection site in order to transfer the source from the strongbox made available to the radiologists to the source storage room. When he opened the strongbox, at about 9 a.m., it was empty, although the register showed that the source had been placed in the strongbox at 2 h. The source was also not in the source storage room. The technician found the gamma radiography device used during the night in the marking equipment storage room, on a trolley. The gamma radiography device had spent seven hours unsupervised in the marking equipment storage room;

during work on reactor 3 of the Chinon B NPP, a radiologist entered the operation area to change the film, without informing his assistant that the source had to be reinserted into the gamma radiography device before making the change. The dose received was 32 µSv in three seconds, corresponding to an exposure at an equivalent dose rate of 38.4 mSv/h.

In September 2013, EDF defined an action plan on gamma radiography inspection which was implemented on the sites from 2013 to 2015. This action plan does not seem to have had the anticipated effects in 2015: EDF must consequently continue the actions undertaken on the preparation and the conditions of gamma radiography inspections in partnership with the industrial radiology companies.

EDF has reinforced the preparation of reactor outages by improving the identification of work with radiation protection issues.

A high percentage of events involving risk analysis inadequacies

Risk analysis for a work job is carried out in the work preparation phase. The analysis must be reassessed if the radiological context changes during the work: more than half the events providing evidence of inadequate risk analysis concerned failure to review the analysis after the occurrence of an alarm generated by an operational dosimeter.

The event that occurred on 18 February 2015 on the Bugey site highlighted inappropriate reactions of personnel carrying out work on the liquid waste treatment system pump. In the morning, when a component was being removed from the system, a worker reached the individual dose limit and left the controlled area immediately. Late in the afternoon, the operation to refill the component started, taking account of the dosimetric risk. During the operation, the three workers reached the individual dose limit one after the other, but none of them left the controlled area.

The workers continued the operation for several hours without wondering about the continuous alarm from their dosimeters. Moreover, at no time did they contact a person responsible for radiation protection. The site management implemented corrective actions, including awareness-raising for the workers and reinforcement of the radiation protection preparation of work done while the reactor is generating.

Furthermore, some event analyses report work conditions (wearing of a ventilated hood or a ventilated leak-tight suit, noisy environment, etc.) that prevent dosimeter alarms being heard.

Dosimeters with audible, visual and vibrating alarms, such as the ones used by the divers working in the reactor or fuel building pool, seem to be effective. According to IRSN, the risk analysis should always take the acoustic conditions of the work into account. EDF should make general use of dosimeters with audible, visual and vibrating alarms for work in “noisy” environments or carried out wearing ventilated hoods or ventilated leak-tight suits.

On this topic, EDF has identified and upgraded an alarm reporting
An increase in the number of radioactive source management errors

As part of the fire detection systems renovation work, the detectors containing americium-241 (241Am) radioactive sources are being withdrawn. In 2015, 75% of the events related to radioactive source management errors concerned losses or errors in interim storage of fire detectors containing americium-241.

These radioactive sources must be subject to strict management, identical to the management of the other sources in an NPP. EDF must ensure better application of the storage rules and strict management of the radioactive sources removed with the fire detectors.

Américium-241 (241Am): artificial isotope of americium, with a radioactive half-life of 432 years. Its radioactivity is α (alpha) emission of energy 5.486 MeV, and each of its decay events is accompanied by emission of β (electrons) and X and γ (gamma) radiation.

Ionisation smoke detectors use an ionisation chamber with two electrodes and in which a radioactive material is placed. The air is ionised by the charged particles emitted by the radioactive source (generally a pellet of americium-241).

Application of a voltage across the electrode terminals ionises the chamber air, generating a current. When smoke particles enter the detector, the intensity of the current is affected, and this triggers the detector alarm. This type of detector has been prohibited in France since 2011.

EDF decided to set up a new organisation incorporating radiation protection as part of the preparation of reactor outages. This organisation is intended to establish a radiation protection risk analysis incorporating the risk phases, which will be reviewed in the event of contingencies or schedule changes.

The analysis by IRSN of the appropriateness and the adequacy of the organisational measures proposed by EDF, along with the effectiveness of the deployment conditions and the pertinence of the planned technical measures, is presented in chapter 4 of this report, in the section on “Optimisation of the radiation protection of workers in nuclear power plants”.

The event that occurred at the Penly NPP on 18 June 2015, involving the overflow of the reactor building pool, provided evidence of lack of reviews at various stages:

› when the reactor outage schedule was modified, there was no re-assessment of the risk analysis;

› when the pool was filled despite the unavailability of a reactor coolant system water level sensor and without using the procedure for monitoring the water level in the pool.

These risk analysis inadequacies led to the overflow of the pool and the surface contamination of 33 rooms. The decontamination of these rooms resulted in the integration of a collective dose of 1.8 mSv.

EDF decided to set up a new system that can be connected to the EDF operational dosimeters and generate a visual and vibrating alarm at the wrist, supplementing the dosimeter visual and audible alarms. The existing system was tested initially at Chiron B, Saint-Laurent-des-Eaux B, Nogent-sur-Seine, Flamanville and Chooz B. The operational experience feedback acquired in 2015 is currently being integrated by the supplier with a target of general use by late 2016.

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Application of a voltage across the electrode terminals ionises the chamber air, generating a current. When smoke particles enter the detector, the intensity of the current is affected, and this triggers the detector alarm. This type of detector has been prohibited in France since 2011.
Analysis of events and incidents is an essential IRSN activity in connection with monitoring nuclear power plant (NPP) operations. Analysing an event or incident requires thorough knowledge of the facts and context. This is required before analysing root causes, estimating actual and potential impact on the plant’s safety and, where relevant, the populations and the environment, and evaluating whether the corrective actions taken by the plant operator and the potential improvements are appropriate to prevent a recurrence.

The events or incidents have various origins, ranging from human or organisational failures to equipment failures or failures resulting from design faults.

One feature of the EDF pressurised water reactor fleet is its standardisation. It consists of three reactor series. Each series includes similar reactors of the same power (900 MW, 1300 MW and 1450 MW). Beyond the economic aspect, standardisation offers operating advantages including uniform operating baselines, optimised maintenance and shared operational experience feedback. Nonetheless, standardisation can also be a weakness if the plant operator discovers a failure or error that is liable to affect several reactors or even all the reactors in the fleet. This is referred to as a “generic anomaly”. IRSN pays particular attention to early detection of such anomalies and the measures EDF takes to address them. Some generic anomalies may require complex measures and take several years to be corrected. Palliative measures may be introduced to maintain a satisfactory safety level while such anomalies are corrected.

Events, incidents and anomalies

- Shutdown of Fessenheim reactor 1 following a water leak in the turbine hall
- Worker radioactive contamination incident at the Blayais NPP
- Uncontrolled cooling of Cattenom reactor 1 during restart
- Fuel assembly repair at the Nogent-sur-Seine NPP
On 28 February 2015 a pipe, common to the two Fessenheim reactors, conveying water to the steam generator emergency feedwater tanks cracked due to vibration fatigue. The crack caused a very large leak of non-radioactive water in the turbine hall of Fessenheim reactor 1. On 5 March 2015, when reactor 1 was being restarted, the pipe cracked again, close to the first crack.

**The steam generator emergency feedwater system**

The steam generator emergency feedwater system (EFWS) maintains reactor cooling if the normal feedwater system is unavailable and during reactor startup and shutdown periods. It is fed by the EFWS tank, which contains deaerated water. The parameter values required (availability, water volume, temperature, quality, etc.) are defined in the reactor operating technical specifications.

**Event sequence**

On 28 February 2015, reactor 1 of the Fessenheim nuclear power plant was generating. A major water leak was detected in the turbine hall of the reactor, located in the non-nuclear part of the facility. The leak was through a circumferential crack in a pipe conveying non-radioactive water.

The crack was in the part of the normal water feed pipe to the EFWS tanks (Figure 3.2) common to the two reactors. The leak on this pipe could not be isolated.

Consequently, the EFWS tanks could no longer be fed through the pipe. They could nevertheless be fed by other systems conveying deaerated or non-deaerated water or even by untreated water.

However, because of the leak, the means available to supply water of suitable characteristics was a deaerator.

**The operating technical specifications (OTS):**

Within the general operating rules (GOR), the OTS define the normal and degraded operating modes of the facility. They define the permissible variation of the monitored parameters and the acceptable downtimes for equipment needed in the event of incident or accident. In particular they define the minimum required water volume in the EFWS tank and the procedure to follow in the event of non-compliance with this volume.

**Figure 3.1** Schematic diagram of SG feedwater supply by the EFWS.

**Figure 3.2** Locations of the breaks on 28 February and 5 March 2015
The deaerated water production capacity was insufficient to feed the two reactor EFWS tanks at the same time, but non-deaerated water supply sources were available and could have been used if necessary.

During the restart of the reactor, large vibrations of the repaired pipe caused a second crack close to the first one and a new water leak.

The pipe vibration fatigue is a mechanical degradation which may result in an in-service break in the affected pipes. Static and vibratory loads result in initiation of a fatigue crack and its subsequent propagation, which may be fast. Crack initiation generally occurs in areas of geometrical or metallurgical changes, for example between the base metal and a weld (Figure 3.3). Pumps or valves may be sources of pipe vibration, due to water flow disturbances. Strong vibration such as the vibration that affected the Fessenheim pipe is usually easy to detect (noise, small displacements of the pipes) during inspection rounds, in particular in the turbine hall. In the 2009 PWR public report, vibration fatigue was the subject of an article on cracking of small-diameter branch connections (for further information refer to the IRSN report on safety and radiological protection of French nuclear power plants in 2009).

Circumferential cracking of a pipe subjected to vibration fatigue caused a leak of non-radioactive water in the turbine hall.

Reactor 2, in normal outage, was being cooled by the steam generators and also using EFWS water. Because of the unavailability of one deaerator for maintenance and the increased water consumption because of the need to shut down both reactors at the same time, the deaerated water production capacity was insufficient to maintain the minimum required water volume in the two EFWS tanks.

During the transition to shut-down of reactor 1, a bank of rod cluster control assemblies (RCCAs) remained blocked. Conforming to the normal operating rules, EDF decided to bring reactor 1 to the maintenance outage state: in this state the reactor is cooled by its residual heat removal system, without using water from the EFWS. The reactor completed transition to maintenance outage on 1 March 2015. The management of this event did not require application of the emergency operating procedures.

The water supply to the EFWS tank of reactor 2 (shut down and cooled by the steam generators) was maintained throughout the event.

The cracked pipe of reactor 1 was repaired. Nevertheless, during the restart of reactor 1 on 5 March 2015, large vibrations of the same feed pipe were detected and a second crack formed a few tens of centimetres from the previous crack, causing a new break in the pipe and a new water leak, this time at an isolatable location (Figure 3.2). Because the leak could be isolated, the plant operator was authorised to proceed with the startup of the reactor, keeping the section of pipe concerned isolated. Final repair of the pipe was completed at the end of March 2015.

Corrective actions taken by EDF

For the Fessenheim reactors, EDF identified four flow control valves of the same type as the one at the origin of the incidents of 28 February and 5 March 2015. Since these incidents, EDF has reinforced the monitoring of the maintenance operations on these valves and checked the vibration behaviour of the connected pipes. After the event, EDF made vibration measurements on the EFWS tank feed pipe common to the two Fessenheim reactors.

IRSN position

The circumferential break that occurred on an EFWS water supply pipe common to the two Fessenheim reactors did not have any impact on nuclear safety, but was the subject of a special analysis and of a site visit in order to obtain a better understanding of...
Events, incidents and anomalies
Safety and radiation protection of the French nuclear power plant fleet in 2015

the management of the incident. IRSN asked EDF about the potentially generic aspect of this failure. EDF stated that only the reactors of the Bugey nuclear power plant had a similar pipe configuration for supplying the EFWS tanks (at Bugey, there are two pipes of this type for the four pressurised water reactors); EDF checked the condition of the pipes concerned.

IRSN noted that the cracking of the pipe was caused by vibration fatigue due to the malfunction of a flow control valve, which could have been anticipated.

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MIP 10 radiation contamination monitor: monitor capable of detecting α, β, γ and X-ray radiation, depending on the connected probe, and measuring the radiation count rate or the dose rate. This monitor is used extensively in pressurised water reactors for contamination checks on persons (hands, feet, clothing). In accordance with the EDF radiation protection baseline, it is placed in all the worksite exit airlocks and in controlled area exits immediately before the C2 radiological monitoring portal.

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Worker radioactive contamination incident at the Blayais NPP

On 18 August 2015, reactor 4 of the Blayais nuclear power plant (NPP) was shut down for its third ten-yearly reactor safety review. During maintenance work on a heat exchanger located in the nuclear auxiliary building, a contractor worker suffered radioactive contamination of his face. This contamination resulted in a dose exceeding the statutory limit for skin exposure.

Background

Reactor 4 of the Blayais nuclear power plant (NPP) was shut down for maintenance and refuelling as part of its third ten-yearly safety review. On 18 August 2015, during preparation of the requalification of a heat exchanger located in the nuclear auxiliary building, a contractor worker was contaminated on his face.

The requalification of the heat exchanger consisted of the replacement of a seal, necessitating the removal and refitting of the heat exchanger head (Figure 3.4), preliminary tightening, three tightening operations and a leak test. The leak test necessitated the insertion of metal blanking plates between the flanges of the heat exchanger inlet and outlet pipes. The heat exchanger is located in a contaminated space, so a negative-pressure airlock was installed for worker entry to and exit from the heat exchanger requalification worksite. The airlock had an MIP 10 contamination detector (Figure 3.7) to detect any contamination of the workers leaving the worksite exit airlocks and in controlled area exits immediately before the C2 radiological monitoring portal.

MIP 10 radiation contamination monitor: monitor capable of detecting α, β, γ and X-ray radiation, depending on the connected probe, and measuring the radiation count rate or the dose rate. This monitor is used extensively in pressurised water reactors for contamination checks on persons (hands, feet, clothing). In accordance with the EDF radiation protection baseline, it is placed in all the worksite exit airlocks and in controlled area exits immediately before the C2 radiological monitoring portal.

Figure 3.7
MIP 10 contamination detector

Figure 3.4
Simplified diagram of the heat exchanger
worksite. The workers wore the clothing defined in the prevention plan, i.e. a ventilated leak-tight suit (Figure 3.5) or a Tyvek® overall (Figure 3.6) with over-gloves and over-boots; a worker helped them to put on and take off the clothes.

**Incident sequence**

On 17 August, the heat exchanger seal was replaced and the preliminary tightening of the head studs was completed. The space was decontaminated to improve the working conditions for the subsequent operations.

During the inspection by the quality, safety and risk prevention (QSPR) department on the morning of 18 August, an abnormal amount of grease used for refitting the studs was observed. Early in the afternoon, the contractor assigned a first team to clean up the grease and carry out the first of the three tightening operations; this first team, wearing ventilated leak-tight suits, entered the air-lock at about 2.30 pm and exited from it at about 3.30 pm, without self-checking using the MIP 10 detector.

Between 3.30 pm and 4.30 pm, QSPR checked the radiological state of the room and, given the decrease in the measured contamination level, authorised the replacement of the ventilated leak-tight suit by a Tyvek® overall with over-gloves and over-boots for the subsequent work. Between 4.30 pm and 5.30 pm, a second team, wearing Tyvek® overall with over-gloves and over-boots, carried out the second and third tightening operations on the heat exchanger head.

At about 5.30 pm, the first team returned to install the two blanking plates between the flanges of the heat exchanger coolant inlet and outlet pipes in preparation for the leak test. At about 6 pm, the team exited from the work site, again without self-checking using the MIP 10 detector.

At about 6.05 pm, at the small object monitor (Figure 3.8), one of the first team members checked his glasses and his helmet; the
check detected contamination of the helmet, which was disposed of in the contaminated waste.

At about 6.10 pm, during the check using the MIP 10 detector before passing through the C1 radiation portal monitor (Figure 3.9), the same worker discovered contamination on his chin and contacted the attending QSPR technician.

The QSPR technician informed the infirmary, removed the particle and made an initial measurement on it using a small object monitor (device for contamination detection and measurement on small objects such as tools or helmets) which confirmed the presence of cobalt-60.

The worker passed through the portal monitors without triggering them and left the workplace. Having doubts about the first measurement, the QSPR technician used another procedure to make a second measurement on the particle, giving an activity of 640,000 Bq of cobalt-60.

Analysis of the incident by the plant operator

EDF evaluated the dose on the basis of the following assumptions:

› an activity of 504,000 Bq, measured in the occupational health department two days after the event, in a sub-millimetric particle of cobalt-60, probably in stellite;

› an exposure time of 2 hours 45 minutes, corresponding to the elapsed time between the first exit from the work site by the worker at about 3.30 pm and the removal of the particle at about 6.15 pm. The fact that the worker was not checked when he removed his ventilated leak-tight suit on this first exit raised the possibility that he was contaminated then.

The equivalent dose to the skin estimated by the plant operator was 1.5 Sv, three times the statutory annual limit for skin exposure of 0.5 Sv.

In its analysis of the event, EDF stressed that:

› there were several possible causes for the contamination of the worker; inappropriate application of the clothing removal method, inadequate cleaning of the tools, reflex gesture (scratching the face, etc.);

› checks using the MIP 10 detector were not systematic, which is a non-compliance with the radiation protection baseline.

IRSN position

IRSN reviewed the actions taken by the plant operator after the contamination of the worker was detected and concluded that the accidental contamination detection and measurement procedure was applied strictly. It should be noted that this procedure had been updated in 2013 following a similar event.

IRSN confirmed the equivalent dose to the skin of the worker by its own calculations. However, IRSN noted that the plant operator had not estimated the effective dose nor the equivalent dose to the crystalline lens, an organ close to the location of the contamination and also subject to a statutory

C1 radiation portal monitor: the C1 radiation portal monitor is installed between the controlled area and the hot changing room; its function is to detect clothing or body contamination. It is equipped with whole-body NaI γ scintillators on the vertical walls.

Figure 3.9
C1 radiation portal monitor

During the preparation of the leak test on a heat exchanger in the nuclear auxiliary building, a worker was contaminated on the chin by a particle of cobalt-60.

Cobalt-60 (60Co): isotope of cobalt, radioactive half-life 5 years. Its radioactivity is β-emitting (electrons) and each of its decay events is accompanied by emission of two highly penetrating γ (photons) of energy, respectively 1.17 MeV and 1.33 MeV.

Stellite: stellites are alloys, mainly of cobalt, with high resistance to wear and corrosion; they are used in particular in coatings for pump bearings and valve components in the chemical and volume control, safety injection and containment spray systems. Operating incidents (pump seizure, for example) may result in release of insoluble and generally submillimetric stellite particles into the reactor coolant system and the systems connected to it. These particles may be carried by the water flows in the systems and deposited at places in the systems where their transport by the water is prevented. If such particles flow through the core, cobalt-59 (the only natural isotope) is activated to cobalt-60, and the deposits form hot spots.

Equivalent dose and effective dose: the equivalent dose to an organ is the average dose (energy per unit mass) delivered by ionising radiation to the organ, taking account of the type of radiation. The effective dose is a radiation protection indicator taking into account the equivalent doses delivered to each organ of the human body exposed to ionising radiation, weighted by the sensitivity of each organ to the radiation. Equivalent dose and effective dose are expressed in sieverts (Sv) or fractions thereof (mSv or µSv).

The fact that the worker was not checked when exiting from the worksite means that he may have been contaminated during his first work period.
Exposure limit. IRSN evaluated the effective dose due to the particle: it was negligible compared with the effective dose received by the worker while working in the nuclear auxiliary building, and in any case negligible with respect to the statutory annual limit for the whole-body effective dose, which is 20 mSv.

As shown by the analysis of the events presented at the meeting of the Advisory Committee for Reactors on 11 June 2015 dedicated to optimisation of radiation protection (refer to chapter 4 of this report), events involving contamination detection after exit from worksite airlocks are frequent in EDF plants: gaps (omission or incorrect execution of checks) are observed in the application of the principle of worker self-protection against contamination risks. For IRSN, EDF must reinforce the measures ensuring proper implementation of worksite exit contamination checks. Moreover, the risk of transfer of contaminated particles from clothing to skin is high when removing clothes.

Consequently, IRSN considers that EDF must reinforce radiation protection assistance, in particular when undressing or removing ventilated leak-tight suits, for worksites with contamination risks (for further information, refer to the notice IRSN-2016-00271–Observation 7).

Uncontrolled cooling of Cattenom reactor 1 during restart

On 28 May 2015, reactor 1 of the Cattenom nuclear power plant (NPP) was in the restart phase at the end of its maintenance and partial refuelling outage. The reactor power was released as steam to the atmosphere. Inadvertent opening of a steam release valve caused sudden cooling of the reactor coolant system, entailing the application of the on-site emergency plan. IRSN analysed the origin and the consequences of this failure, and whether it was generic for all the reactors.

Steam removal system

When the temperature and the pressure of the reactor coolant system are high enough, reactor power is removed by the steam generators (SG) in the form of steam generated in the secondary system. This steam is routed to the turbine (Figure 3.10) when the reactor is connected to the electricity grid.

When the reactor is not connected to the grid, the steam does not feed the turbine, and is routed:

- to the atmosphere (via the MSBa system bypassing the turbine to the atmosphere); this is the case during reactor outage and restart phases, when the reactor is cooled by the steam generator emergency feedwater system (EFWS);
- to the condenser (via the MSBc system bypassing the turbine to the condenser), when the power to be removed exceeds EFWS cooling capacity.

The MSBa system, which bypasses the turbine and routes the (non-radioactive) steam to the atmosphere, comprises two valves positioned in series on a pipe connecting the steam release line from each SG to the atmosphere (Figure 3.10).

The first valve is an isolating valve, the position (open or closed) of which is controlled from the reactor control room by means of an electric servomotor. In normal operation, this valve is open.

The second valve is a control valve supplied with compressed air. The position setpoint of this valve comes from the reactor instrumentation & control system (automatic control) or the control room (manual control). It is transmitted electrically to the positioner. The positioner converts the electrical signal to a pneumatic signal to displace the actuator stem and open or close the atmospheric steam dump valve of the main secondary system; this controls the pressure of the steam (Figure 3.11).
Incident sequence

On 28 May 2015, reactor 1 of the Cattenom NPP was in the restart phase after a scheduled refuelling outage. Inadvertent opening of the control valve of the steam generator 1 MSBa system bypassing the turbine to the atmosphere caused a release of steam into the environment and a sudden cooling of the reactor coolant water. This cooling resulted in contraction (decrease) of the water volume contained in the system, which caused a pressure drop.

Two minutes after the inadvertent opening of the control valve, the first alarms appeared in the control room, alerting the operators to an abnormally low water level in the pressuriser. This type of situation requires the application of the emergency operating procedures. When the low-low water level threshold in SG 1 was reached, resulting from the steam flow rate to the atmosphere through the open MSBa control valve, the reactor tripped. Borated water was injected automatically into the reactor coolant system and the containment was isolated.

The opening of the control valve caused a substantial release of steam to the atmosphere. As this

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Figure 3.10
Location of the atmospheric dump system control and isolation valves

The pressure difference between the reactor coolant system (still pressurised) and the secondary side of the steam generator (pressure decreasing rapidly) results in increased mechanical stresses. The ability of the steam generators to withstand such stresses is tested in periodic hydrotests. During these tests, checks are carried out to make sure that the pressure difference does not generate permanent deformation of the internal structures or tube cracking likely to result in leakage of radioactive reactor coolant water into the secondary side (non-radioactive) of the steam generator.

Inadvertent opening of a control valve of the system bypassing the turbine to the atmosphere caused a sudden cooling of the reactor coolant water.
steam came from the secondary system and was consequently non-radioactive, no increase in radioactivity was measured on site or in the environment of the power plant.

**Incident management**

Supplementing these automatic actions, the operators applied the emergency operating rules. Twenty-five minutes after the inadvertent opening of the control valve, the operators closed the MSBa isolation valve of steam generator 1 from the control room. This interrupted the uncontrolled cooling of the reactor coolant system.

Given the thermal-hydraulic parameters of the reactor, the emergency operating procedures required the activation of the on-site emergency plan: ASN and IRSN were alerted and mobilised their emergency response teams. The plan was finally de-activated a few hours after the opening of the valve.

The fallback of the reactor was continued until the following morning to reach a state in which the reactor was cooled by the residual heat removal system and not by the steam generators.

On completion of reactor fallback, EDF carried out checks which did not provide evidence for any damage to the steam generator, despite the mechanical stresses generated, and replaced the positioner with a new-generation positioner.

**Origin of the failure**

The expert assessments conducted by EDF provided evidence of a failure of the printed circuit board of the positioner; the type of positioner involved had been fitted to the MSBa control valves of the Fessenheim reactors and the CPY and 1300 MW series reactors since the early 2000s. During the outage of Cattenom reactor 1 in 2015, the positioner at the origin of the event had been replaced by a reconditioned positioner.

All the functional tests on the valve carried out after the replacement gave satisfactory results.

**IRSN analysis**

The inadvertent opening of the MSBa system control valve had no impact on the safety of the facility nor on the environment; it was nevertheless a significant event that was the subject of a specific analysis by IRSN.

Following this event, IRSN compiled a summary of the malfunctions identified by EDF involving this type of positioner over the last three years. Of the fifteen or so failures identified, some were due to a generic ageing process that could compromise the operability of the control valve, and others to drift or instability of the positioner signal that could result in incorrect positioning of the valves. However, none of these failures caused complete and inadvertent opening as observed in the case of Cattenom reactor 1.

In July 2015, a similar problem affected reactor 2 of the Chinon B plant (MSBa system control valve blocked in closed position), and its origin was attributed to a failure of the positioner printed circuit board.

At the conclusion of its analysis, IRSN considered that EDF must take the necessary measures to improve the reliability of the positioners concerned in the reactors in service. In this regard, it should be remembered that, given their obsolescence, these digital positioners are gradually being replaced by more recent digital positioners of the same brand (for further information, refer to IRSN notice 2015-00221).
Repair of fuel assemblies at the Nogent-sur-Seine NPP

Fuel assemblies can become deformed during reactor operation, which can lengthen the drop times of rod cluster control assemblies (RCCAs) or even prevent them dropping fully, in the event of a reactor trip. This situation, which affected reactor 2 of the Nogent-sur-Seine plant, led EDF to carry out in 2015 an unprecedented in-cycle repair operation on two fuel assemblies in order to ensure that the reactor trip function remained operational until the scheduled refuelling outage.

Fuel assembly deformation: in-service monitoring and impact on safety

Fuel assemblies (Figure 3.12) can become deformed laterally while they are in the reactor under the effect of hydraulic and mechanical stresses, irradiation and temperature (above 300°C).

Excessive deformation of the fuel assemblies may slow the insertion of the rod cluster control assemblies (RCCAs) into the core, or even prevent their full insertion. When needed, rapid drop of the RCCAs and their full insertion into a reactor core are required in order to fulfill the safety functions (control of reactivity/halting of the nuclear reaction).

RCCA drop time measurements are made periodically to check compliance with the assumptions applied in the safety demonstration (limit values). EDF carries out these measurements at the start and the end of the irradiation cycle.

For about 15 years, a specific tool has been used by plant operators on “control” reactors to measure the lateral deformations of fuel assemblies when they are unloaded. This examination is carried out during transfer of the fuel assemblies to the spent fuel pool.

Sequence of events at Nogent-sur-Seine

Since 2012, EDF has observed a significant change in the lateral deformations of the fuel assemblies of reactor 2 of the Nogent-sur-Seine power plant. The particular situation of this reactor is explained by the transition of this unit to the GALICE fuel management scheme.

The GALICE management scheme is characterised by a specific fuel assembly positioning plan and fewer new fuel assemblies introduced at each refuelling than under the GEMMES management scheme implemented at all the other 1300 MW reactors. These two specific features explain the significant degradation of the behaviour of the core. As a result of this situation, EDF has definitively halted implementation of the GALICE management system (for Nogent-sur-Seine reactor 2, the only reactor using the scheme).

Substantial deformation of the fuel assemblies can lengthen the RCCA drop times in the core, or prevent full insertion of the RCCAs.

The fuel assemblies can be deformed laterally under the action of the stresses exerted on them during reactor operation.

A fuel assembly is composed of 264 fuel rods that are approximately four metres high and approximately one centimetre in diameter. The rods are inserted in a structure known colloquially as the “skeleton”. The structure consists of eight or nine grids that determine the spacing of the rods and which are assembled with 24 guide tubes in which the absorber rods of an RCCA can be inserted.

Insertion of RCCAs in about one-third of the core fuel assemblies stops the nuclear reaction.

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8. An irradiation cycle is the period of reactor operation between two partial refuelling outages. A cycle lasts from 12 to 18 months, depending on the reactor.

9. The main change between the GEMMES and GALICE fuel management schemes is the increase in the authorised burnup from 52 GWd/tU to 62 GWd/tU (burnup is the energy released by the combustion of one unit of mass of nuclear fuel).
This led EDF to propose in 2013 a design change in the guide tubes (increase in thickness and change of material) so as to limit the deformations. Despite the introduction of these changes, IRSN considered that it was necessary, given the observed deformations, for EDF to reinforce the RCCA drop time monitoring by additional tests in mid-cycle (² refer to the 2013 PWR public report, pages 48-51).

In 2014, during these additional tests performed during the 19th cycle of the reactor, some drop time measurements reached the limit values; in such cases, the plant operator must carry out monthly tests to make sure that assembly deformation does not compromise the availability of reactor trip. Following significant increases in drop times of some RCCAs during the cycle and the incomplete insertion of five RCCAs, EDF decided to shut down the reactor three months before the scheduled outage date and unload the core. During the 20th cycle, the reinforced monitoring of the assemblies of Nogent-sur-Seine reactor 2 provided further evidence of incomplete insertion of an RCCA. The event occurred in March 2015, when the next refuelling outage of the reactor was not scheduled until September 2015. EDF decided to proceed with a shutdown during the irradiation cycle to ‘repair’ two highly-deformed assemblies so as to prevent drop time anomalies during the second part of the 20th cycle.

Unprecedented in-cycle "skeleton assembly replacement" operation

In order to carry out the “skeleton assembly replacement” operation, EDF unloaded the two deformed assemblies. It had previously unloaded two adjacent assemblies to increase the space between assemblies and facilitate the removal of the two deformed assemblies. This procedure minimised the number of assembly handling operations, which always risk damaging the grid; the rest of the core remained in place.

EDF then carried out an unprecedented “assembly skeleton replacement” operation. Assembly skeleton replacement consists in transferring the fuel rods one by one from an assembly with a deformed structure to a new structure (“skeleton”). This operation is carried out using a gripper which is lowered through the grid cells (Figure 3.13) of the new skeleton, positioned in a section placed above the deformed assembly (Figure 3.14), to grip the top end of the fuel rods in the deformed assembly positioned in the lower section (Figure 3.14) and pulls the rods into the new structure as it is raised again.

The upper assembly is the reconstituted assembly.

Figure 3.13  
Diagram of part of a fuel assembly grid (a grid consists of 17 cells x 17 cells)

Figure 3.14  
Diagram of the STAR skeleton replacement system
replacement” operation which consisted in transferring the 264 fuel rods from a deformed assembly into a new assembly structure not showing any deformation.

This operation was carried out in the fuel building spent fuel pool using a dedicated tool called STAR (Figure 3.15). The assemblies were then reloaded in the core in their initial positions. The operation lasted several days.

**IRSN position**

IRSN analysed the restart conditions for reactor 2 of the Nogent-sur-Seine NPP for the second part of the 20th cycle, following the unusual outage for in-cycle partial unload/reload. IRSN requested that regular RCCA drop tests be carried out at intervals no longer than 60 days in order to verify compliance with the limit values and absence of RCCA drop blocking up to the end of the 20th cycle.

IRSN also considered that the production of a flux map at low reactor power (6% to 8% of rated power) was necessary in order to check core conformity after the reloading operation.

No limit values were exceeded and no RCCA blocking was observed during the second part of the 20th cycle in the four drop time tests after the reloading of the two fuel assemblies with replacement skeleton assemblies.

IRSN has also conducted studies to obtain a better understanding of the excessive deformation of the fuel assemblies and its impact on safety. It has asked EDF to take such deformation into account in the safety demonstration, as part of the review associated with the fourth ten-yearly reactor safety reviews of the 900 MW reactors.

EDF carried out an unprecedented in-cycle operation on Nogent-sur-Seine reactor 2, replacing the deformed “skeletons” of two fuel assemblies with new “skeletons”.

Producing a flux map consists in measuring the neutron flux by inserting fission chambers into a number of fuel assemblies. These measurements are used to calculate the power distribution in three dimensions inside the core.
Significant upgrades

Changes and upgrades are made to France’s nuclear reactors throughout their lifetime, with the aim of continuously improving safety.

Advances in technical and scientific knowledge, weaknesses detected and lessons learned from operational experience feedback, changes in the environment or regulations, together with economic factors are just some of the reasons behind the changes made to facilities or operating procedures.

Periodic safety reviews, carried out every ten years in accordance with Article L.593-18 of the Environment Code, provide an ideal opportunity for implementing these changes.

They are associated with the preparation of long ten-yearly reactor outages, during which such work as replacing heavy equipment is carried out, and major changes are made to facilities.

It may take several years of research and exchange, during which IRSN examines the documentation submitted by EDF, before some changes and upgrades can be precisely defined and implemented. Others, however, must be implemented more rapidly according to a suitable schedule.

900 MW reactors: guidelines of the periodic review associated with the fourth ten-yearly reactor safety reviews

Optimisation of worker radiation protection in nuclear power plants

Control of subcontracted operations in operating reactors
900 MW reactors: guidelines of the periodic review associated with the fourth ten-yearly reactor safety reviews

EDF wishes to extend the operation of the 34 French 900 MW reactors, put into service from 1977 to 1987, beyond forty years (operating life used as the design basis for certain structures and equipment).

In this context, EDF has presented the guidelines of the periodic review associated with the fourth ten-yearly reactor safety reviews, which IRSN has examined with regard to the objectives defined by ASN in 2013. IRSN stressed the unprecedented magnitude of the review programme, which will be undertaken and concluded within tight deadlines; the first ten-yearly reactor safety review within the framework of this periodic review is scheduled for mid-2019 (Tricastin 1).

What does the periodic review cover?

A periodic review consists of:

- a review of the conformity of the state of the facility to the safety baseline and to the regulations in force in order to deal with any non-compliances;

- a safety reassessment, with the objective of improving the safety of the facilities, in particular by bringing the safety level of the oldest reactors as close as possible to the level of the most recent reactors;

- implementation of the equipment and documentation improvements resulting from the safety reassessment on the occasion of the ten-yearly reactor safety reviews.

The 900 MW reactors

The 34 French 900 MW reactors were put into service from 1977 to 1987 in a programme of three phases grouping reactors with similar characteristics.

For the purpose of standardisation, EDF ordered 900 MW nuclear steam supply systems from under “Programme contracts” (CP):

- CP1, launched in 1974, covered 18 reactors at Tricastin, Dampierre-en-Burly, Blayais and Gravelines;

- CP2, launched in 1976, covered 10 reactors at Saint-Laurent-des-Eaux, Chinon and Cruas.

Prior to these programme contracts, the construction of six reactors (four at Bugey and two at Fessenheim) had been undertaken from 1971. These six reactors were subsequently referred to as the CP0 series.

The guidelines of the periodic review for the fourth ten-yearly reactor safety review

In September 2010, EDF presented the programme of guidelines concerning the extension of the operating life of the reactors beyond forty years (operating life used as the design basis for certain structures and equipment). IRSN reviewed the programme and presented its conclusions at two meetings of the Advisory Committee for Reactors in January 2012. In June 2013, on the basis of this review, ASN defined the objectives for the next periodic reviews of the 900 MW and 1300 MW reactors in view of their fourth ten-yearly reactor safety reviews.

Statutory framework for the periodic review

In accordance with the statutory texts, the operator of a basic nuclear facility must conduct a periodic review of its facility every ten years, taking into account best international practice, operational experience feedback, new knowledge, and other factors.

However, the legislation makes provision for the definition of a different periodicity if justified by the specific characteristics of the facility.

What is a ten-yearly reactor safety review?

The reactors of nuclear power plants undergo periodic “unit outages” for partial refuelling and for inspection and maintenance of parts of the facility not normally accessible when the reactor is operating.

French regulations require a series of inspections and tests of the nuclear steam supply system equipment every ten years of operation to be conducted during an outage designated for the purpose lasting about three months, referred to as a “ten-yearly reactor safety review”.

The Advisory Committee for Reactors is charged by ASN to issue notices and recommendations on the safety of nuclear power or research reactors, on the basis of assessments by IRSN.
Significant upgrades

**Objectives for the 900 MW fourth ten-yearly reactor safety reviews**

The objectives defined by ASN concern:

› control of the conformity of the facilities and maintaining it over time to take account of the effects of ageing. This necessitates specific actions by EDF concerning 1) the extent of field verification of the conformity of the facilities and 2) the clearing of all non-compliances and anomalies no later than during the fourth ten-yearly reactor safety reviews. More complete knowledge of the ageing mechanisms, with particular attention paid to non-replaceable components such as the reactor pressure vessels and the containments, is necessary (for further information about ageing, refer to the 2011 PWR public report, pages 58 to 63).

› improvement of facility safety to attain a safety level similar to that specified for the third-generation nuclear reactor under construction at Flamanville (European Pressurised water Reactor, EPR). This requires changes to limit the radiological impacts of accidents without core melt, to prevent or mitigate the impacts of accidents with core melt (severe accidents) and to reinforce the safety of stored spent fuel.

To meet these objectives, in late 2013 EDF presented the guidelines for the periodic review associated with the fourth ten-yearly reactor safety reviews of the 900 MW reactors.

**Analysis of the guidelines for the periodic review associated with the 900 MW fourth ten-yearly reactor safety reviews**

IRSN reviewed the guidelines presented by EDF with regard to ASN’s objectives, in particular in terms of ageing control and safety improvements, and presented its assessment to the Advisory Committee for Reactors early in April 2015 (read IRSN’s position in notice no. 2015-00098). In its review, IRSN noted that EDF had undertaken to demonstrate its capacity to control and maintain over time the conformity of its facilities. IRSN also stressed that the reinforcement of the prevention of the accidents studied for the fourth ten-yearly reactor safety review, along with the measures resulting from the additional safety studies conducted following the accident at the Fukushima-Daiichi power plant in Japan, deployed at the same time, would significantly improve the robustness of the facilities to extreme hazards and to certain accident situations.

IRSN considered that the guidelines of the periodic review associated with the fourth ten-yearly reactor safety reviews were ambitious and unprecedented in magnitude. However, IRSN noted that some points needed to be improved:

› the proposed checks to ensure conformity of the facilities and its maintenance over time;

› the procedure for taking the Flamanville 3 EPR reactor design-basis accidents into account in the safety demonstration for the reactors in service;

› the safety of spent fuel storage in the pools;

› certain assumptions made for the hazard studies (unforeseen event levels, in particular) and the study of the load collision and drop risks in the reactor building;

› the taking of human and organisational factors into account in the design of changes in the facility or in the operation baseline.

IRSN also considered that topics related to the design of safety-related systems or systems in late 2013 EDF presented the guidelines for the periodic review associated with the fourth ten-yearly reactor safety reviews of the 900 MW reactors.

IRSN considered that the guidelines of the periodic review associated with the fourth ten-yearly reactor safety reviews were ambitious and unprecedented in magnitude, but that some points needed to be improved.
involved in the control of certain risks would benefit from further analysis, which EDF has undertaken to conduct as part of the 900 MW fourth ten-yearly reactor safety review.

Lastly, IRSN considered that investigation must continue in order to decide on the adequacy of the guidelines defined for the fire and explosion risks. In addition, the selection of the external hazards – other than earthquake – which might undergo probabilistic assessment necessitates additional review.

**Conclusion**

The fourth ten-yearly reactor safety reviews of the 900 MW reactors will take place from 2019 to 2030, with the first review scheduled for mid-2019 (Tricastin 1); the magnitude of this review is unprecedented. The associated studies, their assessment and the implementation of the changes will be carried out on particularly tight deadlines. IRSN will assess the report on the studies conducted by EDF on the basis of the guidelines defined for this review after its assessment. The roll-out of the measures resulting from these studies will be assessed reactor by reactor on conclusion of the fourth ten-yearly reactor safety review of each 900 MW reactor (Figure 4.1).
Significant upgrades

Optimisation of worker radiation protection in nuclear power plants

For many years, EDF has implemented a radiation protection optimisation scheme on all its nuclear sites. In the context of the extension of the operating life of its reactors and the associated increase in the volume of work entailing a rise in the collective dose over the coming years, EDF has defined a strategy including new organisational and technical measures for controlling the increase in the collective dose of the workers over this period. IRSN has assessed the appropriateness and adequacy of these new measures.

**The collective dose** is the sum of the individual exposures to ionising radiation received by the workers over a given period.

The proposed extension of the operating life of the reactors involves an increase in the volume of the maintenance and other work, with an increase in the collective dose received by the workers if no optimisation is implemented.

**EDF** is going to roll out a number of changes to the operating reactors as part of their proposed operating life extension. Work involved in these changes will be done in both the conventional part of the facility and the nuclear island, so some of it will be in contact with equipment conveying radioactive fluids. This project involves an increase in the volume of the maintenance and other work done during the reactor refuelling outages, with an increase in the collective dose received by the workers if no optimisation is implemented.

For many years EDF has implemented optimisation measures specific to each worksite in compliance with the ALARA approach. To continue this optimisation over the coming years, EDF has planned to roll out additional technical measures, tested on some reactors, and organisational measures.

**IRSN** has assessed the measures proposed by EDF to optimise the radiation protection of workers in the nuclear power plants, and presented its conclusions in June 2015 to the Advisory Committee for Reactors.

**Operational experience feedback.** At NPP fleet level, EDF has introduced several promotion actions contributing to maintaining the impetus behind the ALARA approach. IRSN considered that these actions taken at national level were satisfactory.

EDF has also proposed the additional measures described below for the various phases of the operations.

**Preparation phase:** successful optimisation is based on good coordination and good communication, both between the various EDF entities and between EDF and the service providers involved in radiation protection from the preparation phase. For this purpose, EDF has proposed a new organisation as part of the preparation of reactor refuelling outages, consisting of logistics and risk prevention reviews. The objective of these reviews is earliest possible identification of the radiation protection issues and the equipment needs for worker radiation protection.

In its assessment, IRSN considered that the contractors must be informed of the planned work in advance of the ten-yearly safety reviews of the reactors, to enable early placing of orders and adequate preparation for the work (radiological issues, work volumes).

**Organisational measures**

The radiation protection optimisation process is applicable to all phases of the maintenance or change operations: preparation, execution, and management of operational experience feedback.

**Execution phase:** looking forward to the ten-yearly reactor safety reviews, EDF is introducing a new
Significant upgrades
Safety and radiation protection of the French nuclear power plant fleet in 2015

The effectiveness of the optimisation approach during maintenance or other work is based on good communication and good coordination between the various personnel involved.

Technical measures
Preventive actions for source term control
EDF has implemented various measures for limiting the source term:
- measures to limit the level of activated corrosion products in the reactor coolant system water, including zinc injection into the reactor coolant system (RCS) and use of low-cobalt materials. Injection of small quantities of zinc into the RCS water reduces the source term associated with activated corrosion products, among other effects;
- a change increasing the flow rate in the RCS in order to purify the RCS water more rapidly in the reactor outage phase. This change allows the RCS water activity concentration criterion which authorises reactor coolant pump shutdown to be satisfied more rapidly. IRSN noted that, in the context of this change, the activity concentration criterion was not revised downward, which would have been beneficial for radiation protection. IRSN consequently considered that EDF should assess the dosimetric usefulness of lowering this criterion;
- operations to decontaminate systems of the most contaminated operating reactors, carried out before the major work operations planned in the coming years: this is an effective means of reducing worker exposure;
- updating of the good radiation protection practice guides to limit the formation of hot spots, which have an impact on the dose received by workers on the sites: this should favour the eventual elimination of hot spots.

The source term during work operations corresponds to the activity of all the radioactive products present in the reactor and the systems after unloading of the fuel. This source term has the following main origins:
- activated corrosion products (corrosion products are released by the internal structures of the reactor coolant system and then “activated” by ionising radiation as they pass through the reactor core);
- residual radioactive fission products released through small defects in the fuel rod cladding.

The activity, i.e. the number of atomic nucleus disintegrations per unit time, is often expressed with respect to a volume (activity concentration in Bq/l or Bq/m3).

The main technical measures concern the control of the source term and the implementation of the risk prevention supervision station.

Operational experience feedback (OPEX) management phase: analysis of OPEX from EDF reactor events with regard to radiation protection shows the existence of at-risk situations, whether in certain configurations during reactor refuelling outages or during the work itself. These at-risk situations are included correctly in the preparation of each operation. In contrast, review of the OPEX shows that such situations would benefit from more general consideration in the preparation of reactor outages. On this point, IRSN stresses that the new organisation introduced by EDF, stipulating a radiation protection risk analysis for the refuelling outage project in addition to the risk analyses for the various planned operations, acts as a first line of defence for inclusion of at-risk situations.

In its review, IRSN also noted that differences between the individual doses received and the predicted doses for operations were analysed only if a significant difference in the collective dose was observed. IRSN considered that analysis of OPEX from an operation from the radiation protection angle must include an individual dose deviation criterion, independent of the collective dose.

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The main technical measures concern the control of the source term and the implementation of the risk prevention supervision station.
Significant upgrades

Safety and radiation protection of the French nuclear power plant fleet in 2015

Improvement of work monitoring in controlled areas

Operational experience feedback has identified non-compliances with the radiation protection requirements given in the EDF radiation protection guides, policies and baseline: in particular, they involve faults affecting the radiological protection and monitoring devices during work.

Several contamination events have occurred in the EDF reactor fleet resulting in skin exposures close to or exceeding the statutory limits (in this report, refer to “Radiation protection: main trends” in chapter 2 and “Worker radioactive contamination incident at the Blayais power plant” in chapter 3); when workers remove their protective clothing on exiting from worksites with a high contamination risk, there is a major risk of contamination transfer from the clothing to the skin of the worker.

In view of this operational experience feedback, EDF has developed specific training for the persons responsible for assisting workers removing ventilated leak-tight suits. This measure should reduce body contamination events such as the events that have resulted in doses to the skin approaching the statutory limits. EDF must also ensure the quality of the radiological checks performed by the workers when exiting from worksites with a high contamination risk (Figure 4.2).

Cross-functional optimisation tools

With a view to the ten-yearly reactor safety reviews, EDF has planned the development of tools for limiting the individual and collective doses.

These tools involve in particular:

- establishment of a risk prevention supervision station enabling both remote monitoring of work operations and real-time monitoring of worker exposure levels; this results in limitation of the received doses. The forecast reduction is between 5% and 15% of the collective dose, depending on the type of unit outage and reactor shutdown;

- development of an analysis tool for optimising the positioning and the number of the radiological shields (Figure 4.3). The estimated reductions are 120 person-mSv for one ten-yearly reactor safety review.

EDF has undertaken to analyse the operational experience feedback from their use in order to confirm these estimates.

Conclusion

The trend over recent years in the doses received by workers carrying out EDF reactor maintenance and change incorporation operations shows the commitment of EDF to continuous improvement of radiation protection.

After review, the EDF strategy regarding optimisation of radiation protection in order to manage the increase in collective dose over the coming years resulting from the substantial increase in the work to be done during the next ten-yearly reactor safety reviews was considered generally satisfactory by IRSN, which nevertheless judged that additional information must be provided on certain points. IRSN also stressed the importance of operational experience feedback for reinforcing this optimisation approach.

Figure 4.2
Contamination check at the controlled area exit

Figure 4.3
Types of radiological shielding

A hot spot is a localised source of ionising radiation generating a dose rate in its immediate proximity much higher than the ambient dose rate.

A radiological shield is a fixed or moveable shield (water, concrete wall, lead sheets, etc.) intended to reduce ionising radiation locally.

10. The controlled area is defined in chapter 2 of this report.

11. The statutory limit values are given in chapter 2 of this report.
Control of subcontracted operations in operating reactors

During the outages of its reactors, EDF subcontracts about 80% of the maintenance work on large equipment in the areas of mechanical engineering, valves and sheet metalwork. Given the significant safety issues, IRSN has reviewed the measures taken by EDF to control risks associated with subcontracted maintenance operations on its reactors. The review, which assessed the entire subcontracting management process, highlighted the factors that ensure its control by EDF as well as certain organisational weaknesses.

**Background for the IRSN assessment**

Operational experience feedback shows that more than 30% of the significant safety events reported by EDF in recent years involved maintenance faults and these are likely to cause failures of equipment necessary for reactor safety.

Each year, EDF uses more than 22,000 subcontractor employees to perform maintenance on its reactors alongside the 10,000 EDF employees assigned to these tasks. The volume of subcontracted work is set to increase over the coming years because of the roll-out of changes resulting from the additional safety studies following the Fukushima-Daiichi accident in March 2011 and from the studies associated with the periodic reviews in the context of the extension of the operating life of the 900 MW reactors beyond 40 years.

In the nuclear sector as in the other industrial sectors, the subcontracting of maintenance work is not without impact on risk control. This is demonstrated by the lessons learned from events that have occurred on nuclear sites and in industrial accidents and by the conclusions of research on the topic. In particular, the relationship between project owner and service provider is an important factor to be considered.

Subcontracting in the nuclear industry is also the topic of frequent public debate. On this point, as part of its review, IRSN met members of local information committees and of environmental protection associations; this identified the topics of concern for these stakeholders and recurring in public debates, such as the monitoring of service providers by the project owner or the time constraints to which the workers are subjected.

IRSN has reviewed the measures taken by EDF to control the risks associated with the subcontracted maintenance work on its reactors, and presented the results of its assessment to the Advisory Committee for Reactors in June 2015.

**Organisational measures instituted by EDF for control of risks related to subcontracting**

EDF has instituted measures at national level which are applied at each nuclear power plant; they cover qualification of subcontractors and contracting of services up to and including evaluation of services and feedback of operational experience.

The majority of the maintenance work is concentrated in the reactor outage periods: these outages are necessary in order to replace spent fuel and to perform inspection and maintenance operations on parts of the facility that are not accessible during operation.

**AZF and Challenger accidents:** analysis of major accidents such as the AZF chemical plant explosion in Toulouse in 2001 and the in-flight explosion of the space shuttle Challenger in 1986 has identified problems of loss of skills and of complexity of interfaces related to subcontracting relationships.

**Risk control:** this term covers all measures for prevention and limiting the consequences of risks related to safety and radiation protection.
The plant operator aims for the shortest possible outage periods in order to optimise the availability of its facilities. This constraint has necessitated the introduction of specific work scheduling and preparation measures (Figure 4.4).

IRSN review of the measures instituted by EDF

IRSN has reviewed the measures prescribed by EDF for carrying out maintenance work and its practical effects on the work of the personnel in the field.

For this analysis, IRSN conducted more than 160 interviews on three nuclear sites during unit outages and observed some forty maintenance operations in situ. For each measure that it analysed, IRSN interviewed employees of EDF (project managers, monitoring managers, purchasers, etc.) and of the subcontractors. This mirrored assessment process was useful for analysing the joint contributions of EDF and its subcontractors in the overall control of risks related to subcontracted operations.

The IRSN assessment showed that EDF had implemented a set of technical and organisational measures that make a practical contribution to controlling the safety of subcontracted operations. Nevertheless, IRSN has identified several areas for improvement which it considers essential for control of these operations. These areas for improvement are discussed below.

Capacity of contractors to perform operations that have an impact on safety

IRSN considers that the qualification and contracting stages enable EDF to assess in advance whether subcontractors will be able to provide the management required for carrying out operations while controlling the associated risks. In the field, however, IRSN observed that this approach was insufficient to ensure the actual ability of subcontractors to implement appropriate management and to have sufficiently competent resources to carry out the maintenance operations assigned to them.

To take into account the IRSN observations, EDF undertook to study the introduction of a qualification declaration after the contractor has demonstrated its ability during work done under monitoring by EDF.

Balance between workload and available resources

The ability of subcontractors to handle the contracted workload is a basic condition for ensuring the quality of maintenance operations. Compliance with this condition requires the availability of the appropriate resources, both in quantity and skills. In view of this, EDF recently implemented a number of measures so that subcontractor representatives are more involved in planning work to be completed during unit outages. On this point, EDF has committed to assessing the effects of these measures.

EDF has also planned contractual measures for dealing with

<table>
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<tr>
<th>Figure 4.4: Measures implemented by EDF</th>
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<tbody>
<tr>
<td><strong>Unit outage schedule (J0-6 months to J0-1 month)</strong></td>
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<tr>
<td>Preparation of joint EDF/contractor schedule.</td>
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<tr>
<td>Smoothing of the workload with contractor resources.</td>
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<tr>
<td>Seminars presenting the unit outage to review the main issues with the contractors, etc.</td>
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<tr>
<td><strong>Work preparation (up to start date)</strong></td>
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<tr>
<td>Work risk analysis: decide whether to start the work depending on the acceptability of risks.</td>
</tr>
<tr>
<td>Determine the countermesures and ensure the contractor has assimilated the risks</td>
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<tr>
<td>Pre-work meeting: ensure the implemented resources conform to the requirements: documents, worker qualifications, file, equipment, etc.</td>
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<tr>
<td><strong>Qualification/Contracting</strong></td>
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<tr>
<td>Ensure candidate contractors have management measures considered necessary for “carrying out activities with the required level of safety and quality” and exclude those that do not fulfil these conditions.</td>
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<tr>
<td><strong>OPEX</strong></td>
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<tr>
<td>Acquire and use operational experience feedback of subcontracted work</td>
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<tr>
<td><strong>Assess the quality of the work (resources used, safety culture, technical quality, completion times, etc.)</strong></td>
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<tr>
<td><strong>Ensure quality of worker actions (secure communication, self-checking, cross-checking, etc.)</strong></td>
</tr>
<tr>
<td><strong>Monitoring proportional significance of safety consequences: ensure the overall quality of the work</strong></td>
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</tbody>
</table>
unexpected equipment or scheduling issues. However, IRSN has observed that these measures could weaken the organisation of subcontractors, as they could necessitate greater flexibility in order to ensure availability of sufficient capacity of resources for unexpected issues. IRSN consequently considered that EDF must identify the effects of these measures on the working conditions of the subcontractors in order to ensure that they do not subject the subcontractors and the EDF organisation to stresses that might compromise the control of the risks associated with the work.

**Risk analysis approach**

A major measure in the control of risks that EDF has implemented is the risk analysis performed prior to each operation. The objective of this analysis is to “prepare the workers to carry out the operation, knowing the risks and how to control them”. The IRSN assessment confirmed the difficulties encountered by EDF over many years in the producing these analyses, which do not take sufficient account of the actual risks associated with the operation to be carried out. Aware of these difficulties, EDF has undertaken to implement improvement actions in order to produce risk analyses of better quality that are useful to the workers, and to assess their effectiveness in the field.

**EDF monitoring of subcontracted operations**

The monitoring by EDF of subcontracted work must be sufficiently effective to prevent non-compliances likely to affect the operation of safety-related equipment; this monitoring is conducted by sampling, and is proportionate to the issues in terms of safety. Facing recurring difficulties related to monitoring of subcontracted work (administrative rather than technical monitoring, problem with the legitimacy of those responsible for monitoring, etc.), EDF implemented a new monitoring management policy in 2014, the effects of which have yet to be assessed in the field.

**Acquisition and use of operational experience feedback from subcontracted work**

The IRSN assessment revealed gaps in both the collection and the processing of operational experience feedback data from the subcontracted work; this includes the capacity of the subcontractors to transfer certain information, given the contractual relationship that binds them to EDF and the overall inadequacy of analysis by EDF of all the available data. In this regard, EDF is committed to improving the process for acquiring and using OPEX.

In order to deal with the volume of subcontracted work to come, EDF has planned an increase in the human resources assigned to the multi-year programming of the maintenance and change incorporation work on its reactors and a reinforcement of the coordination between the engineering units and the NPPs. EDF, in collaboration with industry associations, has undertaken an assessment of the capacity of subcontractors to handle the increase in the volume of the work. This innovative approach has produced an initial forecast of the capacity of the subcontractors to meet the future needs.

**Conclusions**

The IRSN assessment showed that EDF had implemented a set of technical and organisational measures that make a practical contribution to managing the safety of subcontracted operations. However, IRSN noted certain recurring weaknesses in the EDF measures, necessitating improvements in order to deal with the fundamental causes. In particular, IRSN considers that the analysis by EDF of the problems related to subcontracting does not sufficiently examine these fundamental causes related to the organisation of EDF itself.

More generally, EDF should adopt a vision that takes into account the overall quality of a service as the product of the joint contribution of the project owner and the subcontractor. For IRSN, this change is a necessary condition for obtaining better control of subcontracted operations.

Lastly, IRSN notes that EDF has undertaken the first satisfactory measures to deal with the increase in the volume of the subcontracted work to come. It nevertheless considers that the definition of these measures to control the risks of subcontracted work must take account of the lessons learned from the review conducted by IRSN. Refer to the assessment of the Advisory Committee for Reactors on management of subcontracted work in the PWRs.

**IRSN has analysed the process of acquisition and use of the operational experience feedback of the subcontracted work in order to assess the capacity of EDF to upgrade its organisation to improve the conditions for carrying out the work.**

**EDF must go beyond the contractual customer-supplier relationship by reinforcing the existing subcontractor-involvement measures in order to move towards joint development of the risk control of subcontracted work.**
Glossary

A

**Accident or incident**
Any unforeseen event occurring during normal operation that may have consequences for security, safety, public health, nature and the environment; the potential consequences of an accident are greater than those of an incident

**ALARA**
The "as low as reasonably achievable" approach optimises radiation protection for workers

**ASN**
Autorité de Sûreté Nucléaire (French civilian nuclear regulator, also known as the French Nuclear Safety Authority)

B

**Becquerel (Bq)**
Unit of radioactivity, 1 Bq equals 1 disintegration per second. The unit is very small and measurements often use a multiple of the Bq, the megabecquerel (MBq), which equals $10^6$ Bq or 1 million Bq. The Bq replaced the curie (Ci) which is the activity of 1 gramme of radium; 1 Ci equals $3.7 \times 10^{10}$ disintegrations per second, or 37 billion Bq (or 37 billion disintegrations per second)

**BK**
Fuel Building

**BL**
Electrical Building

**BR**
Reactor Building

C

**CCWS**
Component Cooling Water System

**Containment**
Keeping radioactive substances inside a defined space using a set of measures to prevent them from spreading in unacceptable quantities beyond the space; by extension, the set of measures taken to ensure this state

**Corrective maintenance**
All operations performed in order to restore failing equipment to service

**CP0 series**
Includes six reactors of the 900 MW series commissioned between 1977 and 1979 (two at Fessenheim and four at Bugey)

**CP**
Programme contract (CP0, CP1, CP2, CPY) – term used for EDF’s 900 MW pressurised water reactors (cf. definitions of “plant series”)

**CPY series**
Includes twenty-eight 900 MW reactors commissioned between 1980 and 1987 (CP1: four at Tricastin, six at Gravelines, four at Dampierre-en-Burly, four at Blayais and CP2: four at Chinon, four at Cruas-Meysse and two at Saint-Laurent-des-Eaux)

**CSS**
Containment Spray System; this safeguard system is activated in accident situations

**CVCS**
Chemical and Volume Control System

**D**

**Dose rate**
Radiation intensity (energy absorbed by matter per unit of mass and time). It is measured in grays per second (Gy/s)

**E**

**EDF**
Electricité de France (French national electric utility)

**EFWS**
The Emergency Feedwater System supplies emergency water to the steam generators

**EPR**
European pressurized water reactor (1650 MW reactor); one is currently under construction at Flamanville

**Equivalent dose rate**
Rate of quantity of absorbed dose weighted for biological effects by various quality factors depending on radiation. It is expressed in millisieverts per hour (mSv/h)

**ESWS**
Essential Service Water System

**Exposure**
Physical contact with ionising radiation ("external" exposure if the source is located outside the organism, “internal” exposure if the source is located inside the organism)

**F**

**FIS**
Independent safety review team responsible for analysing, separately from the operational safety team (FOS), the malfunctions, deviations and incidents involving operating safety at nuclear power plants

**Fission**
Splitting of an atom’s nucleus as a result of bombardment by neutrons. During this reaction, neutrons and ionising radiation are emitted and a great amount of heat is released

**FOS**
Operational safety team responsible for the operation of nuclear reactors

**FPCPS**
Fuel Pool Cooling and Purification System

**Fuel assembly**
Bundle of fuel rods assembled in a metal structure used in nuclear reactors

**Fuel cycle**
A cycle is the period of reactor operation between two outages for partial fuel reloading. A cycle lasts from 12-18 months, depending on the reactor and type of fuel management

**G**

**GOR**
General Operating Rules; they govern the operation of nuclear reactors by providing operational specifications of assumptions and conclusions of the design studies and safety report and by setting limits and conditions for operating the facility

**Gray (Gy)**
Unit expressing the quantity of radiation absorbed by the human body in terms of energy deposited by the particles or radiation in the matter, 1 Gy equals 1 joule per kilogramme of irradiated matter. It is the unit of absorbed dose. The Gy has replaced the rad; 1 Gy equals 100 rads
**H**

**HP turbine**  
High pressure turbine cylinder

---

**I**

**INB**  
French acronym for basic nuclear installation, which includes pressurised water reactors.

**INES Scale**  
International Nuclear Event Scale designed to help the media and the general public understand the significance of nuclear incidents and accidents from a safety standpoint; it defines seven levels of severity based on the consequences of the event: levels 1-3 correspond to “incidents”, levels 4-7 to “accidents” while “deviations” are classified below the scale at level “0”

**Ionising radiation**  
Electromagnetic waves (gamma) or particles (alpha and beta particles, neutrons) emitted with the decay of radionuclides, which produce ions when passing through matter

**Irradiation**  
Exposition, intentional or accidental, of an organism, substance or body to ionising radiation

**IRSN**  
Institut de Radioprotection et de Sûreté Nucléaire (French Institute for Radiological Protection and Nuclear Safety)

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**L**

**LP turbine**  
Low pressure turbine cylinder

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**M**

**Maintenance**  
Set of actions taken to maintain or restore equipment to a specified state or one that is capable of ensuring a specified service

**MCR**  
Main Control Room

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**MeV**  
The mega electron volt (= 10⁶ or one million electron volts) is a unit of energy used in particle physics

**MFWS**  
The Main Feedwater System supplies water to the steam generators

**MNQ**  
Maintenance non-quality

**MSBa**  
Main Steam Bypass to atmosphere

**MSBc**  
Main Steam Bypass to condenser

**MSB**  
Main Steam Bypass

**MW**  
The megawatt is the unit of energy used for measuring the amount of energy provided to the electric grid by a nuclear power plant

**N**

**N4 series**  
Includes four 1450 MW reactors commissioned between 2000 and 2002 (two at Chooz and two at Civaux)

**NAB**  
Nuclear Auxiliary Building

**NERT**  
Nuclear Emergency Response Team

**NPP**  
Nuclear power plant where there may be several reactors (for example, there are two at Fessenheim and Civaux, four at Bugey and Cattenom and six at Gravelines)

**Nuclear fuel**  
Fissile material (capable of undergoing a fission reaction) used in a reactor for initiating a nuclear chain reaction.

**Operator**  
Physical or legal person operating a regulated nuclear facility and responsible for its safety, for example EDF is the operator of pressurised water reactors (PWRs) in France

**OPEX**  
Operational experience feedback, performed on a given topic over a specific period of time

**OTS**  
Operating Technical Specifications; part of the General Operating Rules (GOR), the OTS define the normal and degraded operating domains of the facility by specifying the permitted variations in controlled parameters and acceptable durations for unavailability of equipment required in case of incident or accident

**P**

**Preventive maintenance**  
All actions performed on available equipment to prevent or reduce the probability of subsequent malfunction. These actions are planned in advance and integrated into maintenance plans

**PS**  
Protection System of the reactor

**PWR**  
Pressurised Water Reactor

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**Q**

**QSPR**  
Quality, Safety and Risk Prevention Department (EDF)

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**R**

**Radioactive contamination**  
Presence of radioactive substances on the surface or inside any environment. For humans, contamination may be external (on the skin) or internal (by inhalation or ingestion)

**Radiological activity**  
Number of spontaneous disintegrations - or decays - occurring in atomic nuclei per unit of time. The unit of activity is the becquerel (Bq)

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**RCA**  
Radiation-controlled area

**RCCA**  
Rod Control Cluster Assembly
**RCS**  
Reactor Coolant System

**Reactor shutdown**  
Control operation which consists of bringing the reactor to a state that is safer than the initial state (in which an anomaly has been detected, for example)

**RHRS**  
Residual Heat Removal System, used when the water temperature of the Reactor Coolant System is less than 180 °C

**RWST**  
Refuelling Water Storage Tank of the reactor cavity and spent fuel pit cooling and treatment system

**Spent fuel**  
Nuclear fuel that has been irradiated in the core of a reactor from which it is permanently removed

**SRPE**  
Significant radiation protection event that is likely to harm the health of people by exposure to ionising radiation

**SSE**  
Significant safety event that may have consequences for facility safety

**System alignment**  
Configuration of a system to make it available for operation, e.g., by controlling valves and switching electrical equipment on or off

**S**

**SAB**  
Safeguard Auxiliary Building

**Safety analysis**  
All technical reviews that evaluate measures for ensuring nuclear safety in accordance with the risk assessment

**1300 series**  
Includes twenty 1300 MW reactors commissioned between 1984 and 1993 (eight in the P4 subseries: four at Paluel, two at Saint-Alban and two at Flamanville; twelve in the P4' subseries: two at Belleville-sur-Loire, four at Cattenom, two at Golfech, two at Nogent-sur-Seine and two at Penly)

**SG**  
Steam generator

**Sievert (Sv)**  
Unit used to estimate the biological effects of radiation on an exposed organism (taking into account its nature and exposed organs). Since this unit is very large, a submultiple of the Sv, the millisievert (mSv), which equals $10^{-3}$ Sv or one thousandth of a sievert is often used. Equivalent dose rate is also expressed in millisieverts per hour (mSv/h). The Sv has replaced the rem; 1 Sv equals 100 rem

**SIS**  
Safety Injection System; this safeguard system is activated in a loss of coolant accident

**T**

**Unit outage**  
Period during which a reactor is shut down for refuelling and to perform inspection and maintenance operations on the facility