

---

## Flamanville 3 EPR, safety assessment and on-site inspections

*Corinne. PIEDAGNEL, François TARALLO, Bernard MONNOT*

Institut de Radioprotection et de Sûreté Nucléaire, DSR/SAMS  
92262 Fontenay-aux-Roses Cedex, France

---

### **Abstract:**

As a Technical Support Organisation of the French Safety Authority (ASN), the IRSN carries out the safety assessment of EPR project design and participates in the ASN inspections performed at the construction site and in factories.

The design assessment consists in defining the safety functions which should be ensured by civil structures, evaluating the EPR Technical Code for Civil works (ETC-C) in which EdF has defined design criteria and construction rules, and carrying out a detailed assessment of a selection of safety-related structures. Those detailed assessments do not consist of a technical control but of an analysis whose objectives are to ensure that design and demonstrations are robust, in accordance with safety and regulatory rules.

Most assessments led IRSN to ask EdF to provide additional justification sometimes involving significant modifications. In the light of those complementary justifications and modifications, IRSN concluded that assessments carried out on design studies were globally satisfactory.

The participation of IRSN to the on-site inspections led by ASN is a part of the global control of the compliance of the reactor with its safety objectives. For that purpose IRSN has defined a methodology and an inspection program intended to ASN: based on safety functions associated with civil works (confinement and resistance to aggressions), the corresponding behaviour requirements are identified and linked to a list of main civil works elements.

During the inspections, deviations to the project's technical specifications or to the rules of the art were pointed out by IRSN. Those deviations cover various items, such as concrete fabrication, concrete pouring methodology, lack of reinforcement in some structures, unadapted welding procedures of the containment leaktight steel liner and unsatisfactory treatment of concreting joints. The analysis of those problems has revealed flaws in the organisation of the contractors teams together with an unsatisfactory control of the contractor's activities by EDF. However, some three years after the beginning of construction, the organization and strictness of the main civil contractor and of EDF construction team have improved.

## **1. INTRODUCTION**

More than ten years after the latest construction in France, the Flamanville 3 site has opened, and the first French EPR type unit is due to diverge in 2012.

The construction license Decree was signed by the French Government in April 2007 and prior to the Operation Licence Application to be issued by EDF in 2011, an early assessment of regulatory documents and a control of the reactor construction are under way.

As a Technical Support Organisation of the French Safety Authority (ASN), the IRSN carries out the safety assessment of EPR project design and participates in the ASN inspections performed at the construction site and in factories.

Civil structures are the first elements of the unit to be built. The assessment of the civil engineering design of Flamanville 3 began in 2005, two years before the associated on-site

inspections. According to IRSN, the latter are part of the overall assessment of the ability of civil works to meet their safety functions and requirements. In other words, the design assumptions and features (mechanical principles of structures, practical arrangements, material properties, provisions regarding durability, etc.) are confirmed only if they are correctly implemented and maintained in the plant.

The IRSN experience related to the safety assessment of the design and to on-site inspections is briefly described below.

## 2. CIVIL DESIGN SAFETY ASSESSMENT

The first step in design assessment consists in defining the safety functions which should be ensured by civil structures. Two kinds of safety functions are involved:

- nuclear safety functions such as radioactive material containment and radiation protection;
- functions directly related to a nuclear safety function like protection against internal and external hazards and supports of safety-related equipment.

External hazards can be earthquakes, aircraft crashes, external explosions, extreme temperatures, external flooding, etc.

Internal hazards are failures of components, internal flooding, fire, internal explosions, load drops, etc.

Considering these safety functions, safety requirements are defined as follows:

- leak-tightness and retention in order to meet release criteria;
- resistance, stability and supporting capacity;
- choice of materials and determination of their biologic thickness.

To meet the safety requirements, different behaviour requirements are defined for each structure or part of structure. For example, the EPR reactor building is made up of a double-wall concrete containment and a metallic liner, which is designed to guarantee leak-tightness in case of radioactive material release. The inner containment must withstand internal pressure due to high energy pipe breaks; the outer containment must withstand external hazards, particularly an aircraft crash, and contain the possible leakage from the inner wall, the steel liner included.

Once the behaviour requirements identified, the design of each structure is carried out according to Basic Safety Rules (RFS) which are ASN guides and EPR Technical Code for Civil works (ETC-C) in which EdF has defined design criteria and construction rules and has given a definition of leak and resistance tests related to the reactor containment.

First, IRSN assessment consists in evaluating the ETC-C which has been drafted by EdF, principally in accordance with French regulatory rules with some adaptations to the particular EPR project.

The rest of the assessment described below is based on the ETC-C code.

The IRSN evaluates the global model and calculation of the nuclear island carried out by EdF. For example, assumptions, input data and load cases introduced in the model are checked according to behaviour requirements. The global results which are used for the basemat and structures design are analysed in terms of consistency with assumptions and existence of margins.

Then, a detailed assessment of a selection of safety-related structures is carried out:

- nuclear island basemat;
- reactor building: steel liner, inner prestressed containment, outer containment (airplane shell), internal structures, pool;

- fuel building: internal structures, pool;
- safeguard auxiliary building;
- pumping station.

At this step, the IRSN analyses detailed calculation notes and drawings so as to ensure that results are consistent with the design methodology, the criteria and construction rules defined in ETC-C and also with “Art Rules” and the Book of Technical Specifications (RST). Detailed safety assessments do not consist of a technical control but of an analysis whose objectives are to ensure that design and demonstrations are robust, in accordance with safety and regulatory rules.

Most assessments led IRSN to ask EdF to provide additional justification sometimes involving significant modifications. In the light of those complementary justifications and modifications, IRSN concluded that assessments carried out on design studies were globally satisfactory.

Besides, during its assessments, IRSN identified items whose construction should be inspected, because of their importance for safety, or because of special execution difficulties encountered in the past during the construction of NPPs.

### **3. ON-SITE INSPECTIONS: OBJECTIVES AND GENERAL OVERVIEW**

#### **3.1 Objectives and general overview**

As part of the global control of the compliance of the reactor with its safety objectives, a control of the construction is carried out by ASN and IRSN, through a limited number of inspections. Since the future Operator –EDF- is, according to the French law, sole responsible for the safety of the plant (as far as civil works are concerned), the main idea is to verify that EDF endorses its responsibility and masters the quality of the construction, and its compliance with safety objectives and technical regulations.

Thus, the general objectives of the inspections are the following:

- checking that the safety requirements established in the approved design are still met during the building activities, in particular that the designer’s drawings and specifications are correctly applied by the civil contractors;
- verifying that good practice during construction is respected, resulting in a fair level of quality of the buildings;
- assessing the management and survey of its site by EDF, who is the final caretaker of the construction’s quality, and the future operator of the plant.

IRSN has defined a methodology and an inspection program intended to ASN. Based on safety functions associated with civil works (confinement and resistance to aggressions), the corresponding behaviour requirements are identified and linked to a list of main civil works elements. Those requirements cover stability, no perforation, leak-tightness, fluid retention, protection against climatic conditions, together with the durability for the lifetime of the plant. Finally, a list of sensitive or exemplary elements is chosen as targets for inspections, that are programmed according to the construction schedule. That selection incorporates the experience gained from the construction and operation (incidents and maintenance) of the existing plants and from the Olkiluoto 3 site. The priority order affected to each element depends on its importance for the safety of the reactor.

The first inspections were carried out in 2007, dealing with the preliminary works: foundation rock excavations by blasting, underground galleries and risks caused by the construction activities to the safety of the two nearby units under operation. The concrete works developed during 2008 and the first structural concrete of the nuclear island was poured in December. Foundation works finished in early 2009 for the nuclear island and the pumping

station, giving way to the construction of the first levels of the buildings and to the erection of the bottom part of the reactor containment.

IRSN systematically takes part in the inspections and identified non-conformities as well as bad practices. When necessary, IRSN sends warning letters to ASN, eventually followed by an action of EDF and a higher construction quality level.

A few technical problems highlighted during the inspections are described below.

### **3.2 Water excess in structural concrete**

After two inspections held in October 2007, the IRSN stated in its November 2007 technical assessment that the water/cement ratio (0.50) of the structural concrete delivered by the civil contractor could be too high to meet the objectives of durability of the project, in marine atmosphere. The possible phenomena are higher porosity of concrete and additional cracking due to excessive shrinkage, causing a poor protection of steel reinforcement. Later on, the formulation of concrete was changed, to reach a better ratio (0.45).

### **3.3 Cracks in the concrete of the reactor building basemat**

In early December 2007 the first lift of the reactor building basemat was poured, as first structural concrete of the nuclear island. This lift is a 1.8 m thick, 55 m diameter disk, leading to a concrete volume equal to 4225 m<sup>3</sup>. Two days after the 40 hours long concreting, cracks on the whole surface of the lift were observed. Their initial openings, 1 to 3 mm, decreased after cooling to more limited values: 0.4 to 1 mm. The FA3 civil works contract limits cracks openings smaller than 0.2 mm. Those cracks were eventually grouted by the contractor.

The basic cause of this non-conformity is the thermal effect (expansion and gradient) due to the heat of hydration of the cement during concrete setting. Besides, this lift was concreted without any reinforcement mesh in its upper part. Such a mesh distributes the possible contraction strains, thus leading to elementary cracks of reduced openings.

IRSN thinks that the main risk linked to such a defect is a reduced durability of the structure, because of possible corrosion of the bottom reinforcement, and that the repair by grouting cannot give thorough guarantee on the protection of those rebars. Then, IRSN suggests that the presence of water below the basemat should be detected by EDF, during the lifetime of the plant.

In its November 2007 technical assessment, IRSN had pointed out the risks associated with the execution of large concrete blocks, namely thermal cracking and Delayed Etringite Formation, and asked a special care on temperature limitation inside those blocks during their execution. Moreover, IRSN states that the repair of abnormally cracked structural elements cannot be considered as a current method of execution of nuclear buildings.

### **3.4 Lack of reinforcement in the nuclear island basemat**

During the inspection on 5 March 2008, the IRSN representatives noticed a local lack of transversal rebars in concrete block number 2 of the fuel building basemat, while the concreting of this block was under progress. This problem had not been identified by the internal control of the contractor, or by the EDF control. The concreting work was rapidly stopped, and resumed only after the reinforcement was completed, according to the execution drawings. Among others, this finding clearly showed that the preparation of its tasks by the civil contractor and the control by EDF were not satisfactory. After that inspection, EDF undertook corrective actions in order to improve its control and the quality of the work of the contractor.

### 3.5 Welding process of the containment steel liner

The metallic liner of the reactor building ensures the leak-tightness of the containment in the event of a possible serious failure on components which contain primary coolant water. In the event of such an accident, this 6 mm thick metallic skin on the inner face of the containment concrete structure constitutes the ultimate static barrier for radioactive products. This safety function must be provided throughout the lifetime of the power plant. A first checking of this safety function is made with the pressure air test performed at the end of the construction of the reactor building. This test is however a global test during which a leak cannot be easily located, so that a repair in order to restore leak-tightness will remain very problematic.

Consequently, guaranteeing liner leak-tightness, making it possible to consider a successful pressure test result of the reactor building, mainly relies on the provisions taken before test, on both the level of the quality of liner design and the liner manufacture quality.

The liner is mainly made with thin P265GH steel sheets, and design and manufacturing are subject to technical requirements defined in the contractual specification related to civil works (RST 2.01). This specification requires in particular preliminary qualifications for welding procedures and welders in accordance with European standards, a welding in several layers of welded metal, and radiographic test of butt welds with a random sampling check on 10% welded lengths.

After an interruption of almost 20 years in the construction of PWR containment steel liners in France, IRSN naturally paid detailed attention to the first welding activity carried out on site on an element endorsing a safety function: the liner manufacturing.

IRSN took part in several inspections with ASN from the beginning of the liner welding operations on the Flamanville site. These inspections resulted in detecting deviations from technical requirements of RST2.01 specification, in particular on the welding procedure. These variations lead IRSN to recommend complementary examination tests, and a 100% non destructive vacuum box test on welds was defined. The following inspections revealed perfectible conditions of welding needing implementation of climatic conditions protection, and some non-conformities in documentations. At the same time, the assessments of the first random sampling x-ray inspection campaigns showed abnormally high rates of repairs for an easily weldable steel. These reports, signs of a welding activity not completely controlled in spite of the required qualifications, led IRSN to recommend a 100% volumetric non destructive test of welds until return to a normal situation. In front of these difficulties, the manufacturer defined and applied an action plan aimed to significantly improve the quality of works by optimizing the welding procedures, by the improvement of their conditions of implementation, and by complementary training sessions and selection of welders. After a few weeks of application of this action plan, the results of control on welds already indicate a clear improvement, and a return to a normal situation.

The difficulties faced on the Flamanville site confirm that welding activity on equipment providing a safety function, after a long interruption or by a manufacturer not familiar with the specific environment of nuclear energy, requires an approach going beyond the simple compliance with the technical provisions defined in contractual specifications. Taking into account the safety function of the component concerned, awareness of the importance of this safety function by all those involved in the manufacture appears necessary, first to a good perception of the required quality level, and second to reach quality level consistent with this safety function.

### 3.6 Unsatisfactory treatment of concreting joints

Concerning concreting joints, unsatisfactory treatments were pointed out during several inspections, for instance in November 2008 (no treatment at level -6.35 m in the gusset of the reactor building containment wall), July 2009 (deviation from the technical specifications, in the contractor's execution procedure) and August 2009 (inappropriate use of deactivator). The project's technical specifications state the contractor should roughen the concrete joints using a water and air jet, or should present alternative methods to the approval of EDF. The contractor has presented alternative methods: use of deactivators and jackhammer. EDF approved those modifications.

IRSN recalls that the state of the art advises against those alternative methods, that generally lead to lower quality joints. Such defects may jeopardize the robustness of structures, that could be lower than expected in design, and reduce their durability because of faster than expected steel reinforcement corrosion.

Technical discussions with EDF are under way. As first steps, EDF has stopped the use of one deactivator, whose use for the treatment of concreting joints is not planned by its manufacturer, has undertaken a dedicated test program, and has strengthened its survey of the contractor's activities in that field.

## 4. CONCLUSION

The IRSN safety assessment of the civil works detailed design confirms the consistency of that design with the safety objectives associated with the EPR project, and highlights items whose construction activity should be inspected.

During the inspections, deviations to the project's technical specifications or to the rules of the art were pointed out by IRSN. The analysis of those problems has revealed flaws in the organisation of the contractors teams together with an unsatisfactory control of the contractor's activities by EDF, even for the safety-related activities. Those findings, after endorsement by ASN, led EDF to carry out corrective actions: for example repair of cracks in the reactor building basemat, improvement of concrete and steel liner fabrication, more safety culture in the contractor's staff, strengthening of the supervisors team. Of special interest is the setting up by EDF of a civil design liaison team on the site, whose duty is a better coordination between design teams and construction activities.

The Flamanville EPR site is one example of the restarting of the nuclear civil construction. Some three years after the beginning of construction, the organization and strictness of the main civil contractor and of EDF construction team have improved.