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Operation Extension of 900MWe NPPs: French TSO Main Conclusions regarding Long Term Sump Performance after a Loss of Coolant Accident

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ABSTRACT

During a Loss Of Coolant Accident (LOCA), water is injected by the Emergency Core Cooling System (ECCS) to ensure the long-term core coolability and by the Containment Spray System (CSS) to remove residual heat and to maintain containment integrity. After the drainage of the RWST (Refueling Water Storage Tank), water is taken from the containment sump in the lower part of the nuclear reactor building. A filtering system is implemented at the bottom of the containment to collect debris produced by the pipe break and the degradation of the ambient conditions inside the reactor building, and to minimize the amount of debris entering in the ECCS and CSS systems. Consequently, one of the major issues is the clogging of the filtering system due to physical and chemical conditions which can lead to an inadequate net positive suction head (NPSH) margin for the ECCS and CSS pumps and can affect the mechanical integrity of the strainers. Furthermore, despite the filtering system, a part of the debris bypassing the strainers is transported to the core. That might alter the fuel assembly coolability (downstream effects), which constitutes the second major issue.

Since the Baresbäck incident in Sweden in 1992, which raised questions concerning the risk of strainers clogging at international level, sump performance has become a major concern in France, where this issue is common to all NPPs.

In the framework of the operation extension of the French 900MWe NPPs beyond 40 operating years, EDF presented its safety demonstration based on studies and new experimental program on strainer clogging and fuel assembly coolability. IRSN conducted the evaluation of the EDF safety case and performed simultaneously its own tests on the VIKTORIA loop in Slovakia. IRSN provided its technical position in March 2020.

The paper will present the French background and French Technical Safety Organization (IRSN) conclusions on sumps performance issue for the 4th periodic safety review of 900MWe NPPs dated the end of March, 2020. (322 words)

KEYWORDS: Long term coolability, LOCA, sump filters clogging, debris, head losses

1. INTRODUCTION

Since the Baresbäck incident in Sweden in 1992, which raised questions concerning the risk of filters clogging at international level [1], sump performance has become a major concern in France.

The sump water filtration issue is common to all French plants. It has been the subject of numerous studies and researches by EDF, and several reviews by the IRSN and the French nuclear safety authority (ASN).

In the framework of the operation extension of the French 900MWe NPPs, EDF presented its safety demonstration based on studies and new experimental programs on strainer clogging and fuel assembly coolability. IRSN has drawn up a report on all the assessments carried out since 2016 on the EDF's updated safety case and the lessons from the test campaigns performed simultaneously on the VIKTORIA loop in Slovakia. IRSN provided its technical position in March 2020 [2].

The paper presents the French background and IRSN conclusions on sump performance issue under LOCA conditions for the 4th periodic safety review of 900MWe NPPs.

2. PHENOMENOLOGY

During a Loss Of Coolant Accident (LOCA), borated water is injected by the Emergency Core Cooling System (ECCS) to ensure the long-term core coolability and by the Containment Spray System (CSS) to remove residual heat from the containment and to maintain its integrity. After the drainage of the RWST (Refueling Water Storage Tank), water is taken from the containment sump in the lower part of the nuclear reactor building.

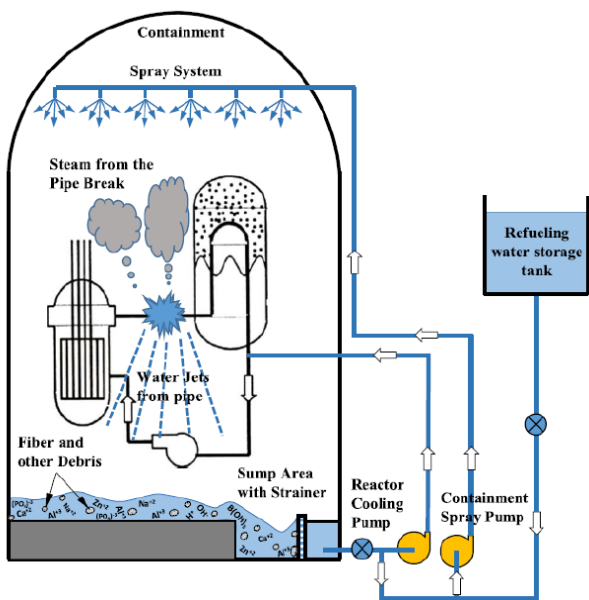


Figure 1 – Scheme of recirculation loop in the NPP

A filtering system is implemented at the bottom of the containment to collect debris – insulating materials, concrete, paints - produced by the pipe break and the degradation of the ambient conditions inside the reactor building, and to minimize the amount of debris entering ECCS and CSS.

Depending on the type of debris particles (size, properties, arrival time...) and on the strainer characteristics, a debris bed may be created on the strainer, due to mechanical phenomena as well as chemical reactions (including mainly soda and boron) under LOCA conditions. The debris bed may increase the differential pressure across the strainer and therefore decrease the Net Positive Suction Head (NPSH) margin available for ECCS and CCS pumps. This may affect the mechanical integrity of the strainers. Consequently, the clogging of the filters is a major issue regarding the sump performance.

Furthermore, despite the filtering system, part of the debris bypasses the filters, is transported to the core and may clog the fuel assemblies grids. That might affect the fuel assembly coolability and the operability of the downstream equipments (downstream effects), which constitutes the second major issue.

3. FRENCH BACKGROUND

In 2003, EDF declared a significant safety event for all French NPPs relative to the risk of sump strainers clogging, what could impair the ECCS and CSS efficiency during a LOCA.

Following the review of EDF safety case, ASN requested the operator to implement as soon as possible changes in the design of the sump filters. ASN also asked for further investigations in order to verify the acceptability of certain data, particularly as regards the definition of the area of destruction of the fiber material and the coating due to the break, or the rate of vertical transport of debris. ASN also considered that physico-chemical phenomena and the possible formation of precipitates should be investigated without delay. As a consequence, EDF changed the filters and increased their surface on all the French NPPs between 2005 and 2009.

Total Surface Increase	
Before 2005	After strainers replacement
From 30 to 90 m ²	From 600 to 1900 m ²

Table 1 – Increase of Filter Surface on French NPPs

Three types of strainers are nowadays installed on French NPPs (cf. figure 2).

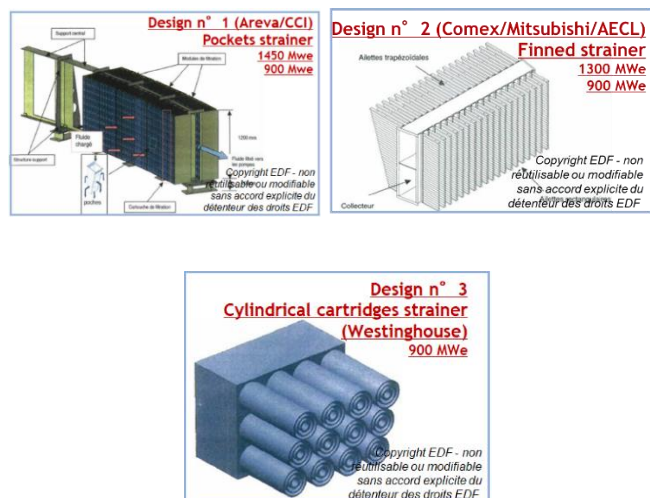


Figure 2 – Strainers designs installed on French NPPs

In parallel, to support the reviews of EDF safety case, IRSN launched in 2004 an experimental R&D program on the clogging (by physical and chemical effects) of the sump strainers and downstream effects.

In 2008, following several other anomalies impacting the ECCS function, ASN requested EDF to conduct a complete review of the ECCS function and in particular to provide a robust and exhaustive demonstration of the recirculation efficiency in the framework of the extended operation of 900MWe plants beyond 40 years.

IRSN reviewed this demonstration and ASN concluded in 2014 that additional elements had to be presented to justify the plants operation extension, especially regarding transport of the debris in the reactor sump, ECCS and CCS pumps NPSH margins, the chemical effects on strainers and fuel assemblies clogging and the operability of the downstream equipments.

In the framework of the 4th periodic safety review of 900MWe NPPs, IRSN reviewed in 2018 and 2019 the additional studies submitted by EDF, in order to provide a technical position in March 2020, as requested by ASN.

Between 2016 and 2020, in order to support the review of EDF demonstration of operation extension of 900MWe plants and to better investigate some aspects related to the impact of debris on strainers and on fuel assemblies, IRSN has undertaken an extensive research program, making use of VIKTORIA experimental facility to perform confirmatory testing. The VIKTORIA loop, co-funded by IRSN and VUEZ and operated by VUEZ at Levice in Slovakia was constructed in 2011.

The objectives of the experimental program were the following ones [3] [4] [5]:

- to collect data concerning the transport and settling of the debris in the reactor sump;
- to investigate the increase of the pressure drop across the filter (due to physical clogging) for different kinds of debris source terms with relevant thermal hydraulic conditions (water temperature and flow velocity on the strainer surface);
- to investigate the long term evolution of the differential pressure across the filter (at least for 30 days) in compliance with the temperature profile and the sump water chemistry during a LOCA (typically in French 900 MWe NPPs, the water contains boron and soda and the insulation materials contain Sodium and Potassium);
- to investigate the downstream effects (clogging of fuel assemblies grids) on a fuel assembly mock-up including a representative lower support plate, a bottom nozzle with its anti-debris grid, a spacer grid and a mixing grid.



Figure 3 – The VIKTORIA Test Facility

For this project, the VIKTORIA test facility includes key features (same filters - at reduced scale - as the ones installed on French NPPs, debris injection and mixing tanks, simulated fuel assemblies) in order to obtain the most representative conditions possible according to IRSN. The tests have been carried out for all types of filters.

4. OPERATION EXTENSION OF 900MWe NPPs: IRSN MAIN CONCLUSIONS

4.1 Main Conclusions from IRSN Tests

The findings of the VIKTORIA experimental tests have confirmed some IRSN concerns and raised particular questions about the recirculation performance.

The first tests campaigns (2016-2017) lead to the following conclusions [3].

Regarding sedimentation and transport, only 45% to 52% of the injected debris reach the filter. The largest particles (concrete and paints mainly and part of the fiberglass) settle before reaching the strainer.

Regarding physical clogging of filters, different configurations can occur depending on debris injection scenario: thick or thin debris bed. "Thin bed" configuration corresponds to a small amount of fibers which forms a thin layer on the whole filtering area (about 3 mm on CCI filter), on which will agglomerate small debris such as particles. "Thick bed" configuration corresponds to a maximized and homogeneous repartition of debris on the filter. The penalizing configuration may be different depending on the strainer design. Consequently, it is recommended to perform tests with both debris injection scenarios. .

Regarding the chemical effects, the temperature and chemical characteristics of the sump water may have a strong impact on the strainer head loss (strainer head loss can be multiplied by 3 for CCI filters). On this subject, in order to understand more deeply the results of experiments taking into account sump water temperature profile and representative water chemistry, PhD works are on-going at IRSN on this subject for LOCA and for severe accidents conditions [6].

Furthermore, additional tests performed in 2018 and 2019 showed that filters and fuel assemblies clogging can be very sensible to various parameters, such as:

- debris nature and characteristics (granulometry, length, insulation material type, presence of organic binder...);
- debris quantity but also fibers/particles ratio;
- timeline of debris introduction;
- fibers preparation mode.

In particular, some specific insulation materials such as microporous insulating material (Microtherm®) or fibrous insulation material with aluminum (Protect1000S) may strongly participate to the strainer and fuel assembly physical and chemical clogging.

Consequently, IRSN notes that the safety demonstration relies on a precise characterization of debris and on the kinetics of their arrival on the filters, parameters which are difficult to estimate for all LOCA scenarios.

Based on the tests results, IRSN concludes that drastic reduction of fibers quantity seems necessary in order to get acceptable head losses of strainers and fuel assembly. Moreover, quantity of Microtherm® and Protect1000S insulation materials should be strongly reduced.

4.2 Main Conclusions of IRSN expertise (March 2020)

IRSN examined the new elements transmitted by EDF in 2018 and 2019 to justify life extension of 900MWe NPPs.

IRSN focused its expertise on the main following points:

- the mass and nature of the debris (from insulation materials and paints) to be considered in the recirculating water;
- the reassessment of the risk of malfunctioning of ECCS and CCS pumps by cavitation;
- the characterization of the transfer downstream the sumps filters of debris likely to have an impact on the core cooling;
- the chemical effects that could occur on the clogging of the filters and the fuel assemblies.

The conclusions of IRSN expertise [2] have incorporated the lessons learned from the VIKTORIA tests and the international feedback from surveys and bilateral meeting with counterparts.

4.2.1 IRSN Position in March 2020 regarding Equipments and Operational Modifications

Concerning the insulation materials in the reactor buildings, IRSN considers necessary that EDF:

- remove the microporous insulating material (Microtherm®), which is still present at the vessel inlet of few reactors;
- implement (on all 900 MWe reactors) modifications on the insulation materials to sufficiently reduce the quantity of fibers likely to be generated in the event of a break in the primary circuit.

4.2.2 IRSN Position in March 2020 regarding Additional Studies, Tests and Qualification

In addition to the study of equipments and operation modifications, IRSN considers that EDF must perform additional tests under conditions as representative as possible (presence of boron, soda, corrosion products, temperature ...) and covering a sufficient set of configurations (sump filter technologies, location and size of breaks, quantity of debris, various fiber/particle ratios ...).

Furthermore, IRSN considers that the following parts of the safety demonstration must be strengthened:

- the justification of debris quantities generated by a break on primary circuit, as well as the quantities of coating micro- debris, especially as EDF still plans to take credit of

- whip restraints¹ to limit break area;
- the justification of the penalization of the upstream and downstream debris source terms with respect to all debris combinations that may be generated in the different primary circuit break situations (quantities, particle/fiber mass ratio, thin bed effect on the strainer, filter technologies).

Finally, after implementing insulation modifications and updating accordingly the debris source term, the absence of risk of ECCS and CCS pumps cavitation and the cooling of fuel assemblies with debris-loaded water should be demonstrated.

4. CONCLUSIONS

During the last two decades, the sump water filtration issue has been the subject of numerous studies and researches by EDF and several reviews and tests by IRSN. IRSN assessments therefore integrate the lessons learned from VIKTORIA tests and up-to-date state of knowledge on the filter clogging and fuel assembly coolability.

In March 2020, IRSN provided its technical position regarding the operation extension of the French 900MWe NPPs, and especially on sump performance issue under LOCA and severe accidents conditions [7].

Regarding sump performance issue under LOCA conditions, IRSN considers necessary that EDF implement (on all 900 MWe reactors) modifications to the insulation material to sufficiently reduce the quantity of fibers likely to be generated in the event of a break in the primary circuit and to remove Microtherm®.

Moreover, IRSN considers that EDF must perform additional studies and tests to complete its safety case on the following subjects: chemical effects on clogging, justification of the quantity of debris generated by pipe restrained breaks and justification of the penalization of the upstream and downstream debris source terms with respect to all debris combinations that may be generated in the different primary break situations (sump filter technologies, location and size of break, quantity of debris, various fiber/particle ratios, thin bed effect on the strainer ...).

Following IRSN position, EDF has committed to replace fibrous insulation materials at steam generator bottom by metallic insulation materials (RMI), to remove all Microtherm® and to reduce the quantity of Protect1000S insulation materials. EDF also decided to add sure hold bands on some parts of auxiliary pipes (pipes with large diameter located at SG bottom).

EDF also plans to conduct additional studies and tests to answer IRSN requests.

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¹ On French EDF NPPs (except EPR), primary circuit is equipped with pipes whip restraints.