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VIKTORIA experiments on sump filtration during a Loss Of Coolant Accident (DBA)

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ABSTRACT

During a Loss Of Coolant Accident, in French PWR's, 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 Refueling Water Storage Tank (RWST), water is taken from the sump in the lower part of the reactor building. A filtering system is implemented to collect debris produced by the pipe break as well as other latent materials, such as fiberglass, paint and concrete particles, and to minimize the amount of debris entering in the ECCS and CSS systems. IRSN has launched an experimental R&D project investigating the clogging of the sump filter by integral tests performed in the VIKTORIA loop. The main objectives are to investigate the head loss of the filter (physical and chemical clogging) for prototypic upstream debris source term in relevant thermal hydraulic conditions (water temperature and flow velocity on the filter surface) in compliance with the temperature profile and the chemistry of the water in the sump during a LOCA transient. For that, the VIKTORIA loop was equipped successively with two types of 2 m² filters use in French 900MWe NPP's. The tests highlight the settling of the largest particles (concrete, painted chips) and part of the fibers; the transport of debris (roughly 55 to 65 % of the injected debris source term) leads to the physical clogging of the filter. The debris carried to the filter generate at 80°C (with chemistry) a very quick increase of the pressure drop across the filter (≈ 7 kPa) that could be due to rapid chemical effects further to fibers corrosion. At the end of the 80°C plateau, a pressure drop increase was observed due to the temperature decrease in agreement with the water viscosity evolution. The two types of filters (rectangular cartridges or planar types) behave very differently with rather low head losses for the second type; $\approx 1,5$ kPa. Nevertheless, downstream debris source term appears to be more significant with the planar filter (compared to the filter with cartridges) during the first hour of injection before the fibrous debris bed formation. We have also observed more stabilized "cake", during the (7 days) medium term evolution compared to that for rectangular cartridges filter due to motion of debris inside cartridges.

KEYWORDS: Sump filtering, LOCA, debris, head losses, rectangular cartridge or planar filter

1. INTRODUCTION

During a Loss Of Coolant Accident, in French PWR's, water is injected by the Emergency Core Cooling System to ensure the long-term core coolability and by the Containment Spray System to remove residual heat and to maintain containment integrity. After the drainage of the Refueling Water Storage Tank, water is taken from the sump in the lower part of the reactor building. A filtering system is implemented to collect debris produced by the break as well as other latent materials, such as fiberglass, paint and concrete particles, and to

minimize the amount of debris entering in the ECCS and CSS systems. IRSN has launched an experimental R&D project investigating the clogging of the sump filter by integral tests performed in VIKTORIA loop (**Figure 1 a**). The objectives are to investigate the head loss of the filter for typical upstream debris source term in relevant thermal hydraulic conditions (water temperature and flow velocity on the filter surface) with the temperature profile and the chemistry in the sump water during a LOCA. For that, the VIKTORIA loop was equipped successively with two types of filters used in French 900MWe NPP's (**Figure 1**).

Figure 2 describe the different part of the VIKTORIA loop, which comprises, several tanks for the sump modelling and a downstream device including a mock-up of a fuel assembly (F.A) to performed integral tests.

The scale factor are 1/250 or 1/213 according to the filter.

2. TESTS CONDITIONS

This section describes the thermal hydraulics parameters (§ 2.1) for the reactor that have been used to perform the VIKTORIA experiments as well as the upstream debris source term (§ 2.2). The tests matrix concern few experiments among those performed since 2017 in the frame of R&D to support IRSN expertise.

2.1 Thermal hydraulics parameters

Table 1 gives information that has been used to perform the experiments. The scale of the VIKTORIA loop versus the NPP was defined according to the ratio between the total filtration surface available in the reactor sump (526 m² or 456 m²) and the filter surface for VIKTORIA (2,1 m² – rectangular cartridge filter or 2 m² - planar filter).

Table 1 Characteristics of VIKTORIA/NPP

Parameter	NPP conditions	VIKTORIA
Sump volume	1650 m ³	6.6/7,5 m ³
Filter surface	526/456 m ²	2,1/2 m ²
Flow rate 1 train	2130 m ³ /h	8,52/10 m ³ /h
Approach velocity	1,125 mm/s	Same

It's very important to respect on one hand the surface ratio and the flow rate ratio, for physical plugging of the filter, and on the other hand the volume ratio with the right amount of water for chemical process between debris and chemical products available in the water, such as boric acid and soda.

The total volume of water can be adjusted by the water level in the external tank (Figure 2).

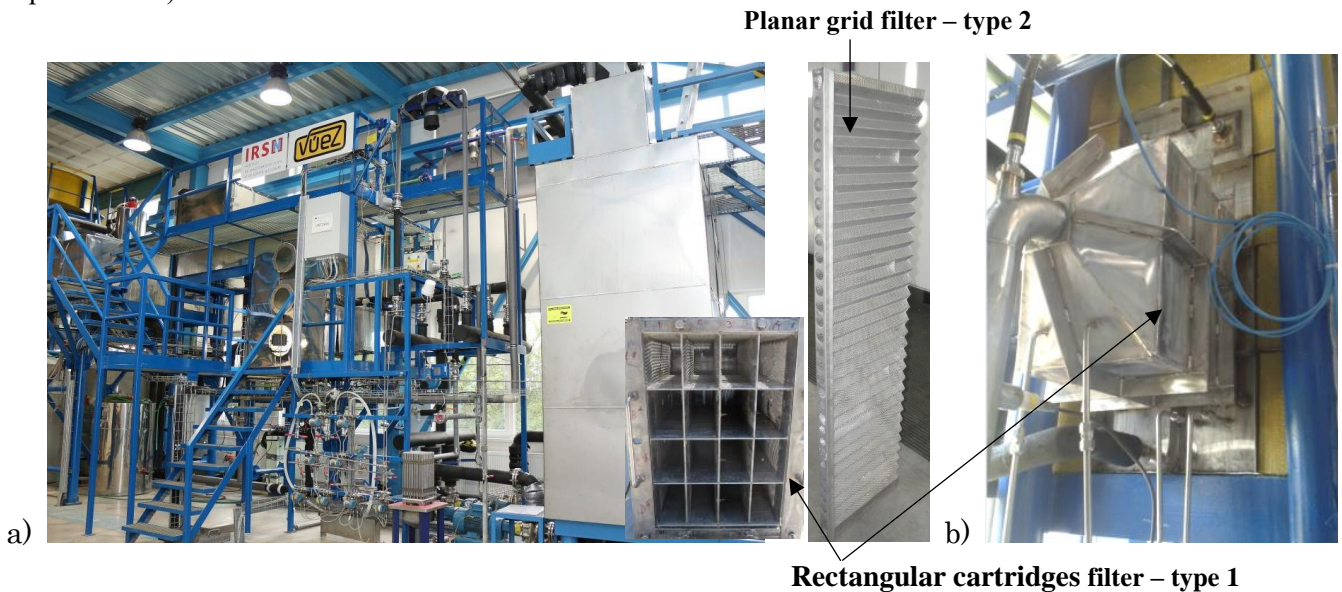


Figure 1 – a) A picture of VIKTORIA Test Facility, b) type 1 filter implementation

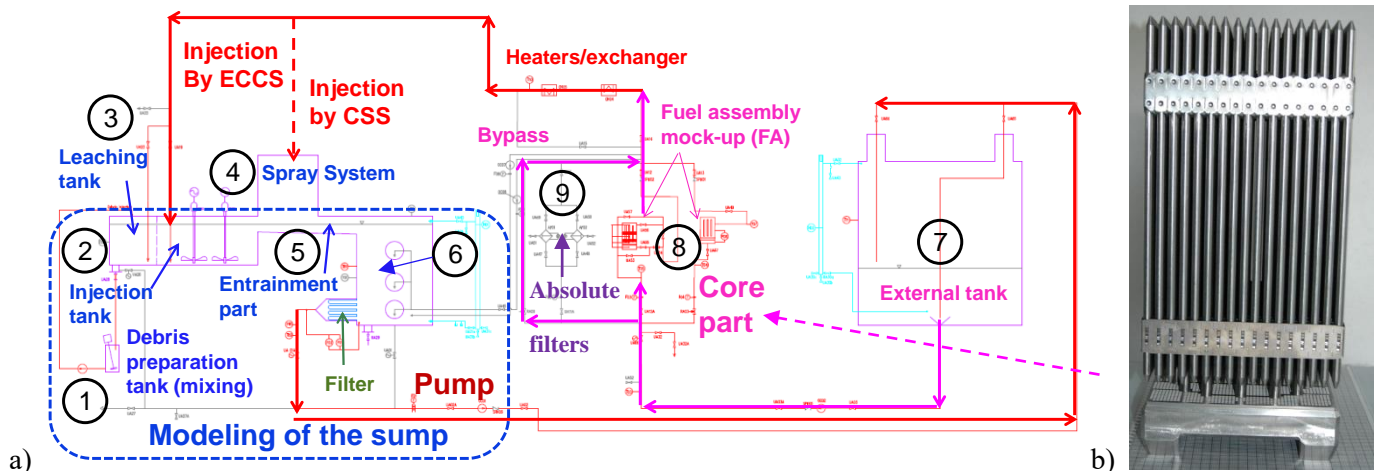


Figure 2 – The VIKTORIA loop

Fiberglass	Painting debris	Concrete powder debris	Fire wall products
ISOVER 785 NE	As chips < 10 mm ²	Class 1 ($\phi < 100 \mu\text{m}$)	MECATISS type
Length : 0,5 mm ($\phi \approx 8 \mu\text{m}$)	Thickness = 100-200 μm	10 kg (produced during the break)	(fibrous insulation)
1010 kg	300 kg	Class 1 ($\phi < 100 \mu\text{m}$)	25 kg
(600 kg not to the filter)	As fine powders	Class 2 ($100 < \phi < 500 \mu\text{m}$)	Ca₂SiO₄ panel
PROTECT 1000S	Gr 1 ($5 < \phi < 20 \mu\text{m}$)	40,5 kg	25 kg
($\phi \approx 5 \mu\text{m}$)	Gr 2 ($20 < \phi < 50 \mu\text{m}$)	Class 3 ($500 < \phi < 1000 \mu\text{m}$)	Silicon foam
40 kg	136 + 128 kg	40,5 kg	50 kg

Table 2 – Type of debris from PWR NPP ([1]) used during VIKTORIA experiments (mass at the reactor scale)

2.2 Debris source term

The upstream debris source term (DST), including insulation materials as fiberglass (**Figure 3**) and powder, painting chips and particles, concrete particles and specific products used as firewall protection, is representative of real materials that may be transported to the filter during the recirculation process. Table 2 gives the main characteristics of the debris (real materials) and the masses injected in the loop (in brackets the values not transported to the filter but presents for chemical concerns – located in the part 3 in **Figure 2**).

For tests investigating transport phenomena silicon carbide (SiC) particles were used instead of coating powder, as proposed by PWROG [2] [and approved by USNRC/ACRS [3]. SiC particles, with diameter similar of Gr1, and the coating powder ones are characterized by a close settlement velocity, and both inert against corrosion.



Figure 3 – Type of fibers (785NE and PROTECT)

2.2.1 Debris preparation

Preparation of fibrous debris follows the NEI guide "ZOI Fibrous Debris Preparation" - January 2012 Revision 1 [4]. Batches of fiberglass, manually removed from the conditioning rolls, are placed for 8 hours on a hot plate at 300 °C +/- 40 °C to simulate aging. Fiber separation is accomplished a few minutes before the start of the tests and by using a high pressure water jet at 10 MPa during 4 minutes.

Non-fibrous debris (painting, concrete, MICROTHERM® insulation of any) are poured in the debris preparation tank (part 1 in **Figure 2**) and mixed together with or without fiberglass before injection in the injection tank of the loop (part 2 in **Figure 2**). Agitators are used in order to avoid debris sedimentation before the transfer of the debris to the filter.

2.2.2 Injection of the Debris in the loop

Thick bed tests correspond to tests with a homogeneous injection of the source term of debris. For these tests, equal batches of debris mixture (non-fibrous debris + fiberglass) are injected discontinuously at the beginning of the tests.

We refer to the recommendations of the NEI Generic Guideline for Test Protocol [5] and the know-how of VUEZ to limit the concentration of debris upstream of the filter (batches of debris injected must not exceed 1/16 of the final theoretical thickness of the fiber bed and time injection interval of debris injected into the test loop must be at least 10 minutes: all the debris are injected within 4 hours).

The series of tests were conducted according to requirements of the RG 1.82 [6] using the conservative assumptions with regards to the plugging of the main filter assuming that the total load of debris arrives to only one available train of ECCS and CSS.

2.3 Reduced test Matrix

Numerous VIKTORIA experiments (up to 50) were performed since 2017 (reported in [7, 8]) with various parameters:

- debris with different type of fibers, real painting powder and surrogate as SiC, presence of particulate insulation as MICROTHERM®,
- water flowrate, temperature profiles,
- presence or not of chemical products...

T1.x tests series correspond to experiments for debris transport/filter clogging investigation without chemistry and T2.y integral tests series taking into account the chemistry by adding soda and boric acid in the demineralized water.

The conditions of the tests reported here are given the Table 3.

Large number of tests were performed with the type 1 filter, T2.13 is the first one for which MICROTHERM® was suppressed in the upstream debris source term [10]. T2.15 was the first test performed in representative conditions as in the reactor case (*i.e temperature profile and chemical composition of the water*) with the planar type filter configuration.

Test n°	Filter type 1 or 2	Water	Duration
T2.13	Rectangular (1)	80→55°C	3 days
T1.9-1/2	Planar grid (2)	30°C	1 day
T1.10	Planar grid (2)	80°C	2 days
T2.15	Planar grid (2)	80→51°C	7 days

Table 3 – VIKTORIA reduced test matrix

In order to catch the effect of the different parameters, and the behavior of a new type of filter, 3 tests are necessary: a two day test at high temperature (80°C) to be compared to a one day test (at 30°C representative of the temperature at the end of the filtration process for the reactor case) for the effect of the water temperature and the 3 or 7 days tests for the effect of the water chemistry and the temperature evolution during a LOCA representative temperature profile.

At the beginning of such tests, before debris injection, boric acid was added to obtain a total boron mass concentration of about 2500 ppm in the circulating fluid. NaOH (concentration 1800 ppm) was also added in the solution in order to reproduce the buffered cooling water representative during the post LOCA transient.

3. MAINS EXPERIMENTAL RESULTS

The main experimental results on which we focused our analyses are the debris transported to the filter, the corresponding head losses and the debris passing through the main filter (downstream debris source term) that may impact the head losses on the grids of the fuel assembly by debris collection.

3.1 Debris transferred to the filter

After each experiment, debris are collected from different parts of the VIKTORIA loop and dried out in order to make the mass balance with the injected debris in the loop to investigate the competition between sedimentation and transport to the main filter.

Figure 4 gives the debris distribution in the different parts of the loop. The non-injected debris, less than 5 % (remaining the so-called injection tank - part 2 in **Figure 2**) correspond to large and heavy concrete particles (Class 2 and 3). Most of the debris were transported to the compartment filter (part 6 in **Figure 2**): 20 to 40% (*according to the water temperature*) of debris settled at the bottom part (mainly fibers), whereas 55 to 65% where collected on the main filter. We clearly see the effect of the water temperature on the transport phenomena due the water viscosity which impact the settled velocity of the debris.

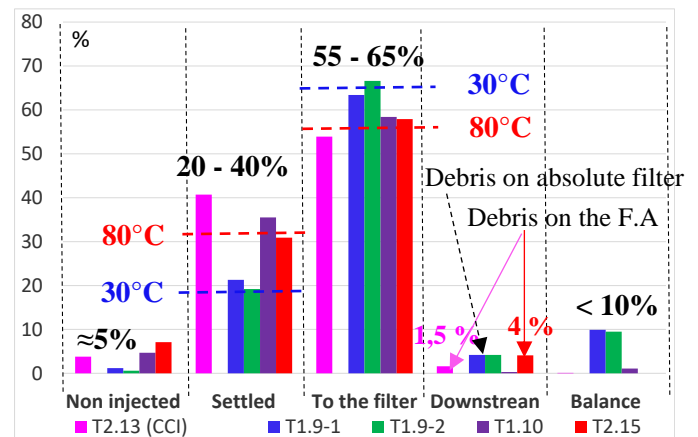


Figure 4 – Distribution of debris in the loop

2 to 4% of debris were collected on the downstream fuel assembly mock-up with significant difference (factor 2) for the two type of filters, that may be due to the size of holes of the grids (\varnothing 2,1 mm for rectangular cartridge and 2,5 mm for planar type filter).

Figure 5 illustrates for the two type of filters, the debris collected in the rectangular cartridges (a) or on the planar grids. We clearly observed that the rectangular cartridges are completely fill with debris whereas the thickness of debris bed on the planar filter type appears to be lower, that may impact the head losses.

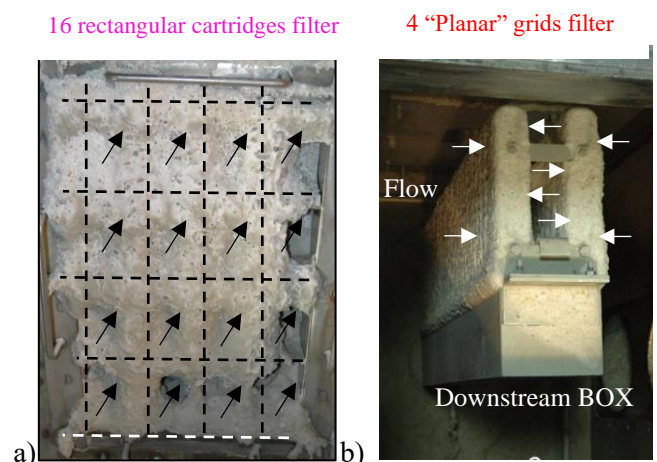


Figure 5 – Debris collected on the two type of filters

Remark: the debris collected in the different cartridges or planar grids, are rather well distributed (less than +/- 10%), that shows clearly the homogeneous flow velocities in front of the filter (arrow on the **figure 5**).

The knowledge of the right amount of debris transported to the filter, allowed the analyses of the head losses evolution.

3.2 Head losses on the main filter

Figure 6 gives the evolution of the head losses for the two representative tests T2.13 and T2.15 performed with roughly similar conditions and two types of filters. Debris are injected according to the procedure (cf. §2.2.2) during the first four hours, with a water temperature fixed at 80°C for around two days plateau.

At the end of the injection phase, the ΔP reached respectively 7 and 1.5 kPa leading to the highest head losses for the type 1 filter. For this type of filter, decrease of ΔP during the transient corresponds to motion of debris inside the cartridges (due to the design); these phenomena were often observed during previous tests [7]. Later in the transient, the decrease of the temperature lead to increase of head losses according the evolution of the water viscosity. At the end of the test (at 30°C), the two types of filters outlined very different head losses, respectively 3,4 kPa for planar type filter and 10/12 kPa for rectangular type filter, i.e a factor 3 that may be due

to the geometry of the design (planar grids or rectangular cartridges). As the ΔP (across the debris bed thickness ΔL) are governed by formula such as the NUREG [9]:

$$-\frac{\Delta P}{\Delta L} = \left[a_0 S^2 \cdot (1 - \epsilon_m)^{1.5} [1 + 57(1 - \epsilon_m)^3] \mu v + b_0 S \cdot \frac{1 - \epsilon_m}{\epsilon_m^3} \rho v^2 \right] \quad (1)$$

ρ: density, v : velocity, μ: viscosity, ε_m : porosity

The thickness of the debris bed on the filter, cross by the water flow rate, has a direct impact on the resulting head losses. So, we may suppose that in the case of planar grids type filter (**Figure 7**), the thinner layer would lead to less ΔP for roughly the same amount of debris.

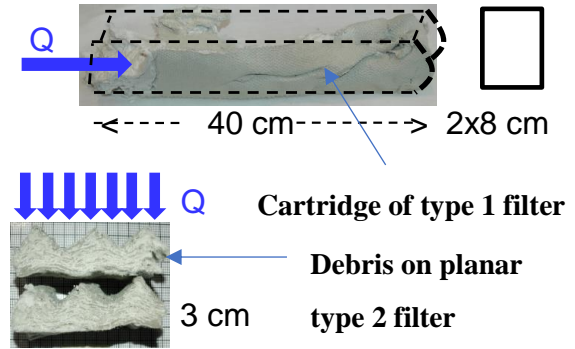
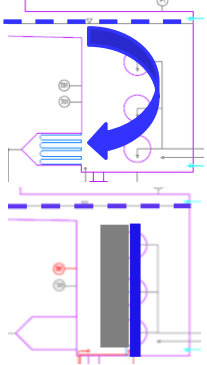
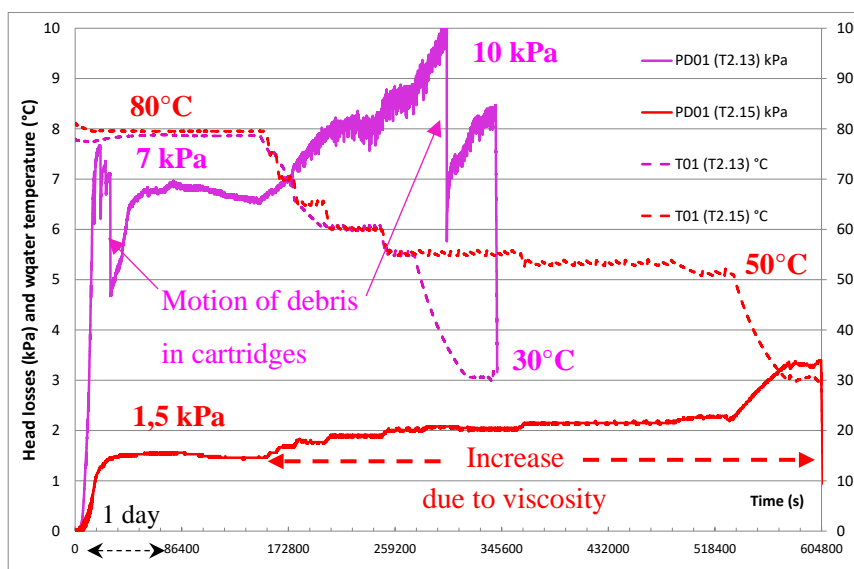


Figure 7 – Debris collected on the two types of filters

Head losses with a rectangular filter



Head losses with a planar filter



Effect of geometry of the filter > X 3

Figure 6 – Comparison of head losses for two types of filters: rectangular cartridges and planar grids

At the end of the tests, decrease of the flow rate allows the determination of the characteristics ΔP = f (V). With rather low velocity (1-3 mm/s), the inertial term (proportional to v² – Equ 1) was found to be quite negligible, then the head loss is proportional to the flow velocity and the viscosity of the water (Equ. 1). So, the head losses may be given for the same temperature by viscosity correction.

Figure 8 illustrates the head losses evolution at similar temperature (30°C) for tests T1.9-1/T1.9-2 performed at 30°C and T1.10/T2.15 (initially performed at 80°C with temperature transient down to 30°C). Tests at low temperature were run with the same conditions and lead to roughly similar ΔP (0,6-0,7 kPa), which indicates the repeatability of those experiments.

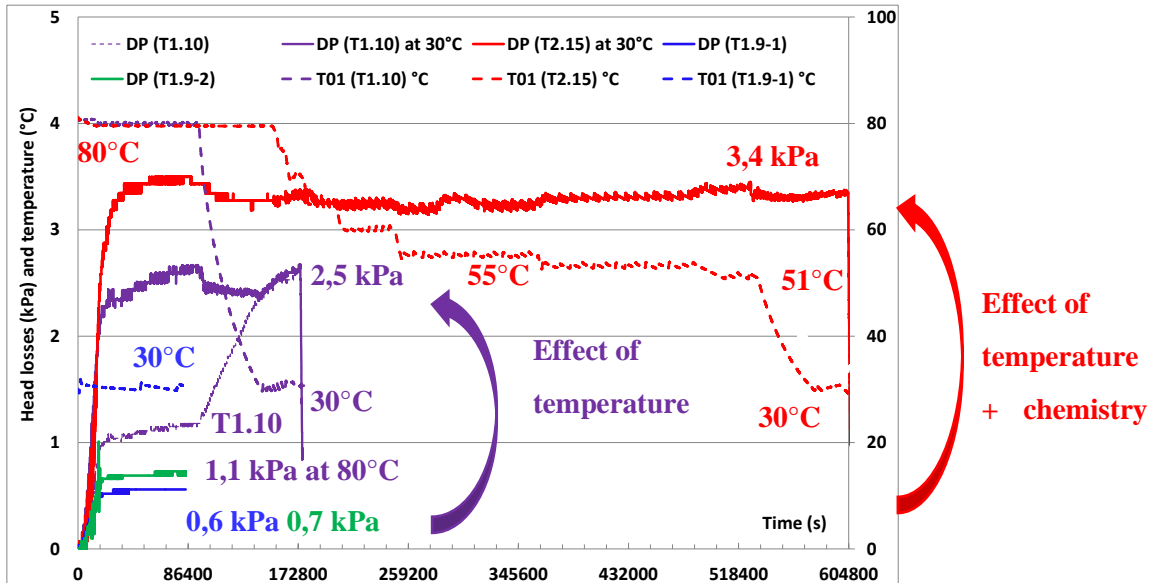


Figure 8 – Main results of VIKTORIA tests for planar filter type

The comparison of the ΔP of those tests with T1.10, respectively 0,65 kPa and 2,5 kPa corrected at 30°C shows clearly the effect of temperature due to corrosion of the debris that may produce precipitates on the debris bed, that have been well characterized during previous VIKTORIA campaigns [6, 7]. This phenomenon leads to factor 3 on head losses.

The presence of chemical products in the water (boric acid and soda) enhanced the corrosion of the debris which lead to additional increase of the ΔP up to 3,4 kPa.

One additional remark, is that corrosion of debris occurred soon, early at the beginning of the high temperature plateau. This justify to perform tests during only few (3/7) days to investigate long term phenomena: the duration of the recirculation process may last up to one year (even more), during accidental sequence on N.P.P after a Loss Of Coolant Accident scenario.

3.3 Debris transferred downstream

Those integral tests allowed the analyses of the downstream impact beyond the main filter by absolute filters (part 9 in **Figure 2**) for the evaluation of the Downstream Debris Source Term, or the debris collected on the grids (part 8 in **Figure 2**) of the Fuel Assembly mock-up (F.A) and the corresponding consequence on the head losses.

Even if it represents a small amount ($\approx 4\%$) of the DST, part of the debris crossing the main filter collected on the fuel assembly module, during the integral experiments, generates significant pressure drops on the grids, in particular in the case of the type 2 filter, up to 100 kPa, early during the transient (**Figure 9**).

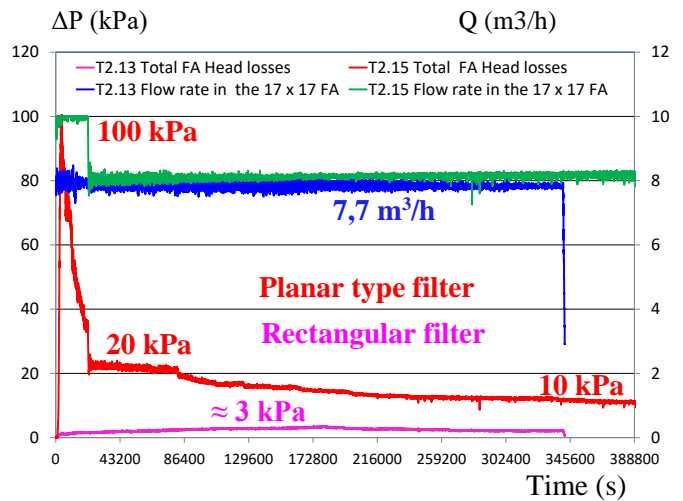


Figure 9 – Head losses in the fuel assembly (FA)

Remark: during the injection phase, all the water flow rate was directed to the F.A (without bypass - part 9 in **Figure 2**) in order to be sure that all the downstream debris will be transferred to the grids. Then, the water flow was reduced to 7,7 m³/h (nominal flow in one fuel assembly in the 900 MWe French N.P.P).

The ΔP decrease during the transient (down to around 10 kPa) due to the formation of bypass (between the grid and tah wall of the test section) explained by the high force on the debris collected on the grids (**Figure 10**) due to the water flow rate.

The analyses of the results show clearly less consequence on F.A head losses in the case of the rectangular type filter: it was the contrary regarding the head losses on the main filter.

The total mass collected in the fuel assembly, were respectively 27 g (with rectangular filter) and 206 g (with planar type filter): the highest value observed with planar type filter is confirmed by the amount of debris collected by the absolute filters (249 and 229 g for T1.9-1/T1.9-2).

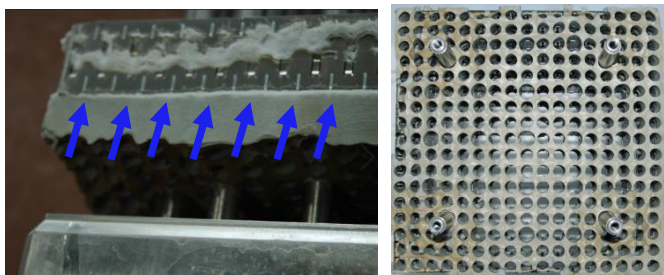


Figure 10 – debris on the grid of the fuel assembly (FA)

Remark: the total mass of debris collected downstream the main filter (**Figure 4**) takes into account in one hand, debris in the Absolute filters or on the F.A grids (mainly fibers) and, in other hand particles (mainly SiC as simulate of painting powder) collected the external tank (par 7 in **Figure 2**): between 40 to 70 g depending on the tests.

During the detailed analyses of the previous tests [8], we have found in the F.A, mainly fibers (estimation in the order of 90%/95% with 5 to 10% of particles).

4. CONCLUSIONS

The two types of filters (rectangular cartridges or planar grids types) behave very differently with rather low head losses for the second type ($\approx 1,5$ kPa at 80°C and $3,4$ kPa at 30°C). Large head losses were observed with the rectangular cartridges filter (7 kPa at 80°C and $10/12$ kPa at 30°C). Nevertheless, downstream debris source term appears to be more significant with the planar filter during the first hour of injection before the fibrous debris bed formation. We have also observed more stabilized “cake” on the filter, during the (7 days) medium term evolution compared to that observed for rectangular cartridges filter due to motion of debris inside the filter.

Thanks to the suppression of MICROTHERM™ (insulation powder) [10] and the reduction of fibers amount, filters head losses allow normal operation of the safety pumps, contrary to that observed for previous experimental campaigns [8] with large amount of fibers including fine MICROTHERM™ particles.

The observations realized during these campaigns of tests demonstrate the need to carry out tests at high temperature with the real “chemistry” in the water to highlight potential phenomenon and to provide relevant

assessments. Those experiments were useful to complete our understanding to analyze the core coolability during the recirculation process and propose validated conclusions for the IRSN safety expertise [10].

REFERENCES

- [1] EDF personal communication (non published)
- [2] PWR Owners group, Evaluation of Long-term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid, WCAP-16793-NP, Revision 2, October 2011.
- [3] ACRS letter- “Draft safety evaluation of WCAP-we16793-NP, Revision 2, “Evaluation of long-term cooling considering particulate, fibrous and chemical debris in the recirculating fluid”, Oct 2012.
- [4] ZOI Debris Preparation: Processing, Storage and Handling, Revision 1, Nuclear Energy Institute, January 2012.
- [5] Nuclear Energy Institute: Generic Guideline, Strainer Fiber Bypass Test Protocol, Revised Draft 12/7/2011.
- [6] US Nuclear Regulatory Commission, Water Sources for Long-term-recirculation Cooling following a Loss-Of-Coolant Accident, Regulatory Guide 1.82 , Revision 4, March 2012
- [7] G. Repetto, B. Migot, JF. Trigeol and V. Soltész, “VIKTORIA experiments investigating the filtering system in the sump of a PWR after a Loss Of Coolant Accident - Part I Physical /chemical effects on strainer head loss evolution” Proc. of 2018 *International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-18)*, Portland, Oregon, August 18–22, 2019.
- [8] G. Repetto, B. Migot, C. Heib and V. Soltész, “VIKTORIA experiments investigating the filtering system in the sump of a PWR after a LOCA - Part II Downstream effects,” Proc. of 2018 *International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-18)*, Portland, Oregon, August 18–22, 2019.
- [9] G. Zigler , J. Brideau, D.V. Rao, C. Shaffer, F. Souto, W. Thomas, “Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris” NUREG/CR-6224, (1995).
- [10] J.F. Trigeol, E. Pariaud, E. Dixneuf and G. Repetto, “Operation Extension of 900MWe NPPs: French TSO Main Conclusions regarding Long Term Sump Performance after a loss of coolant accident”, OCDE/NEA Specialist Workshop on reactor core and containment cooling systems – long term management and reliability, Levice, Slovakia, 6-8 September, 2021.