CORE COOLABILITY IN LOSS OF COOLANT ACCIDENT: THE COAL EXPERIMENTS

Repetto G., Marquié Ch., Bruyère B. and Glantz T.
Institut de Radioprotection et de Sureté Nucléaire,
Cadarache, 13115, BP3, Saint Paul lez Durance,
georges.repetto@irsn.fr; christophe.marquié@irsn.fr; tony.glantz@irsn.fr

ABSTRACT

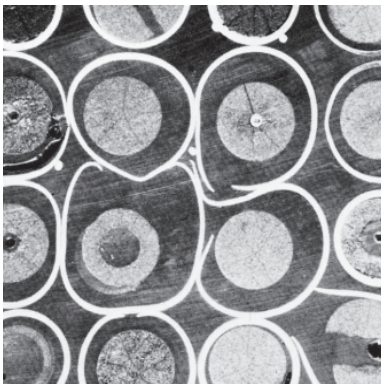
During an accident causing the loss of the primary coolant (LOCA), partial or even complete drying of the fuel assemblies may occur. In these conditions, the fuel temperature increase and the coolant pressure drop in the reactor core may lead to significant deformation and rupture of the fuel rod cladding. Fuel fragmentation may occur, leading to fuel relocation within the ballooned area. Depending on the size and the distribution of the ballooned areas within the fuel bundle, the cooling flow might be impaired, which may challenge the fuel assembly coolability and, by extension, the core coolability. The COAL experiments focus on the outstanding issue of the coolability of a partially deformed fuel assembly, in particular the study of the thermal hydraulics behavior in the ballooned area, during cooling phase by water injection with the safety systems.
Antagonistic influences due to the presence of a blockage will be evaluated through a semi integral experiment using a 7x7 bundle geometry at the full length scale. On one hand, the reduction of the section between the deformed fuel rods will increase the flow velocity. On the other hand, the flow bypass from the deformed fuel rods in the blocked region to the peripheral intact rods (cross-flow phenomena), will lead to a reduction of mass flow in the sub channels of the blockage and therefore the heat transfers. The possible presence of water droplets in the steam flow may modify this trend. Their role in heat transfer is important, whether through the heat extracted at their impact on the walls or via their vaporization in the bulk flow. Due to their inertia, their paths do not necessarily follow that of the steam flow path.
This paper presents the test section, the thermal hydraulics parameters for the experiments and pre-calculations using DRACCAR code developed by IRSN. The results of these experiments will help to refine and validate the heat exchange models implemented in the code.

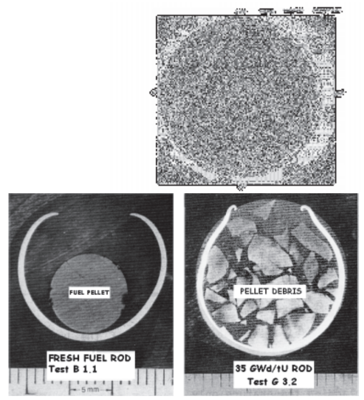
KEYWORDS
Coolability, Blockage, LOCA, Fuel relocation, Reflooding experiments, DRACCAR

1. INTRODUCTION

During an accident causing the loss of the primary coolant (LOCA), partial or even complete drying of the fuel assemblies may occur. In these conditions, the fuel temperature increase and the coolant pressure drop in the reactor core may lead to significant deformation and rupture of the fuel rod cladding. Fuel fragmentation may occur, leading to fuel relocation within the ballooned area. Depending on the burnup of the fuel rod, extensive fragmentation may also lead to fuel particles dispersal into the coolant through the ruptured cladding. Depending on the size and the distribution of the ballooned areas within the fuel bundle, the cooling flow might be impaired, which may challenge the fuel assembly coolability and, by extension, the core coolability.

The results (Fig. 1), which illustrate this phenomenon, come from an experimental LOCA program performed, in the 1980's by the Institut de Protection et de Sûreté Nucléaire former IRSN [1], in 5x5 bundle including fresh fuel rods. All the LOCA experiments performed with irradiated fuel rods (in particular two examples, at 35 GWd/t for FR2-Germany preformed in 1983 [2] (Fig. 2a) and at 90 GWd/t, more recently (2006) in Halden-Norway [3] (Fig. 2b)) have shown an accumulation of the fragmented fuel pellets in the ballooned region [4]. The resulting increase of the power density in the ballooned area may also affect the core coolability.



a) 

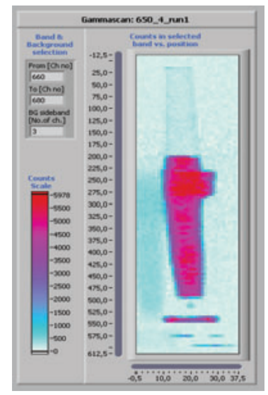
b) 

Figure 1. Bundle of deformed fuel rod Phebus LOCA experiments (1983)

Figure 2. Fuel relocation in the ballooned area a) FR2 Fuel rods fresh or irradiated b) Halden test (2006)

So, the consequences of both deformations and fuel relocation on the cooling efficiency when reflooding the core by the ECCS (emergency core cooling systems) are important safety issues, and have never been experimented.

The knowledge generated by these new experiments will answer long shared concerns by the international community (such as the effect of fuel relocation in blocked areas in the core), and will allow to validate the DRACCAR code [5] developed and used by IRSN to simulate any prototypical LOCA transient. The need of this kind of experiments has been proposed in 2005, in the NURETH11 [6].

2. COOLABILITY OF BLOCKED REGION WITH FUEL RELOCATION

The domestic and international state of the art describing the context and the need of coolability of blocked regions is synthesized in some IRSN publications [1, 7] and internal literature reviews [8, 9].
The main lessons are summarized below. Based on the previous experimental programs (FEBA [10], SEFLEX [11], THETIS [12, 13], ACHILLES [14], FLECHT [15], CEGB [16]), the experimental conditions, including the characteristics of the blockage (blockage ratio, length of the maximum blocked area, cladding thickness in the ballooned zone.) and the initial thermal hydraulic test conditions, the phenomena listed below have been ranked accordingly to their impact level:

1. Representativeness of the blockage,
2. Influence of the blockage ratio,
3. Influence of the length of the blockage,
4. Influence of the blockage configuration: coplanar versus non-coplanar,
5. Influence of the flow bypass,
6. Influence of the nature of the reflooding: forced versus gravity.

The analysis of these phenomena can specify limits of the blockage coolability in the most penalized geometry (length and rate) and thermal hydraulic conditions. Thus, it seems that the blockages although important, if of moderate length (<100 mm), pose no significant cooling impairment, as one might be tempted to conclude in view of only FEBA [10] and SEFLEX [11] results, a 90% blocking is always coolable. It was also shown that the maximum ratio of 90% blockage is not necessarily the most case penalizing the cooling if the deformation is axially extended. Regarding CEGB analysis [5], a possible impaired coolability has been outlined, in the case of long ballooning with high blockage ratio (>80%).
It also follows, from this analysis [9], that the understanding of the deformation and rupture mechanisms of the fuel cladding is a fundamental concern: in fact, the deformation and swelling of the claddings are causing the blockage of sub-channels, and cladding rupture freezes this deformation balancing the internal and external pressures of the fuel rod. Therefore, it is first necessary to understand the mechanisms of deformation and fracture (thermal mechanical behavior) to investigate realistically the effects of the blockage on the thermal hydraulic. All the experimental results and the main outcomes regarding cooling of partially blocked assemblies were obtained on out-of-pile tests using bundles with electrically heated "fuel" rods. Since the heating axial profiles of the simulators were uniform and preset, the tests didn't reproduce the impact the fuel relocation in the ballooned areas as observed in the in-pile tests performed on irradiated fuel rods (FR2 [2] and Halden IFA-650.4 test [3]. The fuel fragments relocation results in a local increase of the power density depending on the filling ratio. However, the significant difference between test results comparable to FEBA [10] and SEFLEX [11] programs suggests [5] a strong coupling between the heat source and the deformed claddings, as it may exist in a balloon filled with fragmented relocated fuel; this may significantly deteriorate the cooling of blocked regions. So the configuration of the rods used in the past was not representative of the real situation. Fuel relocation, as observed in several in-pile LOCA tests with irradiated fuel (listed above), and its potential impact on the local cooling of the blocked areas, have to be investigated and properly modelled.

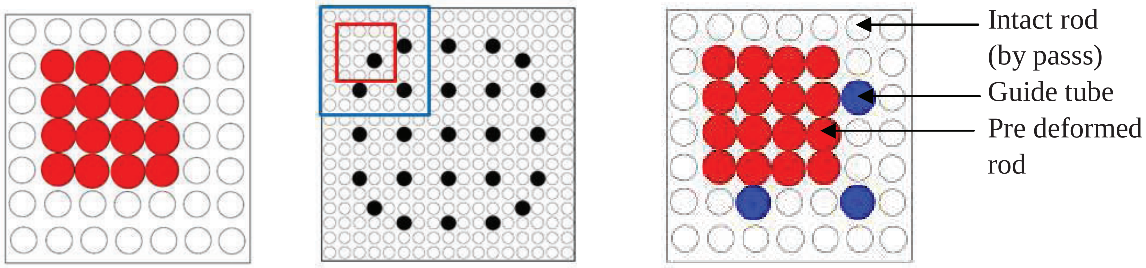
Antagonistic influences due to the presence of a blockage will be evaluated through a semi integral experiment using a 7x7 bundle geometry at the full length scale. On one hand, the reduction of the section between the deformed fuel rods will increase the flow velocity. On the other hand, the flow bypass from the deformed fuel rods in the blocked region to the peripheral intact rods (cross-flow phenomena), will led to a reduction of mass flow in the sub channels of the blockage and therefore the heat transfers. The possible presence of water droplets in the steam flow may modify this trend. Their role in heat transfer is important, whether through the heat extracted at their impact on the walls or via their vaporization in the bulk flow. Due to their inertia, their paths do not necessarily follow that of the steam flow path. More detailed activities foreseen in collaboration with a research laboratory of the Lorraine University (LEMTA) will focus on the characterization of two phase flows with heat transfer in deformed structures at a smaller scale. The work foreseen in this area is described in the more general paper on the PERFROI project [17, 18].

3. THE COAL EXPERIMENT

The COAL program will concern thermal hydraulics experiments on a bundle of electrically heated rods, with simulation of large blockage and fuel relocation.

3.1. The test section and the bundle geometry

The bundle will consist of rods (electrically heated), some with pre-deformed zone with local overheating representing fuel relocation. The test bundle will be made of 49 (7x7) rods (including 16 deformed rods and 33 non deformed rods – Fig. 3a), similar to that of the THETIS [12, 13] tests performed in the past by AEA Winfrith UK in 1983-1984, which will also allow experimental comparisons. This configuration was preferred to that of ACHILLES [14] to limit the number of electrical rods. The COAL bundle will include 3 guide tubes and grids to be as representative as possible of a real PWR fuel bundle.



a) Basis geometry b) PWR type Grid c) Chosen configuration

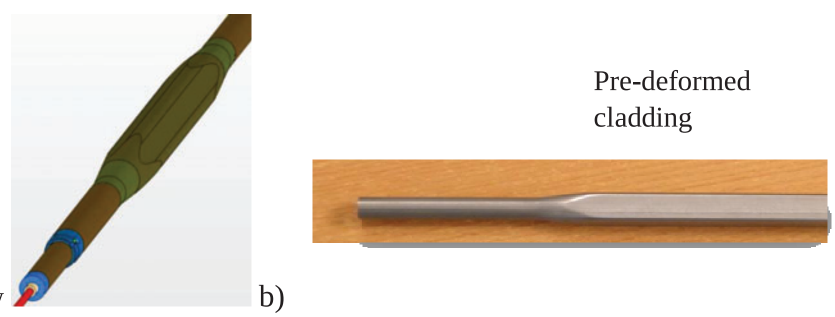
Figure 3. Typical bundle fuel rods for COAL experiments

For these experiments, the cladding of the electrical rods was proposed to be constructed with Hastalloy material to prevent oxidation. To avoid any chemical interaction, the grids should be in Inconel alloy.
It was initially foreseen to cut a real Inconel PWR (17x17) grid for the COAL grid (7 x 7) test section, we added 4 guide tube positions (Fig. 3b). So the presence of guide tubes will increase the representatives of the thermal hydraulics behavior for the reactor case: there are will also necessary for instrumentation and of course, mechanical reason. Nevertheless, it was decided to suppress the guide tube in the deformed area to facilitate the analyses of the results. The chosen configuration is illustrated in Fig. 3c).
Inconel PWR grids are no more available, so a specific fabrication for the COAL bundle has been launched with a design including mixing vanes that would have an effect of thermal hydraulic behavior.
The heating zone is about 3 m hight (close to the real PWR geometry) and roughly 100 mm in diameter.
It should be noted that COAL is a program to be conducted in an existing ad -hoc thermal hydraulics facility (cf section 3.3).

3.2. The SAFRAN electrical prototype rod

The first step was to develop a prototype of the electrically heated test rod with a local overheated balloon (so-called SAFRAN electrical rod - Fig. 4). The main technical difficulties identified at this stage are related to the manufacturing of the test rods, including an adapted instrumentation operational at high temperature and high pressure (3 MPa).

a) schematic view



b)

Figure 4. Electrical deformed fuel rod prototype (SAFRAN)

SAFRAN is a real technological challenge, i.e. besides obtaining a representative tube geometry (Fig. 4a), the following constraints have been added: technique should allow extended test rods manufacturing at a reasonable cost, thermocouples to be welded on the outer surface of the cladding and the resistor should survive multiple cycles in corrosive steam above 1000°C and several quench phases. The validation of the process of the pre deformed balloon (Fig. 4b) has been done in 2013.

During the qualification performed in 2014 on small scale SAFRAN rods (300 mm with a 50mm for the hottest zone), different kinds of resistors (3), insulators (1) and configuration of the heaters have been tested and allow the final design (Fig. 5a) of the electrical rods for the COAL bundle. Specific care has been taking to be as much as possible representative * of the thermal conductance of the UO_2 providing the residual power to the cladding: so aluminia balls (Fig. 5b-1 or 5c) or compacted powder are possible, according to the rod provider, to represent the debris inside the ballooning. The thermal impact of the two solutions is weak according to DRACCAR evaluations.

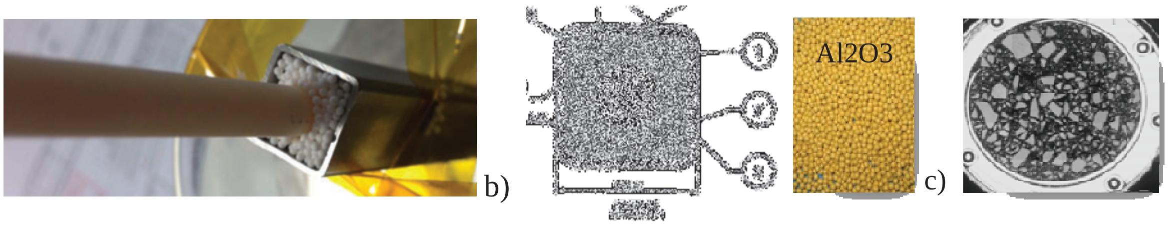


Figure 5. Detail of the design of rod prototype (SAFRAN)

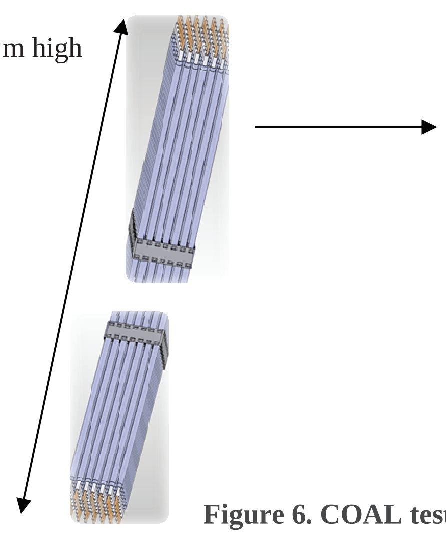
The design of the test section, including the instrumentation, is in progress: the construction of the first bundle is foreseen by the end of 2016. This test section will be inserted in an out of pile thermal hydraulics loop which can simulate the reflooding phase of a prototypical LOCA transient (cf. following section).

3.3. The thermal hydraulic loop

COAL experiments will be performed in the AREVA BENSON facility at Erlangen (in Germany) which allows running high pressure tests to 3 MPa (30 bar). This facility is operating since roughly 40 years for different kinds of experiments in the thermal hydraulic field [19].
Figure 6 describes the circuit of the BENSON facility able to carry out reflooding experiments without important modification, including the installed power needed for heating the electrical rods.

a) COAL Test bundle

3 m high



b) **BENSON facility**

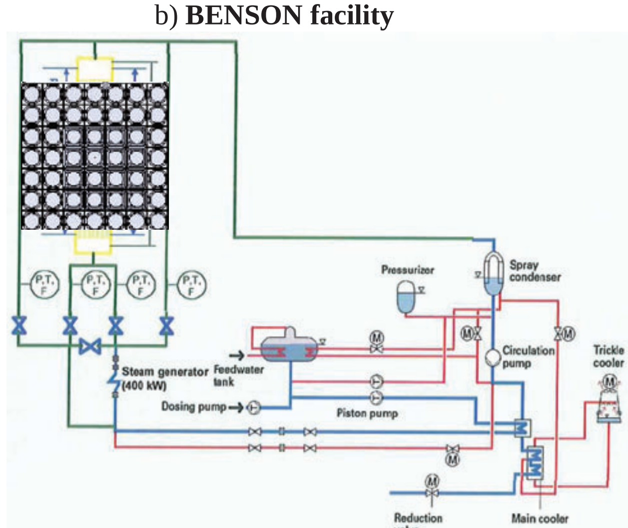


Figure 6. COAL test bundle and circuit of the BENSON facility

* We recall that this aspect has conduct IRSN to demonstrate that the typical rods tested in the 80's was not representative of the real situation in case of fuel accumulation –cf §2)

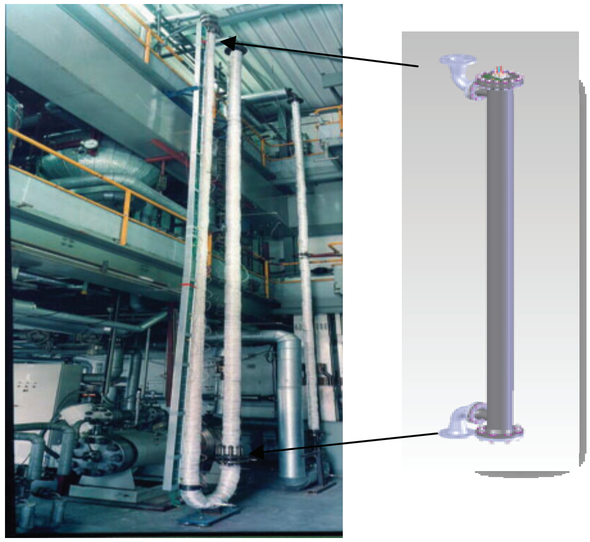


Figure 7. BENSON facility at Erlangen and COAL Test Section

The work will proceed in two steps:

1. Qualification tests will be performed by the end of 2016 on a bundle with non-deformed heated rods. These tests will be used as a reference tests in order to qualify all the experimental process and to compare with already performed experiments such as PERICLES*,
2. Then tests with heated pre-deformed simulators, including local overheating of the balloon regions, will be performed from 2017 up to 2019. Three series of tests are planned with different flow blockage ratios or ballooning lengths (cf. section 3.5). In each series, the effects of thermal hydraulic parameters (cf. section 3.4) will be carefully investigated. The third campaign is optional and depends on the results of the previous campaigns.
3. Finally, all the tests will be analyzed and interpreted. The objective is to validate a heat transfer model adapted to bundle conditions, to be implemented in DRACCAR code [20].

The experimental parameters of the test campaigns will be defined in order to investigate the bundle geometry related phenomena (blockage ratio, balloons lengths) and the thermal hydraulic related phenomena (local overheating of the balloons, injected water temperature, coolant flow rate and system pressure levels and kinetics to simulate various break sizes).

3.4. The scenario and the thermal hydraulic test parameter

The scenario is divided in two phases as classical "Reflooding experiments" already performed in the 80's such as FEBA for example:

1. Heat up phase in dry steam atmosphere,
2. Reflooding by water injection with thermal hydraulic conditions.

The main thermal hydraulics parameters foreseen are in the range below:

- inlet water flow velocity : 1 to 8 cm/s,
- coolant pressure : 0.1 to 3 MPa (30 bar).

* Low pressure reflooding experiment at steady flow-rate on a complete assembly of a pressurized water reactor. (Experiments carried out at the French CEA of Grenoble between 1983 and 1986).

An example of scenario is illustrated in Fig. 8, showing a comparison of FEBA reflooding experimental results compared to DRACCAR [21] and CATHARE calculations [22]. It's not the objective of the paper but the post-test calculation has been improved using DRACCAR compared to CATHARE.

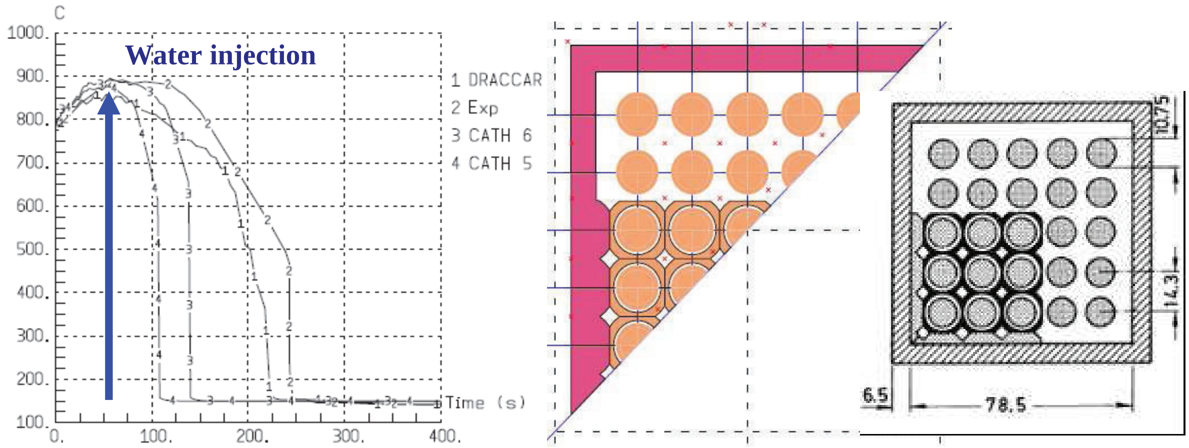


Figure 8. FEBA experiment: test results and simulation.

The range of the thermal hydraulics parameters (Tab. I) that should be tested is provided by results of CATHARE calculations for different break sizes (3 to 14 inches).

Table I. Thermal hydraulic conditions during Reflooding scenario

T/H parameters	Intermediate Break LOCA	Large Break LOCA
Pressure	2 to 6 MPa (60 bar)	0.1 to 0.5 MPa (5 bar)
Cladding Temperature before Reflooding	500 to 600°C	600 to 800°C
Inlet mass flow rate	2 to 25 kg/m²/s	20 to 30 kg/m²/s
Water temperature (under satured conditions)	0°C to 25°C	20 to 30°C
Power by fuel rod	1.5 to 3.0 kW	3.0 to 5.0 kW

The test matrices of those experiments (in progress) will take into account the possibilities of the BENSON loop (Tab. II).

Table II. Thermal hydraulic conditions for the BENSON loop

T/H parameters	Range of the possible values
Pressure	0.15 to 3 MPa (30 bar)
Cladding Temperature before Reflooding	500 to 700°C
Inlet mass flow rate	0 to 50 kg/m²/s
Water temperature (under saturated conditions)	Few degrees to 40°C

Others parameters (flow blockage - ratio and length of the deformed area) will be defined based on thermal hydraulics parametric studies. There are proposed in the following section.

3.5. The geometrical parameters (blockage area)

The blockage region is foreseen to be located in the middle position (Fig. 9 a) with a cosine power (P) profile (Fig. 9c). Table III gives the configuration chosen for different blockage areas: for the first deformed bundle, the nominal blockage ratio should be 80% with a maximal deformation height of 100 mm (with170 mm for the total height of the ballooning taking into account the up and down stream interfaces with the nominal diameter : Fig. 9b). The geometry of the second bundle corresponds to a so called long ballooning situation. For bundles 1 and 2, the balloons are coplanar. The idea is to progressively increase the total pressure drop of the blockage. For the optional configuration we have proposed a reduction of blockage ratio (down to 61% which corresponds to state of the beginning of the contact between fuel rods) or a non coplanarity of the balloons (blockage at different elevations).

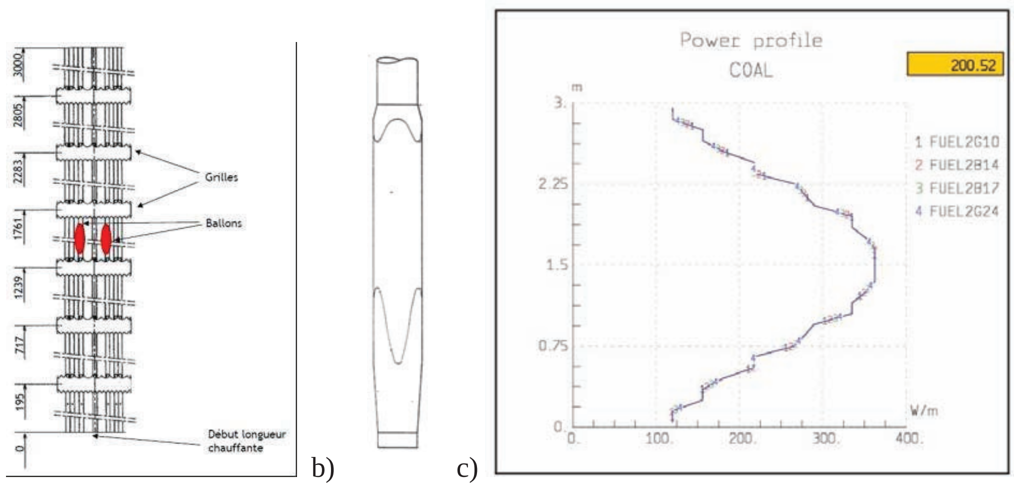
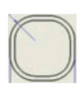
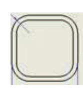
a) 

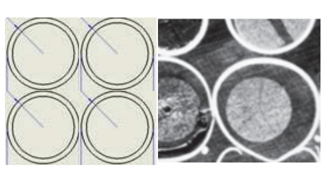
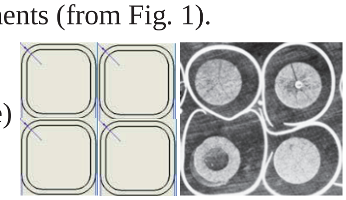
Figure 9. Axial position of the blockage area

Table III. Preliminary proposition for the geometrical parameters

Parameters	Bundle 1	Bundle 2	Bundle 3a*	Bundle 3b*
Blockage ratio (symmetric) and rod shape	80 % 	90% 	61% 	90%
Total height of the ballooning area	170 mm	370 mm	370 mm	370 mm
Height of the maximal deformation (**P x 2**)	100 mm	300 mm	100 mm	300 mm
Coplanarity of the balloon	Yes	Yes	Yes	No

*options (not yet defined)

The propositions will be representative of a significant blockage zone for 3 ratios: 61%, 80 and 90%, which have been really observed in particular in the Phebus LOCA experiments (from Fig. 1).

61% (first contact)  80 or 90% (larger blockage) 

4. THE PRELIMINARY PRECALCULATION USING DRACCAR CODE

The simulation tool DRACCAR [5, 20, 21, 23], developed by IRSN, with the support of EDF, is at this stage, used to define some parameters of the experiments such as the blocked bundles geometry, the heat-up scenario of the bundles or the test matrix. Then DRACCAR will be used to perform the pre-calculation of all the tests foreseen in COAL experiment.

4.1. Brief description of the code

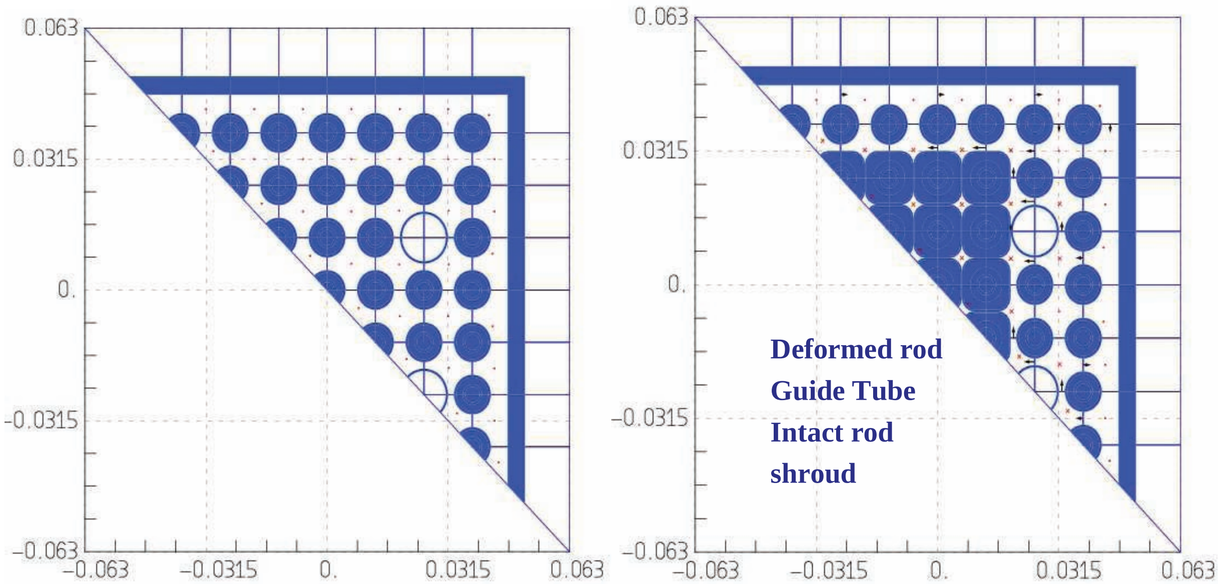
DRACCAR is a simulation tool for fuel assembly mechanical behavior and coolability assessment during a LOCA transient. Its aim is to simulate the 3D thermomechanical deformation and reflooding of a fuel rod assembly including its coolability as well as structure embrittlement.

The DRACCAR code is based on a 3D non-structured meshing able to model a simple fuel rod, a partial or a full assembly, as well as a surrounding shroud. It is based on an axial discretization of the rod which leads to analyze quasi-independent 2D thermal mechanical problems. Important modeling such as pellet eccentricity, heat transfers (within the solid and through the fluid) or material properties evolutions (oxidation layer, phase changing,...) can thus be taken into account and the cladding integrity during a LOCA transient can be addressed even in case of contact between the structural elements. In that case, the geometry is strongly changed (flattened zone contact) as well as the loading nature (mixed stress–displacement loading) and so the rupture is more difficult to model than a threshold criteria used in most of the multi-rod codes: with DRACCAR, nonlinear geometrical effects are added to non-linear behaviour laws in the modeling. Also important is the possibility to get a better knowledge on the system's capability to cool structures whatever are the evolutions of the deformation of the rods and the blockage of the sub-channels. Obviously these two critical issues which are essential to treat in modeling LOCA transient effects, can only be dealt with in a realistic manner with a multi-pin code coupled to an efficient 3D thermal hydraulics code, and that's why DRACCAR is currently coupled to the two phase flow module CESAR of the ASTEC code [24], able to compute deformed geometry evolutions thus actualizing the coolant flow passage within the different sub-channels.

Many results have already been obtained with the DRACCAR code with respect to a substantial validation matrix (e.g. FEBA [10, 21], HALDEN IFA 650 [25], PERICLES [21], PHEBUS 218 [26], REBEKA 6 [27], ROSCO [21], SEFLEX [11, 21] experiments) in the field of a LOCA type transient.

4.2. DRACCAR modeling of COAL experiment.

The bundle is simulated on a height equivalent to the rods heating length, with the square housing (metallic shroud in the same material as the cladding). One boundary condition at the inlet and one at the outlet of this portion close the system. The intact bundle is composed of 46 electrical rods and 3 guide tubes. The ballooned bundles included 16 rods with a local swelling. In the balloon, the fuel fragment is simulated by a porous material which has a density and conductivity close to those of the UO_2 pellet. Taking into account the symmetry of the test sections, half a bundle is modeled (Fig. 10). Several rods deformations have been tested with DRACCAR, the one presented in Fig. 10b is composed of balloons that have a height of 100 mm and are all positioned at the same elevation at the middle of the bundle, leading to a 90% blockage of the test section. The axial power profile imposed in the intact rods has a cosine shape (Fig. 11a). The relocation in the balloon has been simulated by setting a specific axial power profile in the ballooned rods (Fig. 11b). This last power profile has been determined by a DRACCAR calculation of fuel relocation in a pre-deformed rod. The axial meshing takes into account the axial power profile discretization and the balloon geometries. The meshes height never exceeds 100mm (smaller in the ballooned area). Six Grids are taken into account by setting a singular pressure loss at their positions.



a) Intact bundle b) Ballooned bundle

Figure 10. DRACCAR simulation of different bundles

Several rods deformations have been tested with DRACCAR, the one presented in Fig. 10b is composed of balloons that have a height of 100 mm and are all positioned at the same elevation at the middle of the bundle, leading to a 90% blockage of the test section. The axial power profile imposed in the intact rods has a cosine shape (Fig. 11a). The relocation in the balloon has been simulated by setting a specific axial power profile in the ballooned rods (Fig. 11b). This last power profile has been determined by a DRACCAR calculation of fuel relocation in a pre-deformed rod. The axial meshing takes into account the axial power profile discretization and the balloon geometries. The meshes height never exceeds 100mm (smaller in the ballooned area). Six Grids are taken into account by setting a singular pressure loss at their positions.

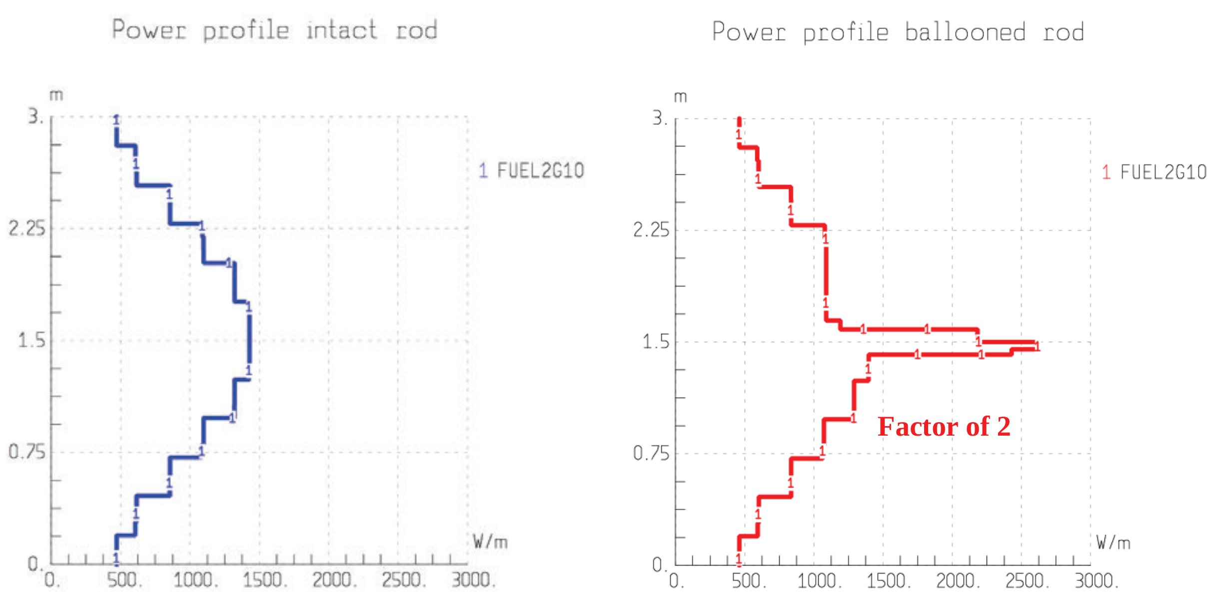


Figure 11. Axial linear power profile of rods for intact rods a) and b) for ballooned rods with simulation of fuel fragments relocation

A typical COAL test will be separated into two phases (section 3.4), the first one dedicated to the heat-up of the test section and the second to the reflooding. The housing or shroud has to be at a temperature close to the rods temperature at the end of the first phase; otherwise it would create a cold spot in the test section which would disturb the reflooding. As a consequence, the housing or shroud has to be heated.
The main issue is that the housing doesn't heat-up at the same rate as the rods.

Several DRACCAR calculations have been performed to define a heat-up phase allowing to obtain a temperature of the shroud and the adjacent rods as close as possible before the reflooding. As a consequence, the test section is first heated up by steam. Then, only the shroud (housing) heating is performed and finally rods are heated-up. Figure 12 presents a DRACCAR simulation of the heat-up phase of the COAL intact bundle.

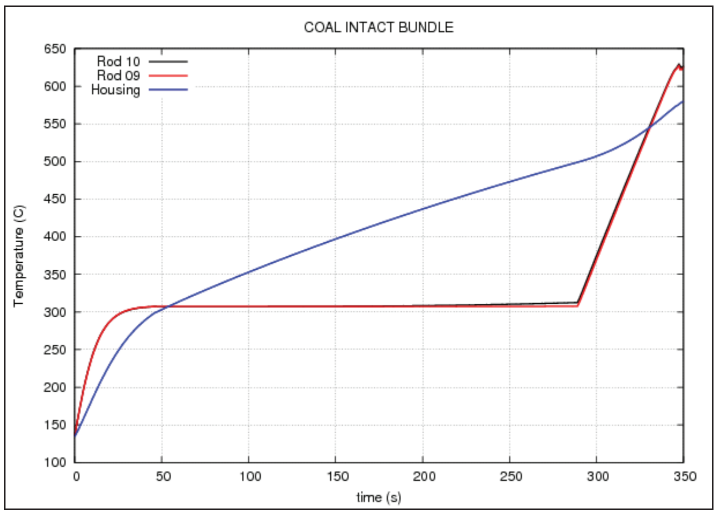


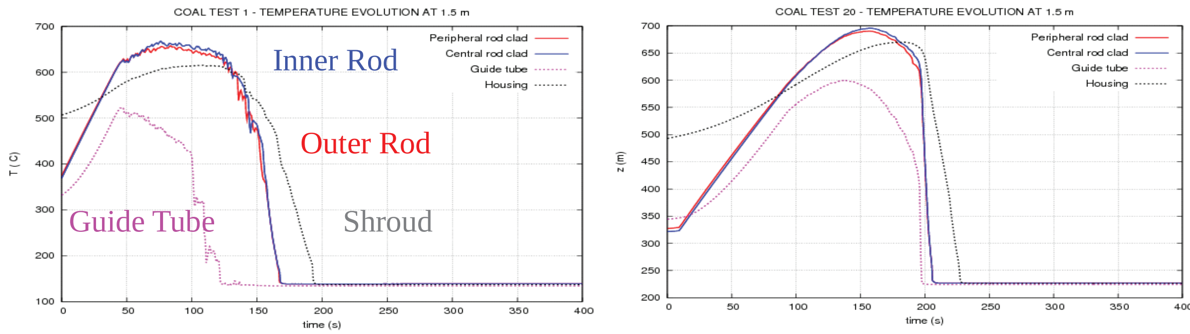
Figure 12. Heat-up phase of a COAL test

The heat up phase will lasted less than 10 minutes, before the water injection. The total duration of a COAL experiment would be less than ½ hour in order to perform numerous transient during one day (Target : 4 experiments a day in order to study numerous thermalhydraulics conditions which seems to be very challenging).

4.3. DRACCAR preliminary results

Several reflooding pre-calculations have been performed with the DRACCAR code. Figure 13 illustrates preliminary DRACCAR calculations for the intact bundle geometry for two thermal hydraulics conditions representative of large break LOCA reflooding (at 3bar) and for intermediate break LOCA (25 bar). In these cases, all the clad reached almost the same maximum temperature around 650/700°C, after water injection for a temperature threshold value at 600°C.

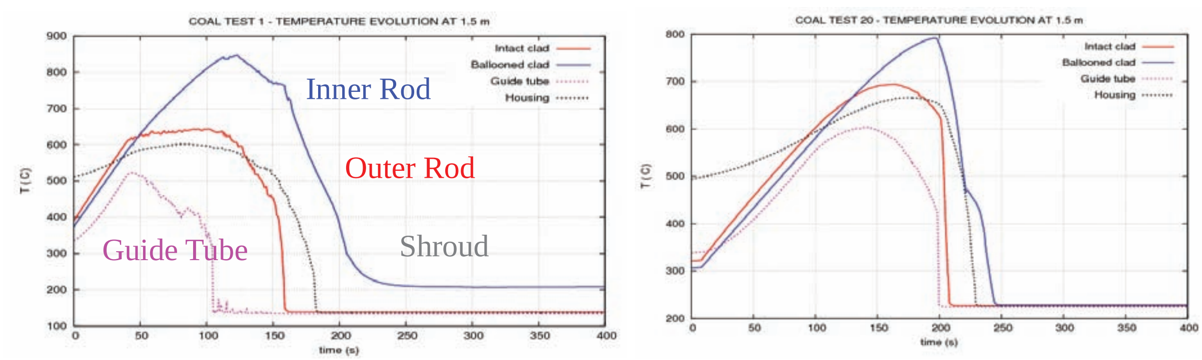
In case of thermal-hydraulics conditions representative of an intermediate break LOCA, the code predicts the coolability of a 90% blocked bundle with short length for the ballooning. For high pressure (25 bar), the quenching of the bundle appears more rapidly compared to the thermal-hydraulic conditions representative of a large break LOCA (low pressure at 3 bar).



a) b)

Figure 13. DRACCAR preliminary Calculations for intact bundle geometry - Clad temperature evolution at 1.5 m for intact bundle geometry for a) Large break LOCA reflooding (3bar) and b) for Intermediate break LOCA (25 bar).

Figure 14 illustrates calculations for the deformed bundle geometry for the two above thermal hydraulics conditions. The results outlined different behavior regarding the blocked area with an increase of the peak cladding temperature (PCT) of about 200°C for the low pressure configuration (650 to 850°C). Again, the reflooding appears to be more efficient at high pressure, limiting the PCT at about 800°C. The temperature stabilized after the reflooding (Fig. 14a) for the blockage region is under investigation.



a) b)

Figure 14. DRACCAR preliminary Calculations for deformed bundle geometry - Clad temperature evolution at 1.5 m for intact bundle geometry for a) Large break LOCA reflooding (3bar) and b) for Intermediate break LOCA (25 bar).

Experimental results are now needed to confirm the behavior predicted by the code and to validate the model implemented in DRACCAR.

The COAL tests matrix will cover the thermal-hydraulic conditions characteristics of a large break LOCA and those of an intermediate break LOCA. As far as possible, the same test conditions will be applied on the intact bundle and on the ballooned bundles, to be able to compare the impact of the blocked area with large ballooning on the fuel cladding.

4. CONCLUSION

Many experiments have been performed in the field of ballooned fuel bundle refloodind (FEBA, SEFLEX, THETIS, ACHILLES, FLECHT, CEGB), nevertheless, IRSN considers that the configurations used for the electrical rods were not representative of the real situation, in particular the fuel relocation (and the right thermal transfer of the heat from the heaters to the cladding) that may occur in case of irradiated fuel rods.

This paper presents the new COAL experiments on the reflooding of a deformed fuel bundle with simulation of the fuel fragments relocation inside the balloons. We have described the test section, the thermal hydraulics parameters for the experiments and some pre-calculations using DRACCAR code developed by IRSN, in order to prepare the experiments. The results of these experiments will help to refine and validate the heat exchange models implemented in the code studying the reflooding and the behavior of the code in the above configuration.

In addition to COAL experiments, it is foreseen to perform specific separate-effect-tests at the sub-channel scale[18] in order to improve our understanding on different processes involved in the reflooding of a deformed fuel assembly, which is not possible to get from an integral experiment.

NOMENCLATURE

COAL : COolability of a fuel **A**ssembly during **L**oca
FEBA: **F**looding **E**xperiments with **B**locked **A**rrays
LOCA: LOssOf Coolant Accident
SAFRAN : SimulAted **F**uel **R**od under loc**A** conditio**N**
SEFLEX: **S**imulator **E**ffects in **Fl**ooding **Ex**periments

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