The 14th International Topical Meeting on Nuclear Reactor Thermalhydraulics, NURETH-14
Toronto, Ontario, Canada, September 25-30, 2011

NURETH14-70

CORE RADIAL PROFILE EFFECT DURING REFLOODING, VALIDATION OF CATHARE2 3D MODULE USING SCTF TESTS

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Abstract

CATHARE2 is a best-estimate system code developed (CEA, EDF, AREVA-NP, IRSN) for PWR safety analysis. The 3D module has been developed to ensure a good description of the large scale thermal-hydraulic 3D effects taking place in a PWR vessel, and particularly during the reflooding phase of a large break loss-of-coolant accident.
This paper illustrates the CATHARE2 3D module assessment against SCTF forced feed reflood tests (ECC injection in the lower plenum) dealing with radial power profile effect on core cooling, focusing on cladding temperature profiles, upper plenum collapsed water level and quench front progression. These calculations assess the CATHARE2 3D module ability to predict the mixing phenomena and to describe the core radial profile effects. Quench front progression, 2D cross-flows and maximum clad temperatures are well predicted by CATHARE2.

Introduction

In a large Pressurized Water Reactor (PWR) with a non-uniform radial power distribution, the two-phase flow during the reflood phase of a Loss-Of-Coolant Accident (LOCA) is expected to concentrate from the lower power bundles to the higher power bundles because steam generation rate and flow rate are higher in these bundles and a natural convection effect is induced. In addition, the water accumulation behaviour in the upper plenum is also considered to affect the flow behaviour in the core. These two-dimensional effects are therefore expected to enhance the cooling of higher power bundles resulting in a lower peak cladding temperature in comparison to the case of one-dimensional fluid behaviour.

1. The CATHARE 2 code

The CATHARE code is a French system code for nuclear reactor thermal-hydraulics developed at CEA-Grenoble by CEA, EDF, AREVA-ANP and IRSN. It can model any light water reactor or test facility using several available modules (0-D, 1-D and 3-D modules).

Two-phase flows are described using a two-fluid six-equation model and the presence of one to four non-condensable gases can be taken into account by one to four additional transport equations. The code allows a three-dimensional (3-D) modelling of the pressure vessel.

The main purpose of the CATHARE 3-D module is the representation of large scale thermal-hydraulic 3-D effects in nuclear power plants. One of the main applications is the modelling of a Pressurized

Water Reactor (PWR) vessel but it can be extended to other geometries. The main phenomena to be addressed are the three main phases of a large break LOCA, i.e. the blowdown, the downcomer refill and the core reflood phases.
The 3-D module is based on the two-fluid 6-equation model. The basic set of equations consists of 10 thermal-hydraulics differential equations. The mass and energy balance equations are of primary form whereas the momentum equations are of secondary form. Up to 4 non-condensable gas transport equations can be added.
The numerical choices are finite volume discretization with structured mesh, first order discretization in space and time, staggered spatial mesh and donor cell principle, a semi-implicit scheme is used (Implicit-Continuous-Eulerian (ICE) method).
As the main objective is the PWR pressure vessel modelling, the CATHARE 3-D module is used with coarse meshing for the present study. Inertial force and interfacial friction play a dominant role in the phase distribution. Interfacial heat and mass transfer play also an important role. Therefore neither molecular nor turbulent diffusion is modelled. Interfacial transfers of mass, momentum and energy on the one hand and wall to fluid transfers on the other hand are modelled by means of a qualified set of physical closure relationships derived from the 1-D approach.
A specific validation program has been developed for the 3-D vessel application considering both separate effect tests and integral tests. It includes PIERO tests for lower plenum voiding, UPTF tests for downcomer refilling and downcomer boiling (UPTF tests 6 and 7, UPTF 25) and upper plenum behaviour (UPTF test 10C), PERICLES tests for core uncovery and for core reflood and two LOFT experiments (L2-5 and LP02-6) to cover a full LB LOCA transient (see [1]).

2. SCTF

The Slab Core Test Facility (SCTF) test program is part of a large scale reflood test program under a contract with the Atomic Energy Bureau of Science and Technology of Japan (see [2]). Major objective of SCTF program is to investigate two-dimensional thermal-hydraulic behaviours in a pressure vessel during the reflood phase of a Pressurised Water Reactor (PWR) Loss-Of-Coolant-Accident (LOCA).

2.1 Experimental set-up

SCTF was built in Japan (Tokai-Mura). It simulates a full radius slab section of a 1100 MWe PWR, of one bundle width. The flow area scaling ratio is equal to 1/21 whereas the height of every component is preserved. A schematic diagram of SCTF is shown in Figure 1 and the vertical cross section of the pressure vessel is shown in Figure 2, the test section width being of the order of magnitude of half a meter. Different core configurations have been investigated and this study deals only with SCTF core-II configuration.

The primary coolant loops consist of a hot leg equivalent to four hot legs, a steam/water separator corresponding to four steam separators, an intact cold leg equivalent to three intact cold legs, a broken cold leg on the pressure vessel side and a broken cold leg on the steam/water separator side. Each of the two broken cold legs is connected to a containment tank, the two tanks being connected to each other by a pressure equalizing line.
The Emergency Core Cooling System (ECCS) consists of an accumulator system and a low pressure coolant injection (LPCI) system.

The pressure vessel includes a simulated core, an upper plenum with internals, a lower plenum, a core baffle and a downcomer. The simulated core consists of eight bundles arranged in a row. The heating power of each bundle can be controlled independently during a test in order to investigate the core radial profile effects. Each bundle consists of 234 heated rods and 22 non-heated rods (16x16 array). The dimensions and pitch arrangement of the rods are based on a 15x15 fuel rod bundle of Westinghouse PWR type. To minimize the thermal effects of the wall, the core and the upper plenum are enveloped by honeycomb thermal insulators with wall plates.

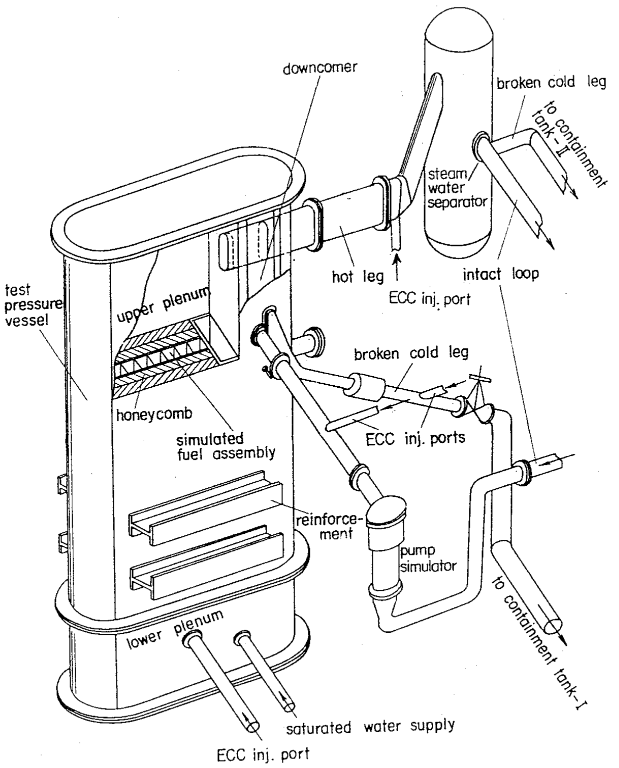

Figure 1: SCTF loop scheme

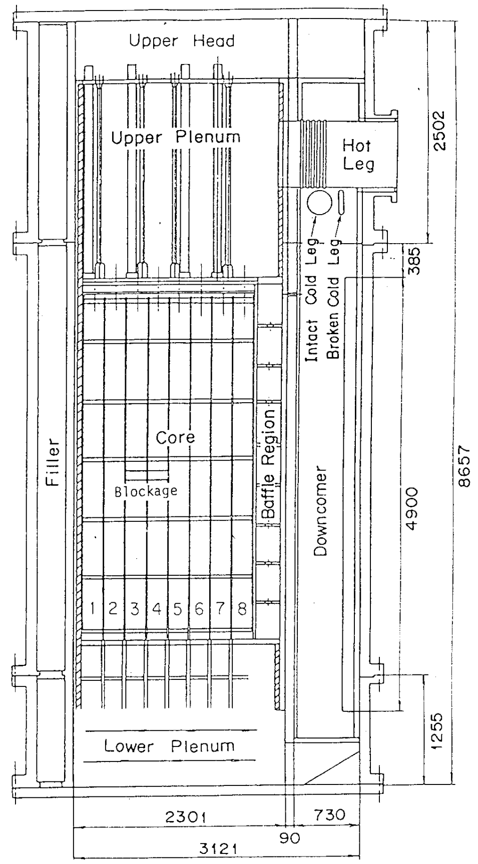

Figure 2: SCTF vertical cross section of the pressure vessel, core-II configuration

2.2 Experimental data presentation and analysis

All the selected tests deal with lower plenum ECC injection, also called forced feed mode. This corresponds to forced ECC injection into the lower plenum and closing of the bottom of the downcomer. This injection mode was adopted for a certain number of tests in order to obtain accurate boundary conditions at the core inlet, in opposition with the gravity feed mode with ECC injection into the cold leg. The gravity feed mode is indeed considered to better simulate the actual reactor but then the core inlet conditions (mass flow rate, sub-cooling) are affected by parameter changes such as the system pressure, the core heating power, etc.
The tests referred in this paper are the tests S2-10, S2-17 and S2-16 and their major test conditions are listed in Table 1.

All the tests follow the same procedure: after setting the initial conditions (pressure, saturated water level in the lower plenum, etc) the core heating is initiated. When four cladding temperatures exceed a specified value (max. core temp at Bottom of Core Recovery (BOCREC), see Table 1), the ECC injection in the lower plenum starts and the core heating power is kept constant. Forty seconds later, the core heating power is decreased along a specified decay curve. The tests are stopped nearly 900s later.

group	Base case	Flat Q and T	Steep Q and T
Feed mode **Test number**	Forced feed S2-10	Forced feed S2-17	Forced feed S2-16
ECC injection	Lower plenum	Lower plenum	Lower plenum
Initial system pressure (MPa)	0.2	0.2	0.2
Max core temp. at BOCREC (K)	1078	1033	1158
ECC mass flowrate (kg/s)	19.6	12.5	19.3
ECC water temp. (K)	377 → 392	360 → 391	362 → 393
Initial supplied total power (W)	7.12	7.12	7.12
Supplied power ratio bundles: 1&2:3&4:5&6:7&8	1.001:1.065: 1.015:0.919	1.0:1.0:1.0:1.0	1.0:1.2:1.0:0.8
Power decay curve	(ANS + actinides) x 1.02 from 40s after scram	(ANS + actinides) x 1.02 from 40s after scram	(ANS + actinides) x 1.02 from 40s after scram

Table 1: list of major measured test conditions

The same power is supplied to the three tests as well as the same axial power profile. The three tests mainly differ by the radial power profile. No radial power profile is imposed in test S2-17, a radial power profile representative of a PWR is imposed in test S2-10, a steeper radial power profile is imposed in test S2-16 to emphasize radial effects in the core.
Indeed perfect mixing can be observed below the quench front and the quench front progression is very similar between the rod bundles.
Top-down rewetting can be observed in the experiment which results in random rewetting of the upper part of the active core (see Figure 3).

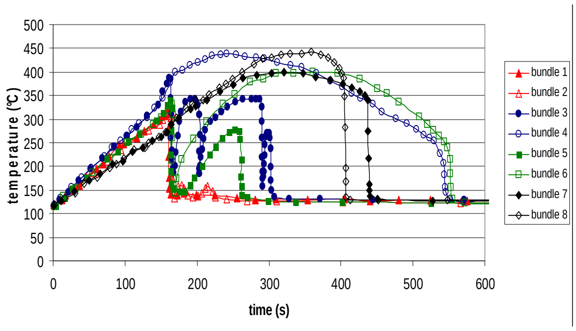

Figure 3: S2-16, experimental clad temperature at the top of the core (TC10-3.62m)

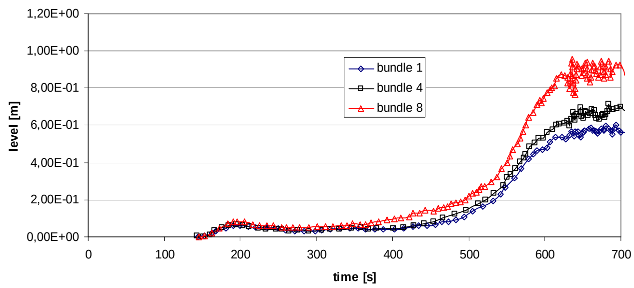

Figure 4: S2-16, upper plenum experimental collapsed water level in bundles 1, 4, 8

SCTF experimental tests pointed out complex water flow behaviour in the upper plenum (see [3]) resulting in non-homogeneous large amount of water accumulation. This is due to the presence of structures and a certain geometrical effect (hot leg connection to the baffle side) which are not fully representative of a PWR. Thus SCTF configuration tends to amplify the phenomena.
Indeed water accumulation in the upper plenum can be observed for all the tests and whatever the radial power is the water level in the upper plenum is non-uniform (see Figure 4). The non-uniform water accumulation in the upper plenum becomes significant as the quench front proceeds upwards in the

upper half of the core and this is observed even for the flat radial power profile test. The impact of the non homogeneous flow accumulation in the upper plenum has been analysed (see [4]). It was observed to result in a significant horizontal pressure gradient in the core (pressure in bundle 8 higher than pressure in bundle 1), especially at the upper part of the core, inducing cross-flows from bundle 8 towards bundle 1 and thus degrading core cooling in bundle 8 side, especially in the later times (see Figure 5 et Figure 6).

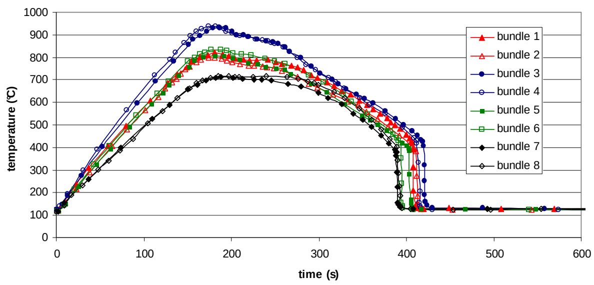

Figure 5: S2-16, experimental clad temperature at TC6-1.905m

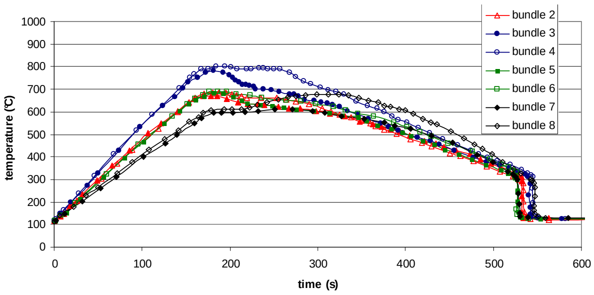

Figure 6: S2-16, experimental clad temperature at TC8-2.276m

Nevertheless since the turnaround temperature (which corresponds to the first temperature peak) appears before the difference in the upper plenum water accumulation becomes significant, the non-uniform water accumulation has little effect on the turnaround temperatures but it probably has a certain effect on the top rewetting of the core.

3. CATHARE calculations

3.1 CATHARE modelling

In the tests with forced feed injection, the overall circuit is simplified and the main element of modelling is SCTF pressure vessel.
The ECC source is located in the lower plenum and it is modelled by means of a source term. As the downcomer is closed at the bottom, i.e. the intact cold loop is not directly active and thus it has not been modelled at present. The break is located on the hot leg and it is modelled by means of a boundary condition connected to the pressure vessel through a pipe element.

To be consistent with the 3D module validation strategy (see § 1.), the meshing of the 3D module for SCTF vessel is consistent with the PWR pressure vessel mesh size, especially in the vertical direction.
SCTF test section is a rectangular slice of a PWR thus a Cartesian meshing is used. As the main effects are two-dimensional, only one mesh in the thickness direction (Y-one) is considered. In the radial direction of the reactor, there is one mesh for the downcomer, one mesh for the baffle and 8 meshes in core (to well take into account the 8 bundles), i.e. 10 meshes in X-direction. In the vertical direction, the active part of the core is divided into 10 meshes in order to be consistent with a PWR vessel meshing. Then there are 6 meshes in the lower plenum and 8 meshes in the upper part of the vessel. The cold leg and hot leg elevations are carefully respected in the modelling together with the corresponding flow section. The meshing is illustrated in Figure 7. Due to the coarse meshing of the core, the axial power profile has to be adapted to CATHARE2 modelling as it is illustrated in Figure 8.

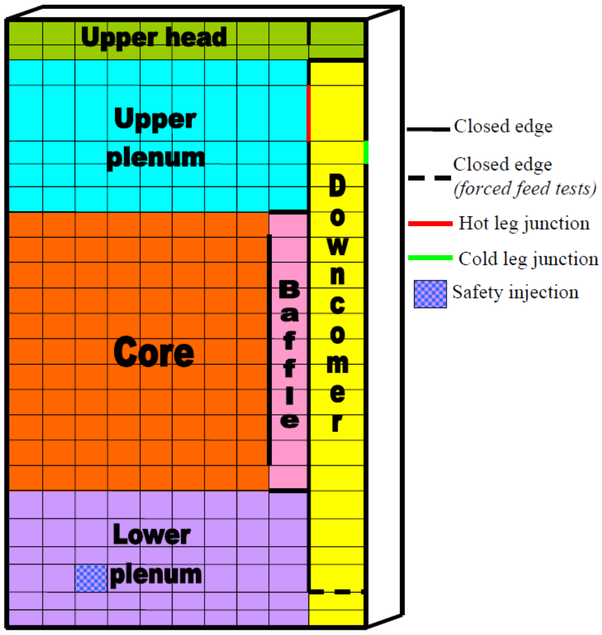

Figure 7: CATHARE2 meshing of SCTF vessel

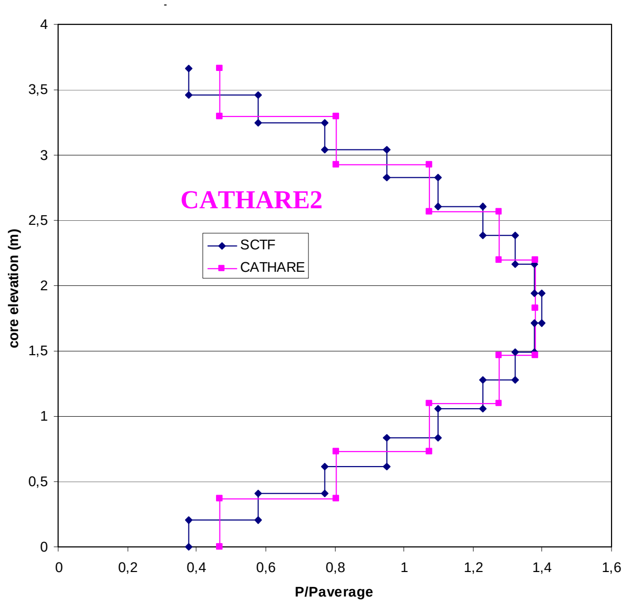

Figure 8: Core axial power profile – Comparison SCTF data / CATHARE2 modelling

The core consists of 8 rod bundles. Each rod bundle is made of 234 electrically heated rods and 22 non-heated rods among which some of them are instrumented (the number of instrumented rods varies for each assembly). CATHARE2 modelling considers only two types of rods: heated and non-heated.

The guide tubes (total of 10) are modelled by means of axial elements directly connected into the core on one side and into the upped head on the other side.

All the grids and flow section expansion/restriction are taken into account by means of singular pressure loss coefficients calculated on the basis of geometrical characteristics and Idel'Cik handbook formulations (see [5]). This concerns the core inlet, the core outlet (grid + end boxes), grids, upper plenum to upper head diaphragm, baffle inlet and outlet (diaphragms), the 8 baffle plates. These singular pressure losses are imposed on the flow direction (Z-direction).
Based on previous validations (see [6]), singular pressure losses transverse to the flow (X-direction) are calculated and imposed in the core (8 cylindrical rod bundles) and in the upper plenum (presence of 10 guide tubes and 9 support columns). The methodology is the same as the one used for PERICLES2D reflooding validation (see [6]).

In the Core-II configuration, the core baffle region located between the core and the downcomer is isolated to minimize uncertainty in the actual core flow. However some leak holes still exist but they are not experimentally quantified. Therefore it was chosen in the CATHARE2 modelling of the pressure vessel not to close the bottom and top core-baffle connection and to impose a singular pressure loss coefficient calculated based on the 'diaphragm' geometry using Idel'cik formulations (which corresponds to high singular coefficients, see [5]).

Boundary conditions are adjusted in order to impose initial conditions which are consistent with experimental data, i.e. lower plenum initial water level (water at saturation), wall initial temperature, core inlet flowrate, core water inlet temperature, pressure at the break, etc. In order to get the wall initial temperatures correctly, a thermal radiation model between the heating rods and the vessel external wall had to be activated during the heating period, prior to the ECC injection start in the lower plenum.

3.2 CATHARE results and comparison to experimental data

The three tests have been calculated with CATHARE 2 and compared to the experimental data. It is proposed to illustrate the main conclusions with the test S2-16 (steepest radial power profile) and for some specific points the two other tests may be used.

For the three tests, the calculated quench front progression is quite uniform between the eight bundles, as in the experiment and the quench front velocity is nearly uniform, except at the extreme top of the core (see Figure 9 and Figure 10). Indeed it is observed, in the experiment, that there is a large amount of water accumulated in the upper plenum (see Figure 4) which tends to be quite rapidly non-homogeneous. Indeed there is a larger amount of water accumulated above rod bundle 8 than rod bundle 1 and this difference tends to increase with time. Thus in the experiment top-down rewetting is observed in the upper part of the core whereas CATHARE top-down reflooding model is not activated in these calculations (the two specific models –bottom-top reflooding and top-bottom reflooding– can be activated separately). It must be mentioned also that in these calculations CATHARE predicts the non-homogeneity but tends to underestimate the amount of water in the upper plenum (see Figure 11). In these calculations, the upper plenum has been basically modelled in the context of CATHARE LB-LOCA validation and simply connected to boundary conditions. Indeed no specific modelling has considered, at this stage of the validation, to take into consideration the SCTF structure impact and geometry effect on the flow behaviour in the upper plenum and the water accumulation heterogeneity specific to SCTF test facility (see §2.2).

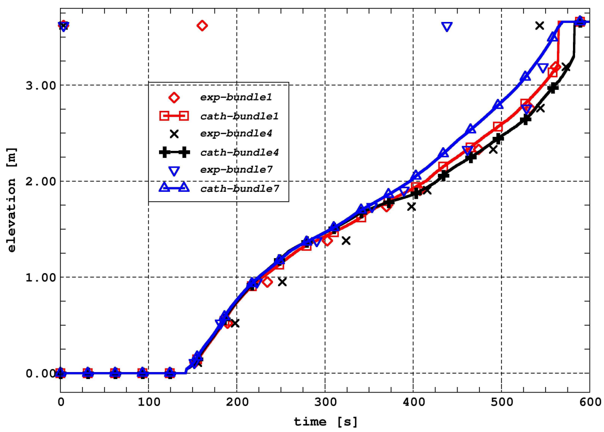

Figure 9: S2-16, quench front in bundles 1, 4, 7

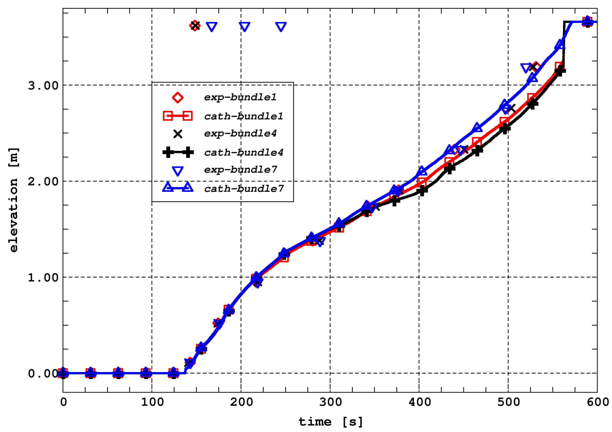

Figure 10: S2-17, quench front in bundles 1, 4, 7

Unlike the quench front progression, the rod temperature evolutions between the rod bundles are strongly dependent on the radial power profile. It must be notified that the CATHARE temperature probes are not located at the exact elevation of the experimental thermocouples therefore it is chosen to plot the CATHARE probe which is the closest to the thermocouple.

When there is no radial power profile (test S2-17), the rod temperature evolution at each elevation is similar for all the bundles except at the top of the core (level 10 – experimental TC10) where the temperature decrease is quite different between bundle 4 and bundle 8, probably due to non-uniform water fall back from the upper plenum. The rod wall homogeneity between the rod bundles is well predicted by CATHARE (see Figure 12).

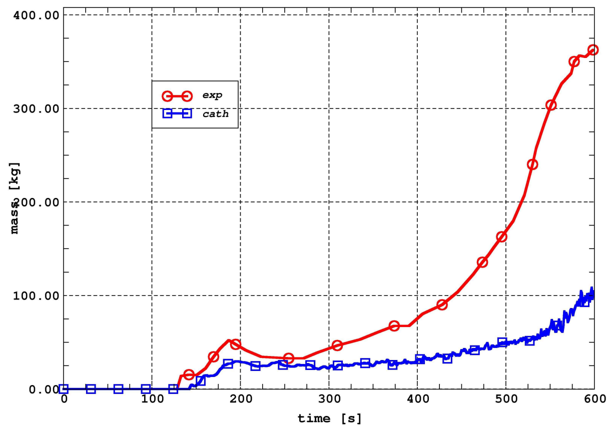

Figure 11: S2-17, de-entrained water accumulated in the upper plenum

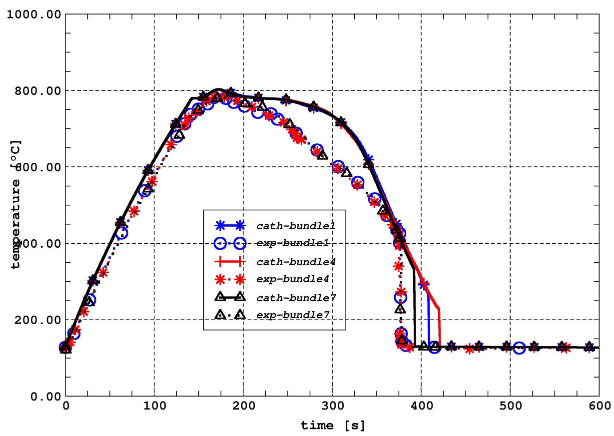

Figure 12: S2-17 – Clad temperature, TC6 (exp: 1.905m, Cath: 2.01m), bundles 1, 4 and 7

Concerning the tests with radial power profile, the comparison CATHARE-experiment (Cath-Exp) can be done considering the bottom part of the core where reflooding occurs very rapidly, the middle part of the core where the maximum of power is applied and the upper part of the core where top-down quenching can be observed.

At the bottom of the core (see Figure 13) the maximum temperature is well predicted by CATHARE compared to the experiment as well as the reflooding time. The difference between the peak temperature obtained in the hottest bundle and the coolest one is of the same order of magnitude in the experiment and in the calculation. Only the shape of the temperature decrease between the maximum value and the quenching one is slightly different from the experimental one.

Near the middle of the core (see Figure 14) the heating slope predicted by CATHARE is similar to the experimental one and the maximum temperatures obtained by CATHARE are very close to the experimental ones. But the experimental peak is replaced by a kind of plateau in the calculation and the temperature decrease rate is underestimated. However the reflooding time is almost the same for the experiment and CATHARE calculations.

In the upper part of the core (see Figure 15), CATHARE prediction shows an underestimation of the maximum clad temperature which can vary between 30 and 90°C depending on the test, whereas the reflooding time is globally well predicted.

At the real top of the core (TC10 elevation, see Figure 16), the reflooding occurrence is quite random and it may appear very early in the experiment due to top rewetting. Indeed the reflooding at the top of the core is quite complex and non-uniform. It is not represented at this stage of the calculations and it will be probably difficult to predict. Nevertheless it can be observed in the calculations that the temperature decrease occurs later in bundle 7 than in bundle 4, i.e. the reflooding is not exactly uniform. The end of the reflooding is globally delayed in the CATHARE calculations and no top rewetting is observed.

Because of the radial power profile, a 2D effect is observed in the experiment and this is well predicted by CATHARE. For instance, for test S2-16, the maximum clad temperature around 2.0 m elevation (TC7) is 200°C higher in bundle 4 than in bundle 7 and the prediction is in good agreement with the experimental observation.

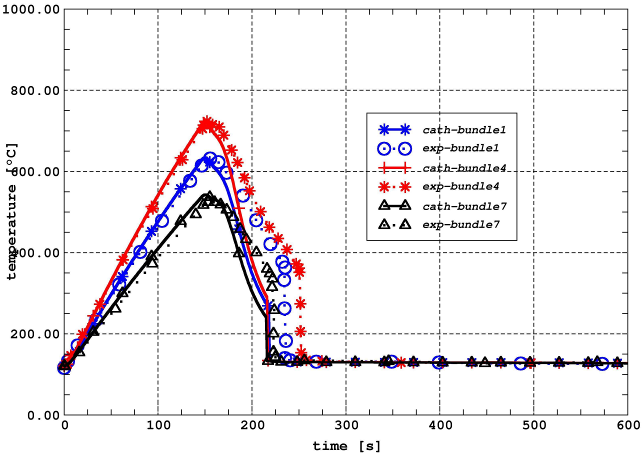

Figure 13: S2-16 – Clad temperature - TC3 (exp:0.95m, Cath:0.915m), bundles 1, 4 and 7

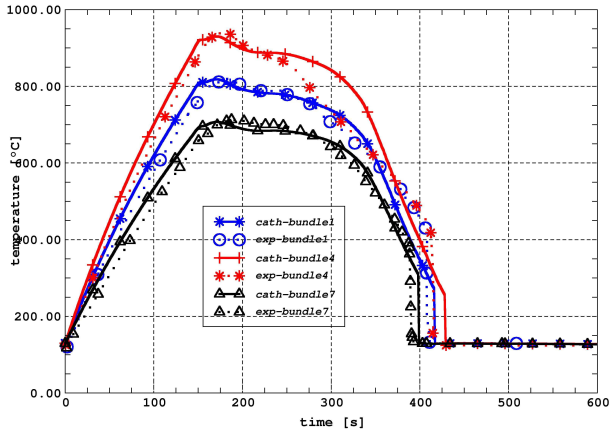

Figure 14: S2-16 – Clad temperature - TC7 (exp:1.905m, Cath:2.01m), bundles 1, 4 and 7

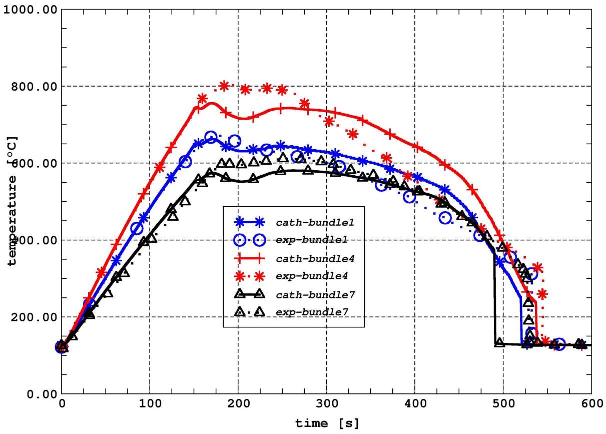

Figure 15: S2-16 – Clad temperature – TC8 (exp:2.76m, Cath:2.745m), bundles 1, 4 and 7

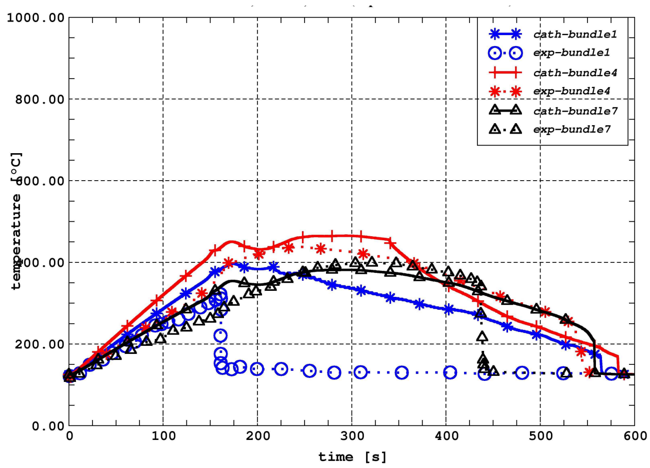

Figure 16: S2-16 – Clad temperature - TC10 (exp:3.62m, Cath:3.477m), bundles 1, 4 and 7

The pressure level at mid core is well predicted by CATHARE which means that the pressure losses imposed at the vessel outlet (to simulate the loop behaviour) are correct (see Figure 17). The pressure evolution is close to the experimental one although twin peaks can be observed in the calculations, when only one peak can be seen on the experimental plot. The maximum pressure is well predicted together with the stabilized pressure reached at the end of the transient. But the pressure decrease after the peak at nearly 0.28MPa is much sharper than in the experiment.

The calculated overall differential pressure (DP) is much lower than the experimental one (see Figure 18). It could be due to pressure loss underestimation in the core or void fraction overestimation in the core. Based on the former comment and the void fraction discussion this underestimation of core DP is probably due to an overestimation of the void fraction in the core. As it is observed in the experiment, DP estimation across the core is very similar for the bundles 2, 4 and 8. It can be concluded that the total water accumulation in the core is homogeneously distributed between the assemblies but CATHARE tends to underestimate the global amount.

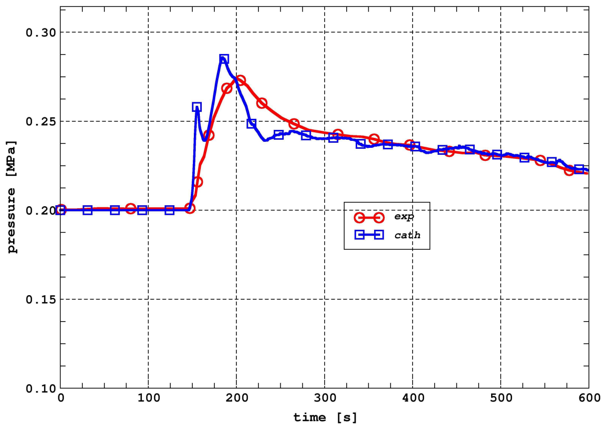

Figure 17: S2-16, pressure at mid core elevation

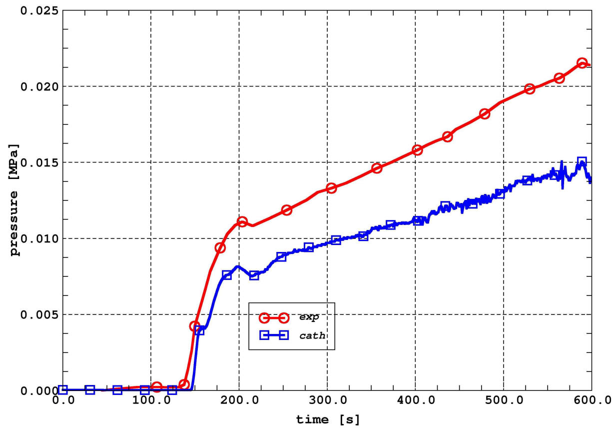

Figure 18: S2-16, bundle 4 differential pressure

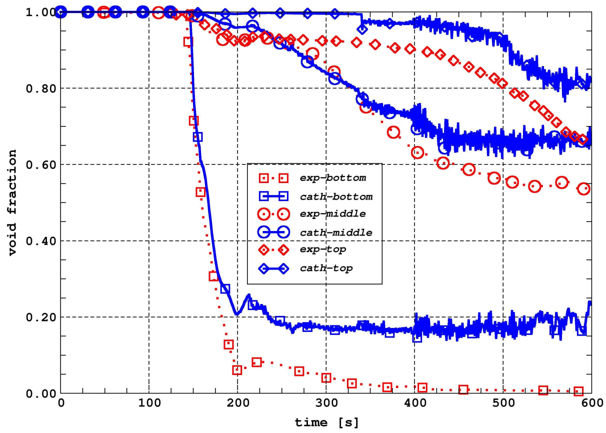

Figure 19: S2-16, void fraction in the core, bundle 4 (bottom – middle – top)

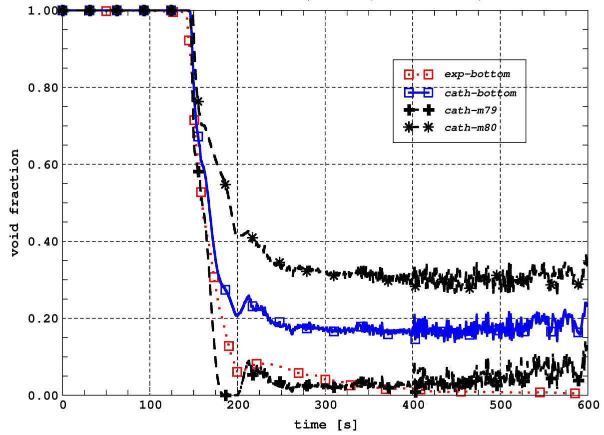

Figure 20: S2-16, core void fraction, bundle 4, bottom , experiment – CATHARE (average and mesh cell value)

The calculated average core void fraction is always higher than the experimental values, particularly at the bottom of the core where only liquid is observed in the experiment whereas an averaged void fraction of nearly 0.18 is predicted by CATHARE (see Figure 19).
It should be mentioned that the experimental void faction is measured over a certain height by means of flag probes:

- bottom of the core: 0.085 – 0.7 m
- middle of the core: 1.365 – 1.905 m
- top of the core: 2.695 – 3.235 m

These elevations are not fully compatible with the core meshing. Therefore CATHARE predictions have to be averaged over two or three mesh cells in order to be compared to experimental data. Thus in order to be more exhaustive, each measured value has been compared to every CATHARE value involved in the averaging process.

For the bottom value, it can be observed that the void fraction in the first elevation is indeed equal to 0.0 (only liquid) but in the elevation just above, the void fraction is in between 0.20 to 0.35 depending on the test (see Figure 20 for S2-16). At mid core, the experimental value lies between the three calculated void fractions. At the top of the core the CATHARE values over-predict the experimental data.

3.3 Analysis / synthesis

The analysis of CATHARE predictions and their comparisons with the experimental data for the three tests S2-17 (flat power profile), S2-10 (reference power profile) and S2-16 (steep power profile) lead to the following conclusions.

The pressure vessel behaviour is globally well predicted, altogether with the quench front progression, the quenching times and the clad temperatures. The 2D effects in the core due to the radial core power profile are well taken into account.

Nevertheless certain points need further investigation:

- The quench front progression is well predicted by CATHARE and it is uniform as in the experiments. In particular it seems that the homogenization taking place below the quench front is well predicted (cross-flows between bundles). No effect of the radial power profile can be observed on the quench front progression, both in the experiment and in the CATHARE prediction. This is currently explained by the presence of cross-flows below the quench-front. This is illustrated by CATHARE calculations of test S2-10 by isolating every rod bundle one from another (i.e. the mesh faces in the transverse direction are all closed) and thus preventing any cross-flow between assemblies (cath-1Dcore). It results in a non-homogeneous quench front progression in the core. As it can be seen in Figure 21 and Figure 22, for bundle 4 which corresponds to the bundle with the highest power, by preventing any cross-flows between the rod bundles, the quench front progression is much slower and the maximum clad temperatures are significantly increased.
- Non-homogeneous water accumulation in the upper part of the core is observed in the experiment whereas CATHARE tends to under-predict the amount water in the upper plenum. This substantial water accumulation in the upper plenum seems to have some impacts on the core thermal-hydraulics (see [5]). This under-prediction is probably one of the reasons for CATHARE not to predict any top rewetting. As it was investigated in [6], the presence of structures in the upper plenum tends to decrease the core carry-over phenomena. This should be further investigated.

- Clad temperatures are quite well predicted except at the top of the core where an underestimation of the turn-around temperature prediction is observed for the three tests (between 30 and 90°C). This underestimation could be explained either by the spatial axial discretization which does not follow exactly the axial power profile (spatial axial discretization chosen to be consistent with CATHARE LB-LOCA validation, see [1]) or by a too strong cooling above the quench front. The temperature plateau and the too small temperature decrease rate observed after the maximum is reached could also be explained by this too strong cooling above the quench front.
  Thus from these first calculations it seems that the exchanges calculated by CATHARE induce too large vaporization and water droplet entrainment, compared to the experiment. This statement seems to be confirmed by the tendency observed in the prediction of the core void fraction distribution.
  This is also consistent with the fact that the predicted DP in the core is smaller than the experimental one after reflooding has started.

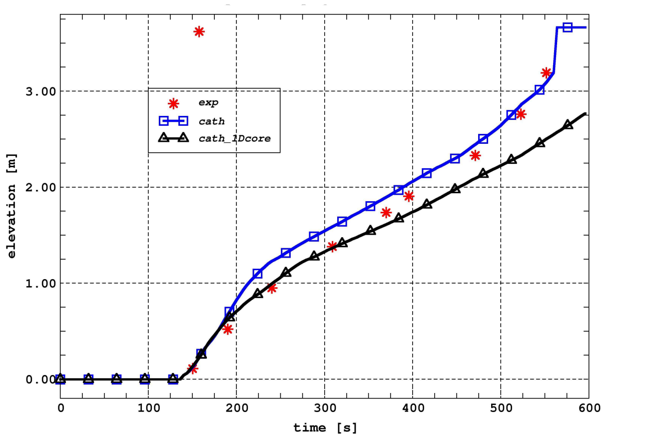

Figure 21: S2-10, quench front progression, bundle 4, impact of the cross-flows

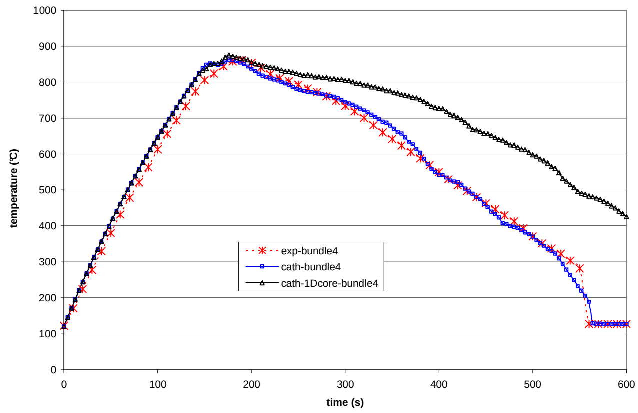

Figure 22: S2-10, maximum clad temperature, bundle 4, impact of the cross-flows

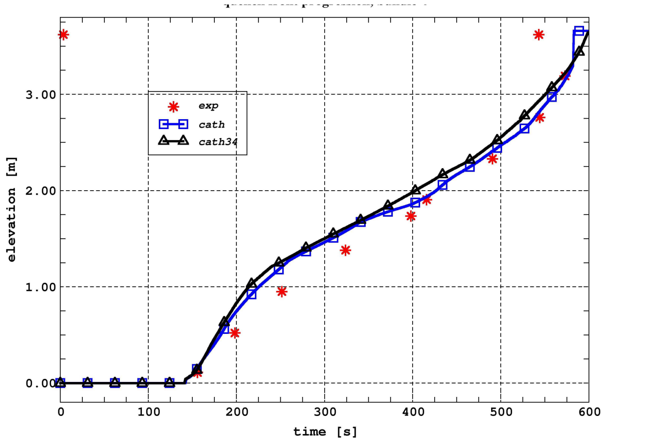

Figure 23: S2-16, axial meshing effect quench front progression, bundle 4

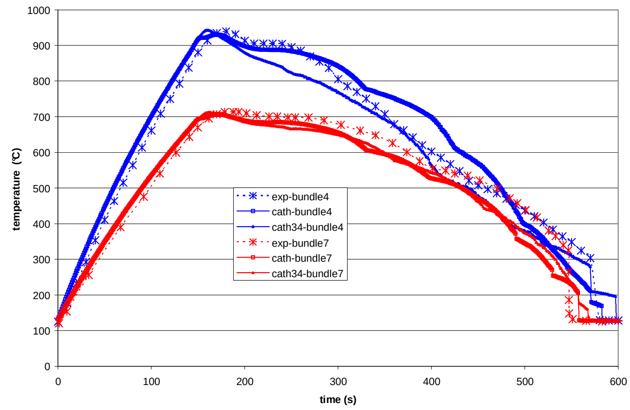

Figure 24: S2-16, axial meshing effect maximum clad temperature, bundles 4 and 7,

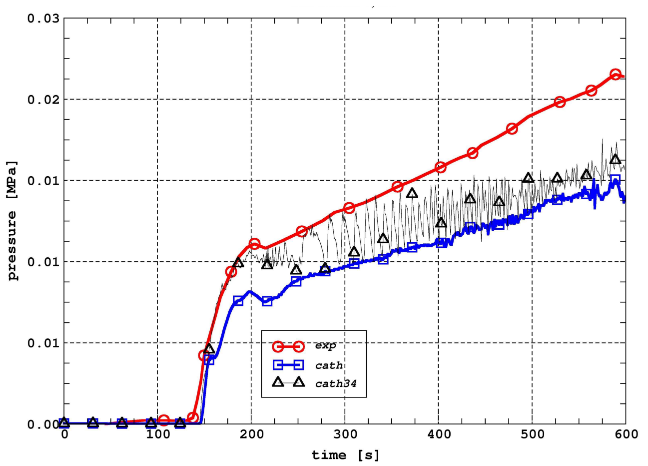

Figure 25: S2-16, axial meshing effect core differential pressure, bundle 4

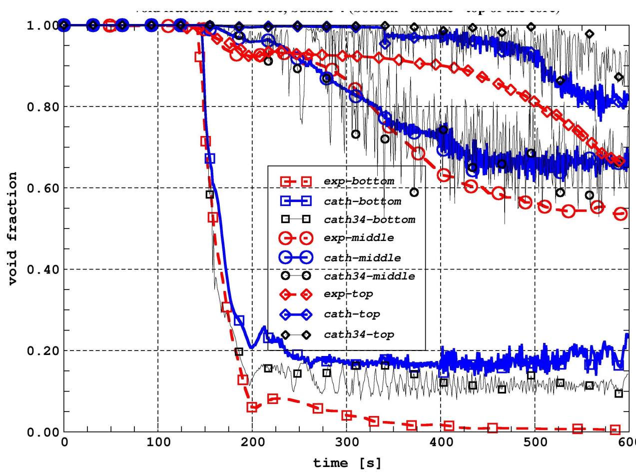

Figure 26: S2-16, axial meshing effect void fraction in the core, bundle 4

The influence of the axial discretization of the core has been analysed by conducting a sensitivity test on the axial meshing of the core: the number of mesh cells in the active part of the core, i.e. along the heating length, has been increased. In order to better describe the axial power on the one hand and to test the meshing effect on the other, it was chosen to get the equivalent of two mesh cells per power step which leads to 34 mesh cells in the active part of the core.

- No significant effect on the quench front progression (see Figure 23) has been observed when refining the meshing in the core.
- The refinement tends to improve CATHARE predictions for the water accumulation and the void fraction distribution in the core (see Figure 25 and Figure 26) which has a direct impact on the maximum clad temperature (the maximum clad temperature is determined as the highest temperature along the bundle for each time step) but not the turnaround one as it can be seen on Figure 24.

- In the CATHARE calculations, the core-baffle connection is not fully closed and small water flowrate is observed through this small hole. The flowrate is of the same order of magnitude for the three tests and always nearly negligible compared to the ECC injection flowrate. It results in filling up the baffle up to its half. Indeed the presence of leak is mentioned in the experimental analysis report but it is not quantified. As the cooling circuit is not fully isolated from the pressure vessel, interactions might exist which are not taken into account with the present simplified modelling of the fluid circuit. Therefore it will require modelling the whole fluid circuit to be fully representative. The modelling of the whole circuit will make easier the use of certain experimental data such as the water and vapour flowrates which are measured in the containment tank-II and in the broken cold leg - water-separator side.

4. Conclusions

This paper illustrates CATHARE2 modelling of SCTF pressure vessel with the 3D module and its capabilities to predict core radial profile effect during reflooding is demonstrated based on SCTF forced feed tests.

The three tests S2-17, S2-10 and S2-16 have been successfully calculated with CATHARE 2 V2.5_2. These tests are very similar in terms of test conditions. The difference lies in the radial power profile definition while the same initial power is supplied (7.12MW): it covers a range from flat radial power profile (S2-17) to a power profile representative of a PWR (S2-10), with a steeper one (S2-16) to emphasize 2D effects. Two-dimensional cross-flows occurring in the core are well predicted as well as clad temperature for all bundles except at the upper part of the core where non-homogeneous water accumulation in the upper plenum has a certain impact on the core thermal-hydraulic behaviour (top quenching and degradation of bundle 8 side cooling).

Some points as water accumulation in the upper plenum and its impact, core baffle connection effect will need to be further investigated in order to be well taken into account in the calculations. This will allow us to better analyse some experimental aspects which are not so well predicted by CATHARE (for instance, impact of water accumulation in the upper plenum and thus liquid carryover). It will permit us to clarify the influence of the SCTF specific cooling circuit.

This study based on SCTF test is therefore an important step for CATHARE 3D module validation, particularly concerning the multi-dimensional effects during the reflooding phase.

Acknowledgements

The authors would like to underline that this work is a collective one done by the CATHARE team and the CATHARE partners. They are gratefully indebt to EDF (Electricité de France), IRSN (Institut de Radioprotection et de Sûreté Nucléaire) and AREVA-NP.

Acronyms

BOCREC: Bottom Of Core RECovery
ECCS: Emergency Core Cooling System
LOCA:Loss-Of-Coolant Accident
LPCI: Low Pressure Coolant Injection
PWR: Pressurized Water Reactor
SCTF: Slab Core Test Facility

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