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METERO-V and PRIUS Experimental Programs: Complementary Separate Effects Tests for Core Mixing Validation

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ABSTRACT

The analysis of Large Break-Loss of Coolant Accidents (LB-LOCAs) required specific experimental programs to investigate large-scale 3D effects, particularly during downcomer refill and core reflooding. SB-LOCAs (Small Break) and IB-LOCAs (Intermediate Break) also encounter significant 3D effects in core due to the radial power profile, with crossflows and diffusion-dispersion. Other transients such as steam line break are sensitive to all mixing phenomena in the core. Then a need exists for a more precise validation of each of the mixing processes, including turbulent terms, 3D interfacial friction and wall friction.

In order to provide experimental data to validate thermal hydraulic codes for PWR core in transient situations, two experimental programs are being carried out at CEA and KAERI. At CEA, METERO-V experimental program mainly focuses on LOCAs, and SLB (Steam Line Break) accidents are also considered. These situations, where significant 3D effects may occur in the core, are reproduced in an 8×34 rod-bundle test section with the aim to develop models and to validate them in a separated-effect way for CFD to system thermal-hydraulic scales. At KAERI, a test facility called PRIUS-II (in-PWR Rod-bundle Investigation of Undeveloped mixing flow across Sub-channel) is devoted to generate an experimental database for a multi-dimensional flow distribution using the MIR technique in a 6×12 rod-bundle geometry, in LOCAs situations. It is useful for component scale analysis codes and CFD codes in open medium validation.

METERO-V and PRIUS-II experiments are complementary in terms of geometry and range of Reynolds numbers, and the data allows separate-effect validation of all codes which may be used for core thermal hydraulic simulations including system codes, sub-channel codes, and CFD codes. New data could be generated in additional single-phase conditions (METERO-V, PRIUS) or two-phase conditions (METERO-V) and could be provided to participants of an international project.

KEYWORDS

Cross-flow, Rod bundle, Experiment, Validation

1. INTRODUCTION

The analysis of Large Break-Loss of Coolant Accidents (LB-LOCAs) requires specific experimental programs to investigate large scale 3D effects especially during downcomer refill, and core reflooding. The 2D-3D program included UPTF, SCTF and CCTF facilities which provided precious information on phenomena and quantitative data for system code validation. However, due to the difficulty to implement instrumentation in high pressure and temperature steam water flow in a very complex geometry, the validation remained global and could not validate separately each sensitive model of the code in presence of 3D effects. SB-LOCAs (Small Break) and IB-LOCAs (Intermediate Break) also encounter significant 3D effects in core due to the radial power profile, with crossflows and diffusion-dispersion [1]. Other transients such as steam line break are sensitive to all mixing phenomena in the core. Then a need exists for a more precise validation of each of the mixing processes.

Today, system codes are used in a BEPU context (Best-Estimate plus Uncertainty) for licensing, and 3D modules are used with a porous body approach for modelling the pressure vessel. A working Group of OECD/NEA/CSNI/WGAMA made recently (2016-2019) a state of the art of existing 3D capabilities in TH system codes, to propose further activities to improve the modelling, and to complement the validation and verification of such tools [2]. If the system codes are able to predict reasonably well the 2D-3D experimental tests, it does not exist a validation of all local 3D processes such as wall and interfacial friction in a 3D flow (e.g. in a downcomer, in a core or an upper plenum) and all diffusion and dispersion terms of mass momentum and energy equations. The state-of-art report suggests to use or to develop several separate effects tests for validation of 3D applications in system codes.

A simulation of the whole core is not possible with CFD in open medium and only CFD in porous body approach is practically applicable. System codes have now 3D modules which can model a PWR core with thousands of meshes (either in cylindrical or Cartesian structured meshing) with a reasonable CPU time. For example, the first 3D core nodalization for the CATHARE system code (developed in France by CEA, EDF, Framatome and IRSN) used about 200 meshes (in cylindrical coordinates with $3 \times 6 \times 11$ meshes) and currently a core nodalization was developed with about 6000 Cartesian meshes (1 row of mesh per assembly) [3]. The METERO-V (V for vertical) program, is carrying out for the validation of the CATHARE 3D modeling of the core when using such finer nodalization.

Some specific analysis may also be investigated with sub-channel analysis for a more local prediction. The CUPID code developed by KAERI includes both the open and porous media CFD. The PRIUS (in-PWR Rod-bundle Investigation of Undeveloped mixing flow across Sub-channel) test facility is designed to generate an experimental database in a rod-bundle geometry addressing the modeling and validation of sub-channel analysis. It can also be useful for CFD in open medium validation.

This paper recalls validation needs for 3D effects modeling in the core, and describes the METERO-V and PRIUS programs. From the corresponding test facilities, new data involving 3D effects could be generated in additional experimental campaigns in single-phase conditions (METERO-V, PRIUS) or two-phase conditions (METERO-V) and could be provided to participants of an international project.

2. VALIDATION NEEDS FOR 3D EFFECTS MODELING IN THE CORE

In SB-LOCAs and IB-LOCAs, core uncovering may occur (see Figure 1 case 2 and case 3) and the peak clad temperature (PCT) depends significantly on the radial transfer processes [1,4,5].

In this type of situations, there is a two-phase zone below a swell level with an apparently good radial mixing. This may result in a partial or perfect radial homogenization of steam mass flux in assemblies of different powers. In order to check and validate this homogenization of the steam mass flux, more detailed information is needed on radial wall friction and interfacial friction.

Above the swell level, crossflows are created in single-phase steam by density differences resulting from the radial power profile. At high pressure P and low mass flux G (case 3), density differences create buoyant crossflows called “chimney effect” which transfers coolant from cold to hot assembly, limiting the PCT. At low pressure (case 2), pressure losses due to the wall friction are dominant with respect to the buoyancy effects, and to equilibrate the pressure losses between the assemblies, radial crossflows occur from hot to cold assembly with some increase of PCT. In order to validate the prediction of such single-phase situation, both axial and radial pressure loss coefficients have to be well known. Although some experimental data exists to characterize the radial pressure loss through in-line tubes, the data covers partially the range of pitch-to-diameter ratios, Reynolds numbers and inclination of the flow regarding the rod axis, or must be carefully used due to the limited size of the test section. From previous studies at sub-channel scale [1,7], diffusion and dispersion of momentum and energy may play a significantly lower role in radial transfers than crossflows in such situations. They are able to homogenize radial differences on small distances for a few sub-channels although crossflows may homogenize radial differences over a more significant part of an assembly. Data are available for the validation of the diffusion and dispersion terms but they remain limited, such as those for the radial pressure drop. New separate effect tests will be able to measure radial diffusion and dispersion with a good accuracy at least in absence of crossflows.

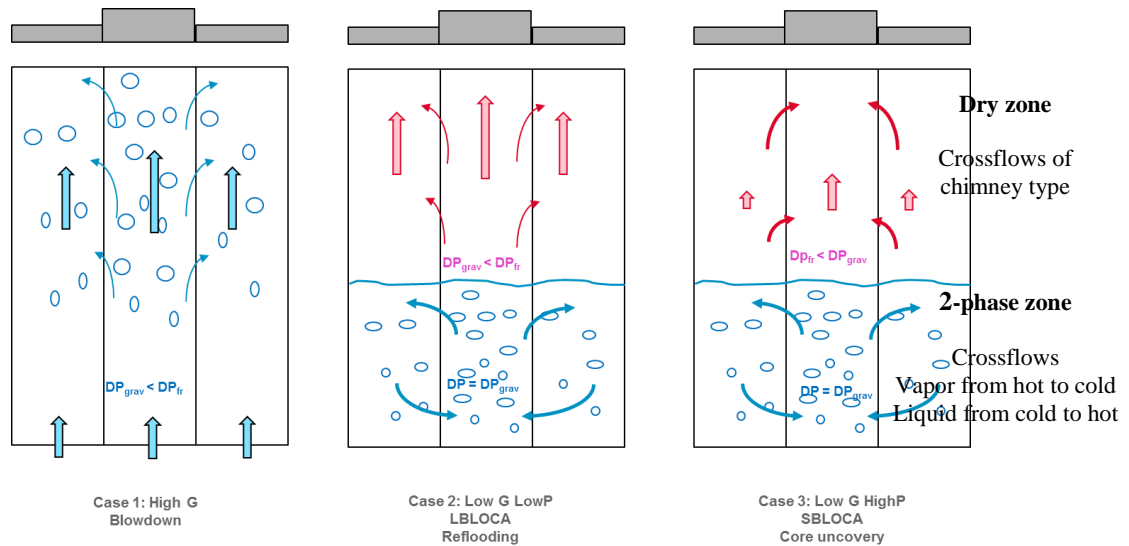


Figure 1. Situations of interest during LOCA with radial transfers and cross-flows: the central assembly is supposed to have a higher power than lateral assemblies (from [6]).

In low flow Steam Line Break (SLB) conditions, non-homogeneous water temperature at inlet of the core may create local power excursion. The radial mixing before the power excursion and after the power excursion depends a lot on single-phase crossflows due to buoyancy [8]. In order to validate the prediction of such situation, both axial and radial pressure loss coefficients have to be well known.

In order to better model and validate the crossflows and mixings within the core, two experimental programs, METERO-V and PRIUS, may be used to investigate in a separate effect way all the processes of interest.

3. METERO-V EXPERIMENTAL PROGRAM

3.1. METERO-V facility

The METERO-V program aims at providing data for the validation of 3D models of system codes and sub-channel codes, using a porous medium or a sub-channel approach for PWR core thermal hydraulics modeling [4]. As a validation tool for these 3D models of system codes, the target is a modeling using a mesh per assembly at least in the region of the highest power assembly. Therefore, all the mixing effects between assemblies or/and between subchannels must be validated. The gathered experimental data will also be useful for Reynolds Averaged Navier-Stokes CFD validation.

METERO-V (V for Vertical) loop is located at CEA Saclay. The test section has been designed to contain a rod bundle with 8×34 rods representing two PWR-type half-assemblies (Figures 2 and 3). In a first phase of experiments, the height of the test section is about 2 m although a full rod bundle length (3.6 to 4 m) will also be possible in future studies. Current rod bundle is composed of identical unheated rods of 9.5 mm outer diameter, with a pitch equal to 12.6 mm, except for the central subchannels having a larger pitch representing the water gap between the assemblies. The test section is equipped with 4 mixing grids separated by 522 mm. Arrangement of the rod bundle would be changed in future campaigns, replacing some rods with other having the same diameter of the guide-tubes, and mixing grids could be changed or removed.

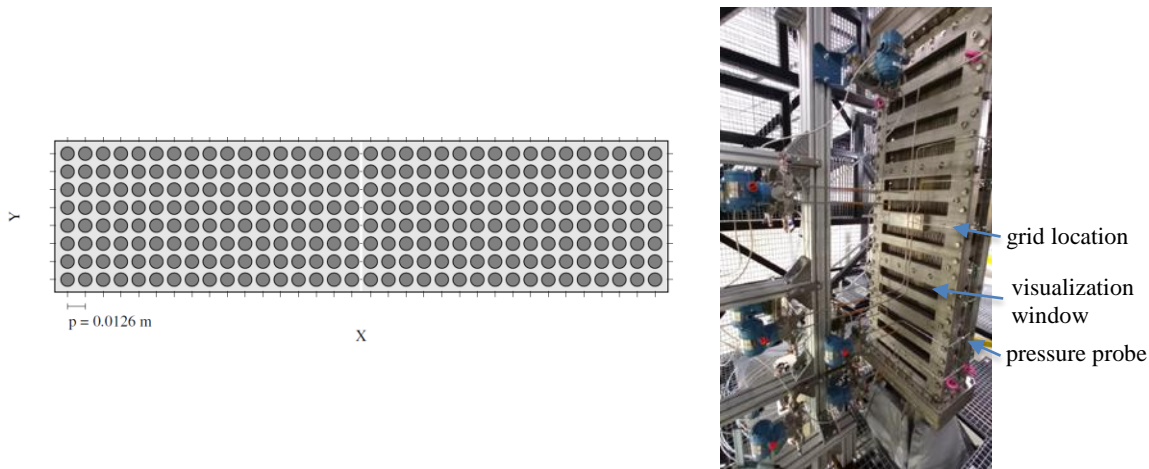


Figure 2. METERO-V test section: radial view with rods arrangement (left) and photograph (right).

Below the test section (Figure 3), a tranquillization chamber has been designed in two separated parts in order to be able create a dissymmetry of the flow (velocity, temperature, void fraction or/and passive scalar) entering the vertical structure. Each part of the tranquillization chamber is composed of a diverging pipe followed by a grid then a straight larger pipe, a honeycomb and a grid. Then a set of parallel deflectors change the orientation of the flow to a vertical one. Another honeycomb is placed before a converging rectangular pipe downsizing the cross-section to fit the vertical structure inlet.

Pressure is close to atmospheric at top of the test section. At the inlet of the test section, the temperature of the fluid may be ambient (14 to 30 °C) with possible heating to create radial temperature difference ΔT between the two half-assemblies up to a maximum of 36 °C (maximum temperature allowed in the loop is 50 °C). The liquid temperature is controlled with two heat exchangers in the circuit. Each of the cooler is theoretically capable of dissipating respectively 110 kW and 80 kW of heat out of the fluid loop. The first

cooler is entirely dedicated to the mean temperature control (before any unbalanced temperature profile at injection). The second cooler is dedicated (in association with an 80 kW heater) to the dissymmetrisation of the temperature profile at injection. The separate feeding of the two half assemblies allows also to create an asymmetrical velocity profile at the inlet of the test section. The range of flowrate is [6 ; 600] m³/h, corresponding to Reynolds numbers Re_{Dh} at the inlet of the rod bundle from 720 to 72,000 at 20 °C, and from 1,100 to 120,000 at 45 °C.

For adiabatic air-water experimental tests, air will be supplied at the inlet of test section using an injection device, allowing unbalanced void fraction profile between the two half-assemblies.

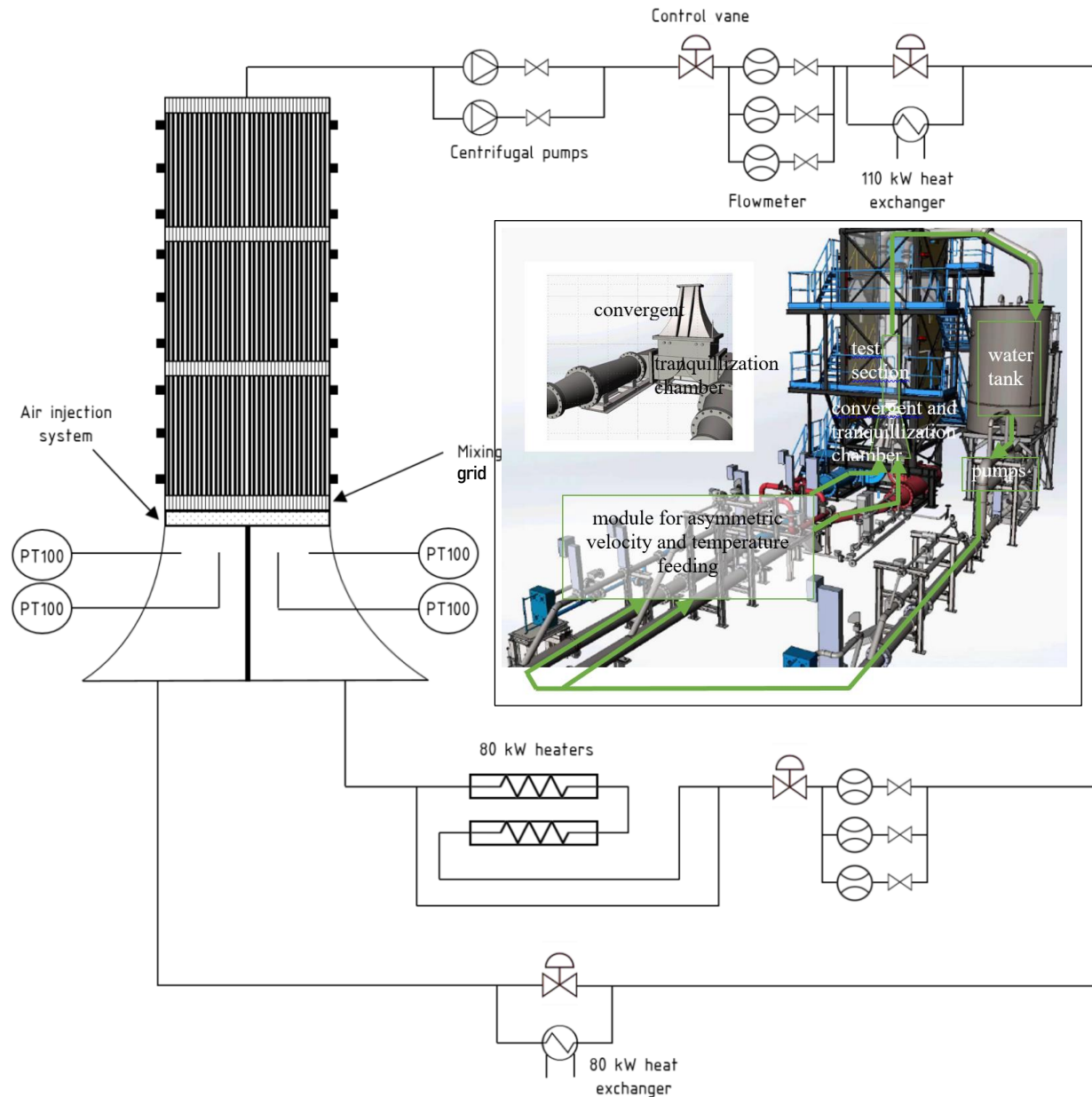


Figure 3. METERO-V loop.

3.2. Current and future campaigns

Several test series are in progress and planned to address the respective processes of interest. They are summarized in Table I (single-phase conditions) and Table II (two-phase conditions).

Table I. Current and future campaigns in single-phase conditions in METERO-V (E: equal, U: unequal, V: velocity, T: temperature, S: passive scalar), from [4]

Process	Test series	Test conditions
Wall friction	Pressure losses in axial flow Pressure losses in non-axial flow	EV, ET. Bare rods and grids UV, ET. Bare rods and grids
Momentum turbulent diffusivity	Pressure losses with transverse flow	UV, ET, equal $\partial P/\partial z$. Bare rods and grids
Scalar turbulent diffusivity, scalar dispersive tensor	Mixing of a passive scalar	EV-US with and without spacers
Energy turbulent diffusivity, energy dispersive tensor	Energy (temperature) mixing	UT with and without spacers

Single-phase conditions test series

Pressure losses

The two first test series concern the characterization of the wall friction and are in progress. Pressure losses in pure axial flow (in Z direction) are measured for bare rods and for spacer grids, for different Reynolds numbers Re_{Dh} at the inlet of the rod bundle, using differential pressure sensors. The obtained results, detailed in the companion paper [9], are consistent for the axial friction coefficient of the bare rods with other experimental data and literature models (see Figure 4). Wall friction model in the transverse directions (X,Y) is determined from measurements at different elevations of the pressure losses in the transverse direction using pressures sensors and the 2D velocity fields in (X,Z) and (Y,Z) planes using the PIV technique through the visualization windows of the test section (Figure 2).

Tests series with transverse flow may be used to determine the momentum turbulent diffusivity, when the boundary conditions are chosen such that the axial pressure gradient $\partial P/\partial z$ are equal to avoid crossflows and to measure the momentum diffusion-dispersion term.

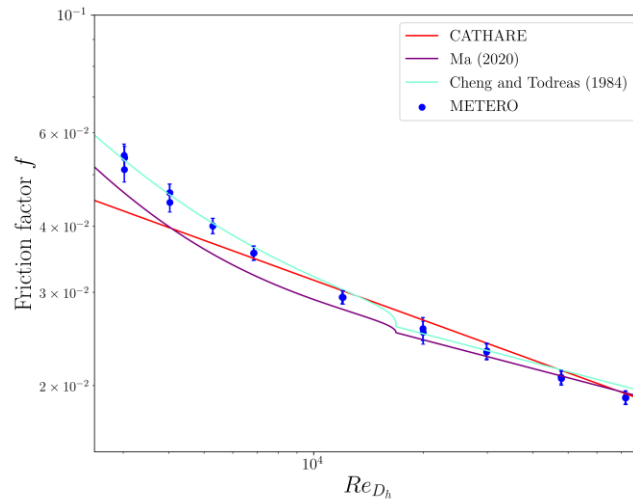


Figure 4. Friction factor in axial direction measured in METERO-V test section, compared to different models.

Radial mixing of a passive scalar

Radial mixing of a passive scalar may be obtained by unbalanced injection of a tracer and using the Laser-Induced Fluorescence (LIF) technique. The mixing in a bare rod bundle may be better obtained by removing some grids. However, in presence of spacers with mixing vanes, the mixing is expected to 30 to 50 times higher, according to previous estimations [10]. The radial mixing is here due to molecular diffusion, turbulent diffusion and dispersion (associated to space averaging in the porous medium approach). In most cases the molecular diffusion is negligible compared to turbulent diffusion which is itself small compared to dispersion in presence of spacer grids. The measured mixing results from the 3 processes. Playing with the Reynolds number and the presence and type of spacers, one may envisage to determine separately the three processes.

Temperature mixing

The radial temperature mixing may be studied using a homogeneous velocity and an unbalanced temperature measurable by LIF. The luminescence of the particles seeded in the fluid is dependent on the temperature of the fluid. Crossflows are buoyancy driven when gravitational axial pressure gradient dominates the friction axial pressure losses. The difference of temperature induces density differences which create different axial pressure gradients in the two assemblies. This creates radial pressure differences and crossflows from cold assembly to hot assembly. As soon as crossflows are significant, they may overpass diffusive radial mixing.

The investigation of friction driven crossflows in presence of temperature differences uses the same configuration as buoyancy driven crossflows but with different inlet velocity in the two assemblies. The buoyancy tends to create crossflows from cold to hot assembly, a higher velocity in the cold assembly will increase the crossflow and a lower will decrease the crossflow or create a reverse crossflow from hot to cold assembly.

In order to eliminate crossflows, both velocity and temperatures are unbalanced in the two assemblies so that the total axial pressure gradient (gravity + friction) is equal. The choice of the velocity and temperature of the two assemblies which may eliminate crossflows will result from the analysis of the previous tests.

In such conditions only the diffusive effects can induce radial temperature mixing. It may be difficult to find exactly the ΔV and ΔT which create equal total axial pressure gradient and no crossflow but it is worth trying to look for a minimum radial temperature mixing.

Two-phase conditions test series

Two phase tests are mainly devoted to wall and interfacial friction in non-axial flow and to void radial mixing due to gravity and void dispersion force. Measurement of the void friction will be done using optical probes.

A matrix of axial and radial pressure loss and map of void fraction in the XZ plane will provide information able to provide the following:

- In axial flow, local measurements of void fraction and axial pressure loss make it possible to validate together wall friction and interfacial friction in bare rod bundle then with local effects of spacer grids.
- Check in two-phase flow the radial pressure losses established first in 1-phase. A possible modified two-phase multiplier may be necessary for radial flow
- See a possible effect of the angle of the velocity with rod axis on the radial interfacial friction
- See a possible effect of the angle of the velocity with rod axis on the axial interfacial friction: a radial flow may break large bubbles and consequently increase the axial interfacial friction
- At high velocity, provide some information on void dispersion force which homogenizes radial quality and may influence critical heat flux and PCT in blowdown phase of a LOCA
- At low velocity provide some information on gravity driven homogenization of the radial quality which may influence steam velocity homogenization at the quench front in reflooding (LBLOCA) and steam velocity homogenization at swell level during core uncovering of SBLOCA. In both cases the steam flowrate influences the cooling and PCT in the dry zone.

Table II. Future campaigns in two-phase conditions in METERO-V [4]

Process	Test series
Two-phase wall friction	<ul style="list-style-type: none"> • Pressure losses and interfacial friction in pure axial flow • Pressure losses and interfacial friction with transverse flows • Pressure losses and interfacial friction with buoyancy driven crossflows
Interfacial friction	<ul style="list-style-type: none"> • Pressure losses and interfacial friction in pure axial flow • Pressure losses and interfacial friction with transverse flows • Pressure losses and interfacial friction with buoyancy driven crossflows
Void dispersion	<ul style="list-style-type: none"> • Void dispersion tests

4. PRIUS EXPERIMENTAL PROGRAM

The PRIUS program has been started in KAERI since 2015 to build a database and improve the turbulence model for crossflow between subchannels. The PRIUS program aims to provide data for the validation of 3D models of porous-medium subchannel codes and open-medium CFD codes for core

thermal-hydraulic modeling. The PRIUS experimental program has addressed many important issues related to the flow behavior in a rod bundle. Flow visualization was performed using a MIR-PIV technique, from which detailed information for the two-dimensional motion of single-phase flow was quantified and compared with results from open and porous medium analyses.

In the PRIUS-I, the test loop to which the MIR technique can be applied was established, and the applicability of the technique was confirmed by using a 4×6 array test section to acquire the flow velocity field information inside the subchannels according to the non-uniform inlet condition [11]. The PRIUS-II program, a follow-up to the PRIUS-I program, produced a 6×12 array rod bundle test section and planned bare rod and spacer grid test. The program also quantitatively represented the inlet flow information necessary for the code analysis by measuring the flow velocity distribution at the entrance of the main test section [12].

4.1. PRIUS-II facility

Figure 5 shows a schematic of the PRIUS-II test facility [12]. The test facility consists of a test section, an inlet section, centrifugal pumps, a heat exchanger, a storage tank, and a 2-inch piping system for the fluid supply. The main centrifugal pump was utilized to control the flow rate in the test section. The maximum achievable Reynolds number was 13,000 based on the bulk velocity and hydraulic diameter of the test section. An auxiliary pump was connected to the storage pump to supply fluid to the main loop. Fluid temperature was maintained at $30\text{ }^{\circ}\text{C}$ with shell-and-tube type heat exchanger whose tube was connected to an air-cooler to maintain low temperature. The Pressure is close to atmospheric at top of the test section. In order to create an asymmetry of the flow entering the main test section, a tranquillization chamber was designed in two separate parts.

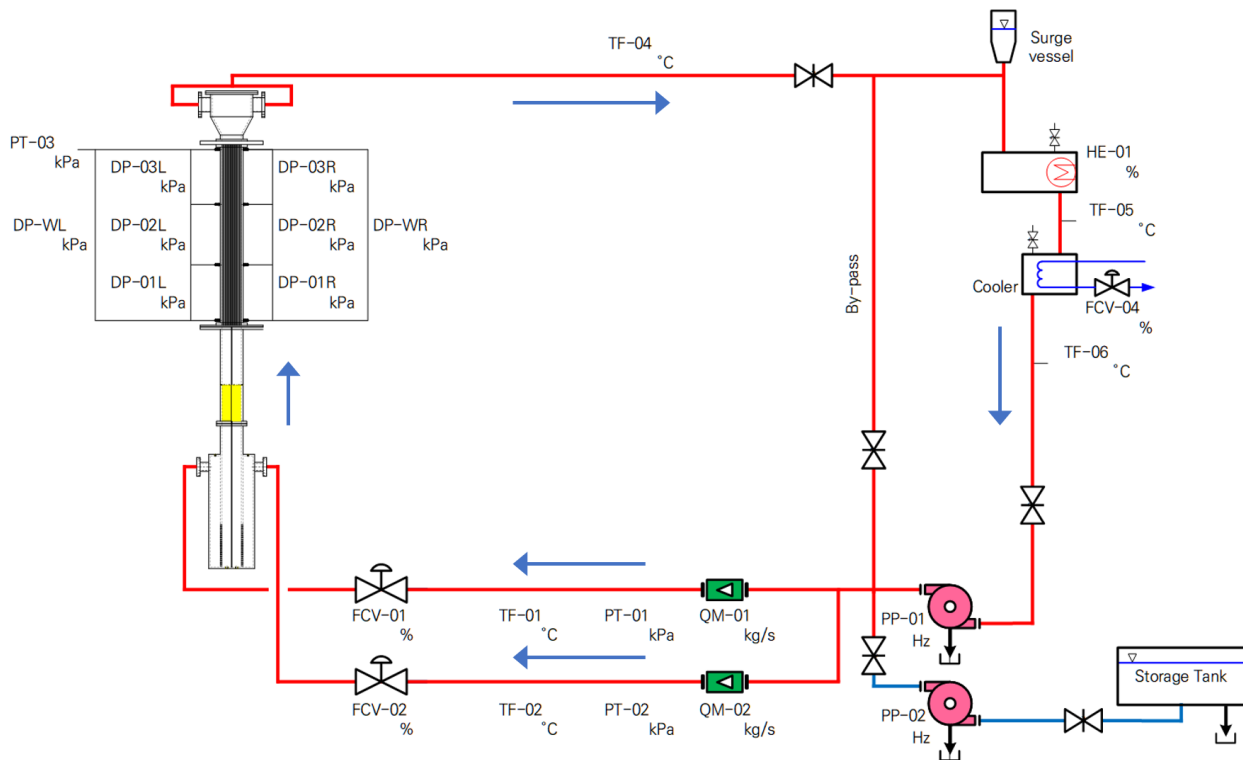


Figure 5. Schematics of PRIUS-II test loop.

The PRIUS-II test section, as shown in Figure 6, has a rectangular geometry with dimensions of 160.21 mm \times 80.1 mm \times 1.5 m. The test section and the rod are all made of acrylic for visualization. The typical configuration for the rod bundle will consist of 6 \times 12 unheated rods representing two scaled assemblies. The rod will be approximately the same size as the APR1400 PLUS7 fuel assembly (16 \times 16, D=9.5 mm, P=12.85 mm, D_h=12.64 mm). The 10 mm diameter is selected for the rods in consideration of commercial products. In order to focus on the flow phenomenon inside the sub-channels, the pitch is set to be 13.35 mm to be equal to the hydraulic diameter of the prototype.

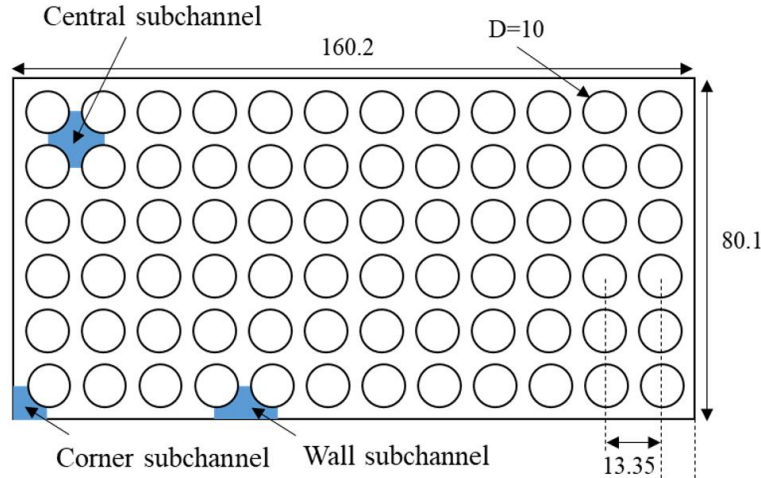


Figure 6. Geometrical arrangement of 6 \times 12 rod-bundle arrays (dimensions in mm).

The matched index of refraction (MIR) technique adopted to match the refractive index of the fluid and the acrylic rods and the test windows utilizes a fluid mixed with NaI (sodium iodide) in demi-water [13,14]. The viscosity of the mixed fluid is low enough to enable Reynolds-number identity with a feasible mass flow. The refractive index of the NaI working fluid is measured by a digital refractometer (KRUSS Co., DR6200-T). The density and dynamic viscosity of the NaI working fluid are also measured by the force tensiometer (KRUSS Co., K20) and the rheometer (Brookfield Co., DV3T), respectively [11]. Because the NaI solution is highly corrosive to ferrous metals, even to stainless steels, piping with Teflon coating for preventing corrosion has been installed. The internals of the circular pump are made of FRP (fiber-reinforced plastic). The valves and the storage tank are made of PVC (polyvinyl chloride).

The MIR-PIV measurement technique was adopted to measure the profiles of the axial and radial components [$V_z(x,z)$, $V_x(x,z)$] by visualizing the entire cross section of the sub-channels including the back side of the rods as well as the gap between the rods. Figure 7 shows the schematic configuration of PIV measurement system. The velocity vector field results are used to calculate the mean velocity field, turbulence intensity, turbulent kinetic energy, and turbulent dissipation rate using the ensemble averaging. A 16 M-pixel camera is used as the recording device in the PRIUS program. The window offset and recursive scheme are used to calculate the velocity field and enhance the sub-pixel accuracy.

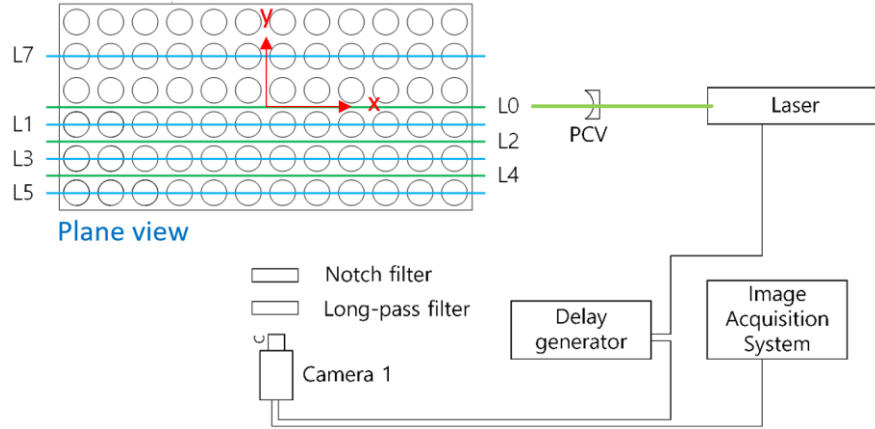


Figure 7. Experimental setup of MIR-PIV measurement system (top view).

4.2. Current and future campaigns

The test matrix for several test series conducted for the bare rod test and the planned test for the effect of the spacer grid is summarized in Table III. The test conditions were configured to simulate a total of three cases: one uniform inlet flow condition and two non-uniform inlet flow conditions. Not only the bare rods but also the spacer grid imbedded bundles can be considered, the Reynolds number, Re_{Dh} may be covered a different range: 0-13,000. In a fully developed turbulent flow regime, similarity of flow characteristics is shown regardless of the Reynolds number. The PRIUS-I experiment confirmed the flow similarity in high Reynolds number region, and in PRIUS-II we plan to build an experimental database of crossflow from the laminar region, through the transition region, and into the turbulent region.

Table III. Test condition of PRIUS-II

Test Condition	$\dot{m}_{left} : \dot{m}_{right}$			Re_{Dh}
Bare rod	5:5	8:2	6.5:3.5	12,000
				9,000
				6,000
Spacer grid	5:5	8:2	6.5:3.5	12,000
				9,000
				6,000

To simulate crossflow between the subchannels, different inlet flow rate conditions were used as test conditions. In the PRIUS-II study, various shapes of flow restrictors and honeycomb were used to make the inlet flow into a sufficiently developed turbulent flow. As a result of measuring the flow velocity distribution at each quarter point on the cross section of the square channel at the inlet, it was confirmed that the turbulent flow shape was well simulated. Figure 8 shows the normalized distribution of flow velocity by different inlet flow conditions measured at the entrance region of the main test section when the Reynolds number, Re_{Dh} is from 3,000 to 12,000.

The performance of the existing source term models of the macroscopic turbulence equation was evaluated by macroscopic analysis conducted using the CUPID code [15], and an improved source term model was proposed based on the evaluation results. Using the PRIUS experimental results, improvements to the source term model were proposed in order to properly predict the TKE in the velocity gradient region. The basic concept behind the improvement is that the velocity gradient affects the generation or dissipation of turbulence. The new models were designed to take into account the axial-velocity gradient, and it was found that these models had little effect on the axial and lateral velocity predictions, but significantly affected the prediction of the TKE and turbulent intensity in the velocity gradient region. In addition, the new models predicted the trend of the TKE under asymmetric flow conditions better than the previous model. The experimental database in a rod-bundle geometry will be used for the modeling and validation of sub-channel analysis, and it can also be useful for validation of CFD in open medium.

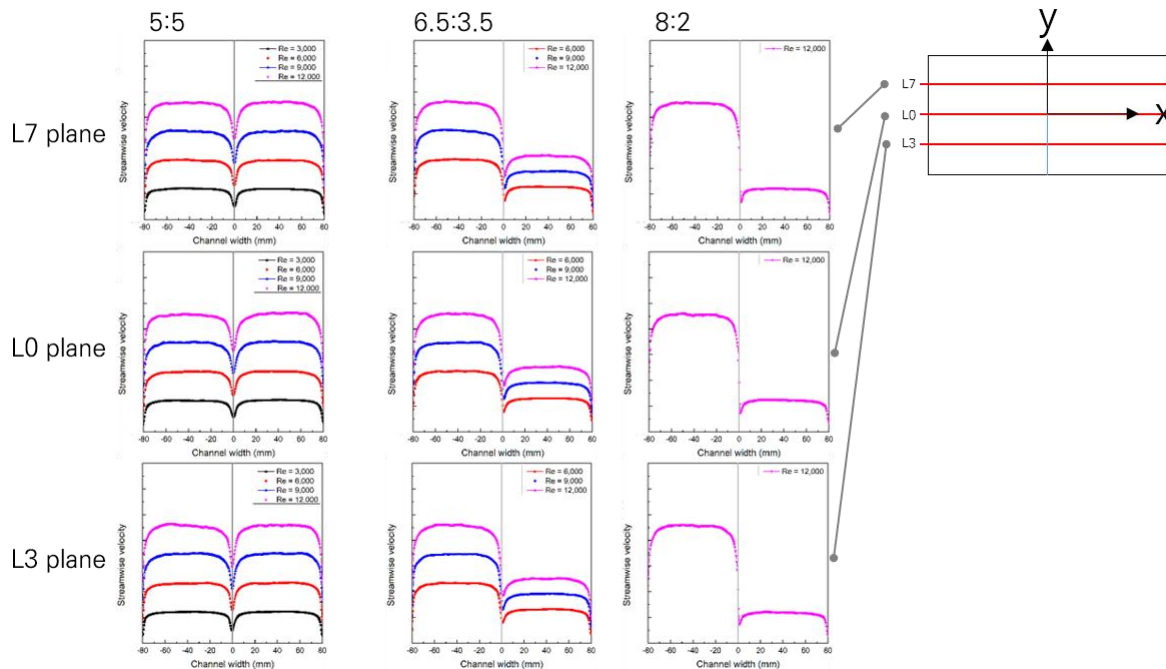


Figure 8. Normalized inlet mean velocity profile of PRIUS-II.

As a future study, several series of experiments are planned to measure the effect of various non-uniform inlet flow conditions on the spacer grid, as well as the pressure drop in the axial and transverse flow direction. The static pressure P and pressure differences ΔP will be measured at several positions on the wall of the test section as shown in Figure 5.

5. CONCLUSION AND OUTLOOK

Previous sections showed that METERO-V and PRIUS-II facilities may be used as two separate tests, providing experimental data to validate thermal hydraulic codes used for PWR core in various transient situations such as LOCAs or SLB, and could be also used for other scenarios involving 3D effects in the core, such as Loss of RHR transients or Boron dilution transients. Main objective of the two ongoing programs is to contribute to the validation of safety analysis codes and thus to the reclassification of LOCA.

METERO-V and PRIUS loops allow to create unbalanced velocities conditions at the inlet of the test section, inducing strong 3D effects in the bundle. Provided data are useful to validate or to develop friction or turbulence models in these conditions. Table IV shows that these experimental programs are complementary in terms of geometry and flow conditions. Thanks to the MIR technique, the velocities and the associated turbulence fields are available in the entire subchannel domain in PRIUS-II. Velocity data is only available in the center of the subchannel in METERO-V, but in a larger Reynolds number range compared to PRIUS-II. Similar inlet conditions could be created in both loops and easily compared or extrapolated using a cross validation, although the subchannel geometries are slightly different. Grid effects can be studied in METERO-V test section, and the spacer grid embedded bundles can be also considered in PRIUS-II.

Table IV. METERO-V and PRIUS-II characteristics compared to PWRs.

	METERO-V	PRIUS-II	French PWR	APR1400
Pitch (mm)	12.6	13.35	12.6	12.85
Rod diameter (mm)	9.5	10.0	9.5	9.5
Typical hydraulic diameter (mm)	11.78	12.69	11.78	12.64
Rod arrangement	2 × (17×8)	12×6	17×17 (assembly)	16×16 (assembly)
Reynolds number range (including PWR transient situations)	700 – 120,000	3,000 – 13,000	0 – 500,000	0 – 500,000

A possible METERO-V/PRIUS-II joint program may be designed to allow separate-effect validation of all codes which may be used for core thermal hydraulic simulation including system codes, sub-channel codes, and CFD codes. Data should validate the following separate processes:

- Wall friction and pressure losses for non-axial flow
- Crossflows with radial mixing effects
- Diffusion-dispersion of momentum

Moreover, METERO-V loop has been designed to create unbalanced temperature at the inlet of its test section, addressing the diffusion-dispersion terms of energy. Air injection is possible at the bottom of the test section to model or to validate, at least in bubbly flows conditions:

- The interfacial friction for non-axial flow,
- The void dispersion force.

This joint program, including also METERO-V specific tests (unbalanced temperatures tests, air/water tests) could be proposed to other organisms in the frame of an international project to be determined. Such a project has already been proposed as an OECD/NEA/CNSI activity in 2019. Since, both loops have been commissioned and have provided experimental data. A project involving the facilities could be proposed again for a beginning early 2025, including new experimental campaigns.

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