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Development of a SIMMER\RELAP5 coupling tool

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The In-Box Loss Of Coolant (LOCA) postulated accident is considered a major concern for the safety connected with the development of EU-DEMO fusion reactor. Relating to the renewed interest in the Water Cooled Lithium Led blanket concept, a unique and innovative experimental campaign is under development at ENEA Brasimone research center aiming at investigating consequences related to the In-Box LOCA applied to the WCLL BB. In this frame, a new coupling tool between the SIMMER-III (modified version to implement the PbLi/water chemical interaction) and the RELAP5 codes (modified version to implement PbLi thermo-physical properties) is developed together with its preliminary application to a simple test case. The coupling procedure can be classified as "two-way", "non-overlapping", "online" technique aiming at investigating multi-physics and multi-scales phenomena in support of the development of fusion technologies.

Keywords: Coupling codes, SIMMER-III, RELAP5,

1. Introduction

Safety aspect of nuclear installations represents a focal point to be pursued in the projecting phase. The development of new nuclear concepts, such as future nuclear fusion power plant, can benefit from new modelling and simulation methodologies accounting for multi-scales and multiple simultaneous physical phenomena. The need of high-fidelity computational tools is a well-known requirement especially for the simulations of abnormal scenario that can compromise the safe operation or, at least, the integrity of fusion reactor concepts. European project inside the HORIZON 2020 framework [1, 2] and works available in the scientific literature confirm the need of coupled computational tools capable to account for multiple physical phenomena such as fluid/structure interaction [3], neutronics/thermal-hydraulic [4] and multi-scales modelling such as 1D/3D thermal-hydraulic coupling tool [5, 6]. In Fusion power reactor, In-Box LOCA accident is considered a major concern for the integrity of the breading blanket component. In particular, for the Water Cooled Lead Lithium (WCLL) breeding blanket during the postulated LOCA accident, the energy released by the chemical interactions between PbLi and water results in temperature and pressure increases inside the BB. To account for these phenomena, PbLi/water chemical reactions were implemented in the SIMMER-III multiphase and multicomponent 2D thermal-hydraulic code [7]. In the present work, the SIMMER-III modified version was coupled with the 1D system thermal-hydraulic code RELAP5/mod 3.3 in order to develop a tool capable of simulating complex geometry while reducing the required computational costs. In this perspective, the use of SIMMER-III is restricted to components easily simulated with 2D axial-symmetric geometry were water/PbLi interaction occurs while the water feeding piping is conveniently simulated as 1D domain using the RELAP5 code. Finally, to evaluate the capabilities of the developed tool, simple test cases represented by two tanks connected by a piping line at their bottom filled with water at different temperature and different pressure are simulated. Obtained results are then compared with RELAP5 stand-alone simulations.

2. Coupling tool

The developed coupling tool can be classified as "two-way", "non-overlapping", "online" techniques being the SIMMER and RELAP computational domain clearly separated by interfaces were data are exchanged between the two codes in both directions with synchronized advancement in the time domain. The codes and the data exchange are managed by a Mathworks MATLAB© script which also checks the "consistency" of the main physical parameters exchanged at the interface. The adopted numerical scheme is the explicit method and the data exchange patterns is reported in Fig. 1.

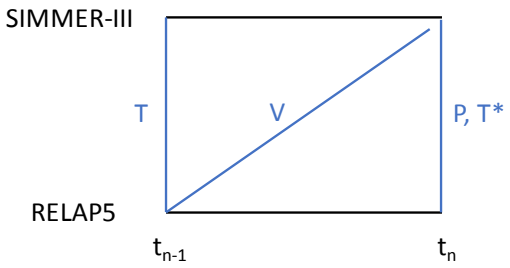

Fig. 1: Sequential data exchange scheme

Temperature exchanged from RELAP to SIMMER is assumed constant during the timestep while temperature exchanged from SIMMER to RELAP (T*) is used by the RELAP code only if reverse flow occurs. Since SIMMER does not allow inlet mass flow rate as boundary condition, the velocity is used instead (the velocity is a vector containing information both on liquid and stem velocity) and the thermophysical properties of the fluid at the inlet interface are evaluated by the code considering the temperature and the pressure at the inlet. The workflow

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(Fig. 2) of the coupling tool can be summarized in four phases:

- Steady-state phase;
- Pre-check phase;
- Run phase;
- Save phase.

In the steady state phase both the codes are run in stand-alone mode with fluid at rest to stabilize thermophysical conditions inside both the computational region. Then, a check phase is performed in order to verify the consistency of variables at the interface of the two domains. At the end of each timestep of the run phase, the MATLAB© script is used to decode both the results files (binary files), to extract the variables to be used in the next timestep, and to write and execute the restart input-deck for both the codes. Finally, the coupled calculation ends if the current time is greater or equal to the end of simulation time.

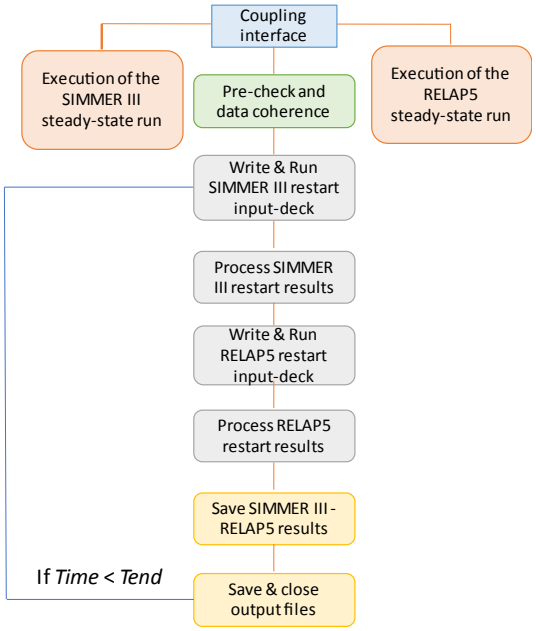

Fig. 2: Coupling tool workflow

3. Application of the coupling tool to test cases

To evaluate the capabilities of the coupling tool, different tests have been analyzed comparing the obtained results against those obtained from a stand-alone RELAP5 calculation.

3.1 Test Matrix and geometrical domain

The geometry of the system consists of two tanks at different pressure connected through a horizontal pipe (Fig. 3). This pipe is closed by a valve opening in 0.01 s. Half of the tank's volumes is occupied by water, and the other half by nitrogen. The basic test consists on the study of the pressurization/depressurization of the two tanks after the opening of the valve. Five different cases are investigated and reported in Table 1.

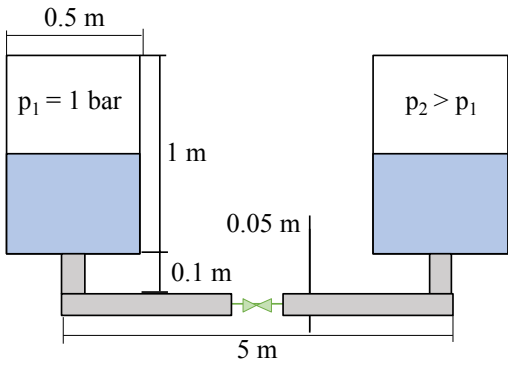

Fig. 3: Geometrical domain

In Test 1 both the tanks have the same water level, same temperature, but different initial pressure. In Test 2 the pressure in the high-pressure tank is kept constant at the initial value, in Test 3 the pressure is kept constant but a different water temperature in the two tanks is assumed. In the Test 4 and Test 5 the pressure in the high-pressure tank is kept constant at higher values (50 and 100 bar) compared to Test 2, and also different initial water levels are assumed in the two tanks, moreover the diameter of the connecting piping is 0.025 m in Test 4 and 5, while in the previous test it is 0.05 m.

Table 1. Test Matrix

Test case	Init. Cond. (RELAP5)	Init. Cond. (SIMMER III)
1. Tanks at different initial P	*10 bar / 20°C*	1 bar/20°C
2. High P tank kept at 10 bar during the transient	*10 bar / 20°C*	1 bar/20°C
3. High P tank kept at 10 bar with different water T in the two tanks	*10 bar / 80°C / 0.5 m*	*1 bar / 20°C / 0.5 m*
4. High P tank kept at 50 bar	*50 bar / 20°C / 0.95 m*	*1 bar / 20°C / 0.25 m*
5. High P tank kept at 100 bar	*100 bar / 20°C / 0.95 m*	*1 bar / 20°C / 0.25 m*

3.2 Computational domains

The stand-alone RELAP5 nodalization (Fig. 4 (a)) consists in 6 pipes: 2 pipes divided into 20 volumes each to simulate the tanks, and the remaining 4 pipes, divided into 10 volumes each, to simulate the vertical parts (2 pipes) and the horizontal parts (2 pipes) of the connecting tube. A valve is also installed between the 2 horizontal pipes, and its opening is set after 2.1 s from the beginning of the calculation. For the coupling simulation, the computational domain is split in two separated regions. The domain simulated by the SIMMER-III code

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represents the low-pressure tank and its vertical tube (Fig. 4 (b)). The axial subdivision of the vertical pipe and the low-pressure tank are the same of the RELAP5 stand-alone calculation: 10 axial levels/volumes for the vertical pipe, and 20 axial levels/volumes for the low-pressure tank. In turn, the vertical pipe is divided in one radial level only making it identical to that used in the stand-alone calculation, while the low-pressure tank is subdivided into 12 radial levels. The pressure drops across the system are imposed according to the system geometry. Although, SIMMER-III does not consider the distributed pressure drop between surrounding cells, they were simulated via small concentrated pressure drops coefficients (0.04) imposed at the top of the cells simulating the vertical pipe, while no pressure drop coefficients are imposed in the remaining cells. The rest of the domain is simulated by the RELAP5 code, substituting in the RELAP5 stand-alone nodalization pipes 100 and 110 with a time dependent volume (*TDV-50*) were pressure and temperature coming from the SIMMER-III interface are imposed. In turn, temperature and velocities to be imposed as SIMMER boundary conditions at the interface are evaluated respectively in *junction 125* and the last volume of *pipe 145*.

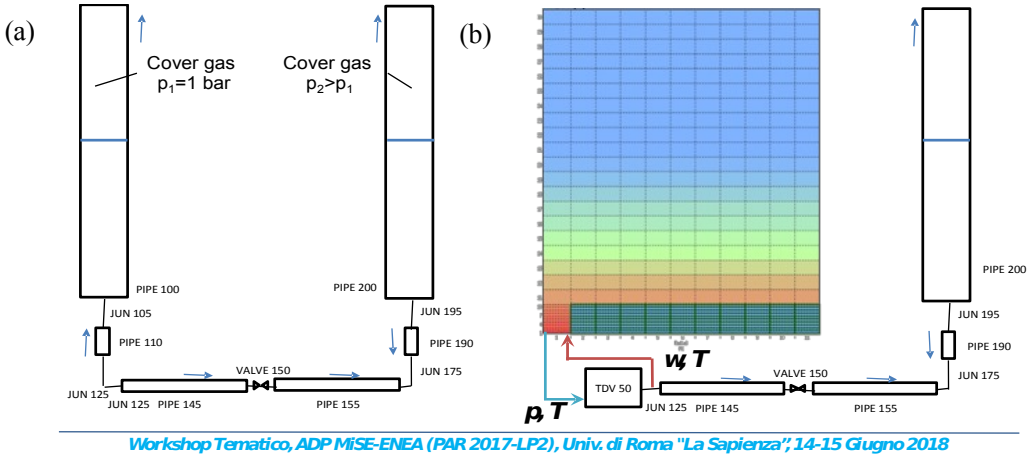

Fig. 4: RELAP5 stand-alone and coupled computational domains.

3.3 Obtained Results

Hereafter results of the coupled calculation obtained for Test 3 and Test 5 are reported and compared with results obtained from the RELAP5 stand-alone simulations. In particular, pressurization time trend of the low-pressure tank is plotted as a function of time for Test 3 and 5 (Fig. 5 and Fig. 6 respectively).

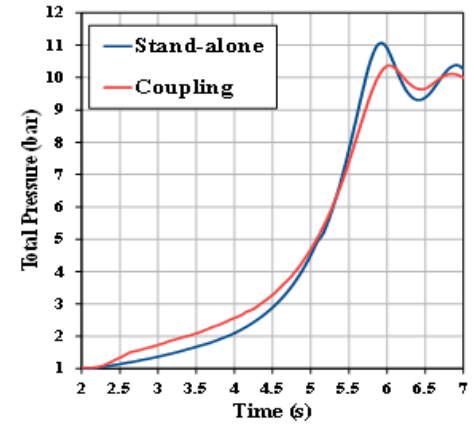

Fig. 5: Coupled Vs RELAP5 stand-alone calculation pressure time trend (Test 3)

In Test 5 the pressurization trend is slower compared to Test 3 because of the lower cross section of the connecting pipe (0.025 m compared to 0.05 m of Test 3). The comparison with the RELAP stand-alone simulation shows a good agreement between the two pressurization trends while once the pressurization ends, the two simulations show different oscillations frequency. This difference is probably because SIMMER-III code does not account for distributed pressure losses. For both tests the final pressure in the tanks is equal because during the simulations the pressure value is kept constant in the high pressure tank.

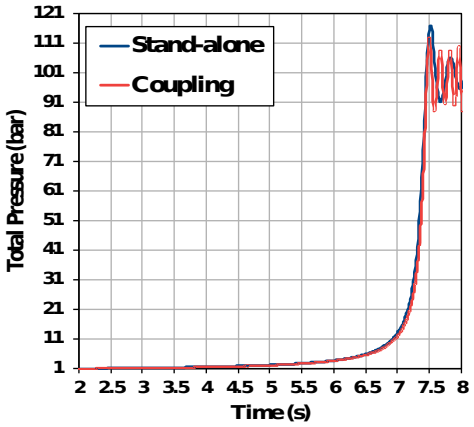

Fig. 6: Coupled Vs RELAP5 stand-alone calculation pressure time trend (Test 5)

Fig. 7 and Fig. 8 show the water velocity entering in the low-pressure tank for Test 3 and Test 5, respectively. Again, a good agreement is found between the coupled

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and the RELAP5 stand-alone simulation. Finally, Fig. 9 shows the temperature evolution inside the low-pressure tank. The inlet water temperature is 80°C while the temperature inside the tank is 20°C at the beginning of the transient.

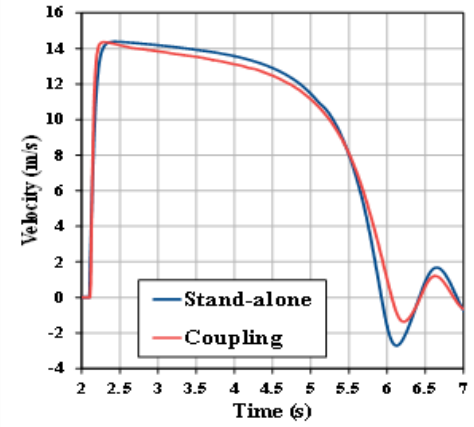

Fig. 7: Coupled Vs RELAP5 stand-alone calculation velocity time trend (Test 3)

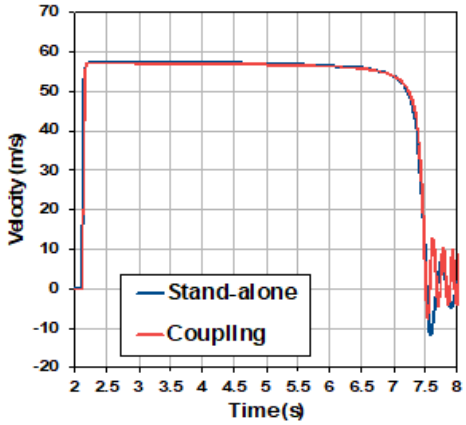

Fig. 8: Coupled Vs RELAP5 stand-alone calculation velocity time trend (Test 5)

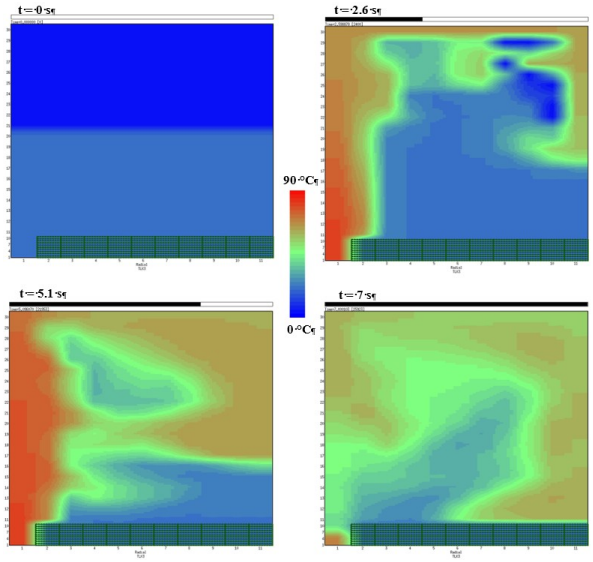

Fig. 9: Temperature evolution in the low-pressure tank

4. Conclusions

In the present paper a novel coupling codes method is developed between the RELAP5/mod3.3 and SIMMER-III codes. The main advantage of the developed tool is the possibility to obtain high fidelity calculations in complex geometry taking into account multiple physical phenomena. In particular, SIMMER-III is a suitable tool for 2D axis-symmetric domain and for the analysis of water/PbLi chemical interaction while the RELAP5 codes is suitable for simulating all the pipe lines as 1D geometry, thereby minimizing the computational cost of simulations without losing accuracy. A preliminary application of the coupling shows that the proposed method is a promising tool. Nevertheless, further improvements are required to implement the same thermophysical correlation in both codes. Moreover, a LIFUS5 [8] geometrical nodalization is under development aiming at simulating the experimental campaign foreseen at ENEA Brasimone R.C. devoted to study the interaction between Water and PbLi in view of deterministic safety analysis of WCLL breeding blanket. The experimental campaign will provide qualified and reliable data to be used for the verification and validation of the coupled tool.

Acknowledgments

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