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Development of a WCLL DEMO First Wall design module in the SYCOMORE system code interfaced with the neutronic one

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The pre-conceptual design of the DEMOnstration reactors has already started and several tokamak configurations have to be tested to find the best design by exploring different design parameters. Fast simulations involving the different components behavior must be performed. Within the European framework, SYCOMORE (SYstem COde for MOdelling tokamak REactor) is developed by CEA for this purpose. The Breeding Blanket (BB) facing the plasma is a key component in DEMO ensuring tritium self-sufficiency, shielding against neutrons and heat extraction for electricity production. Several BB concepts are being studied, among which the Water Cooled Lithium Lead (WCLL) one. SYCOMORE includes several specific modules in Python linked together, one of which has been developed to define a suitable design of the WCLL Breeding Blanket and is presented in this paper.

The method to define automatically the WCLL First Wall (FW) design using analytical design formulae starting from thermo-hydraulic and thermo-mechanical considerations as well as design criteria coming from Codes & Standards (C&S) is presented. Furthermore WCLL FW design obtained with SYCOMORE is compared to Finite Elements (FE) analyses of the DEMO WCLL BB.

Finally, a coupling between thermo-mechanics and neutronics is implemented, several iterations are necessary to obtain a converged design. Neutronic block evaluates the radial build, the BB tritium production, and the nuclear heating in the FW and the Breeding Zone (used by thermo-mechanical block). Thermo-mechanical module gives the design data (FW thickness, compositions, etc.) to the neutronic block.

Keywords: DEMO, SYCOMORE, System Code, WCLL, Breeding Blanket.

1. Introduction

SYCOMORE is a modular fusion reactor system code under development at CEA [1] to simulate speedily various DEMO tokamak configurations in scrutinizing their key parameters.

The aim of the system code is to describe a fusion power plant with all its subsystems in using simple models in an integrated approach: several modules are built as elementary calculation tools, each one treating a separate aspect such as plasma physics, engineering and costing. They are all integrated together and chained in the SYCOMORE multiphysics platform. One target of this system code is to analyze feedback between its subsystems and how each module impacts the others. In SYCOMORE, a concept of BB called Helium Cooled Lithium Lead (HCLL) [2] has been previously implemented and is described in [3]. This present model has been built in taking into account the particularities of the WCLL BB for DEMO [4] developed within the European framework.

The present article is focused on the method to define automatically the WCLL FW design via analytical design formulae starting from thermo-hydraulic and thermo-mechanical considerations: the initial HCLL BB FW design module in SYCOMORE [3] has been rethought and adapted for building a water BB concept. In particular, for the WCLL BB, the FW thermo-hydraulic limits – due to the incident Heat Flux (HF) –

are taken into account to avoid any Departure from Nucleate Boiling (DNB) due to Critical Heat Flux (CHF). The structural integrity is analyzed regarding Codes & Standards (C&S). Finally, the results are compared with ones obtained on the WCLL BB module regarding neutronics [6], thermo-mechanics and thermo-hydraulics.

2. WCLL BB concepts in DEMO

In DEMO, the BB is the component surrounding the plasma which has to withstand severe and various operating conditions while insuring tritium self-sufficiency (target: Tritium Breeding Ratio (TBR) above 1.1), neutron shielding and coolant temperature range suitable for heat extraction in order to supply a turbine for producing electricity. Moreover, the design has to fulfil the RCC-MRx structural design criteria [7] in order to ensure the structural integrity of the component when it has to withstand the thermal and mechanical loads it undergoes under nominal and accidental conditions.

The WCLL BB module in SYCOMORE derives from the HCLL one. Two major options are possible for the BB global design: #1 the Single Module Segment (SMS) configuration which consists in a unique component in poloidal direction and #2 the Multi-Modules Segment configuration which postulates different elementary modules.

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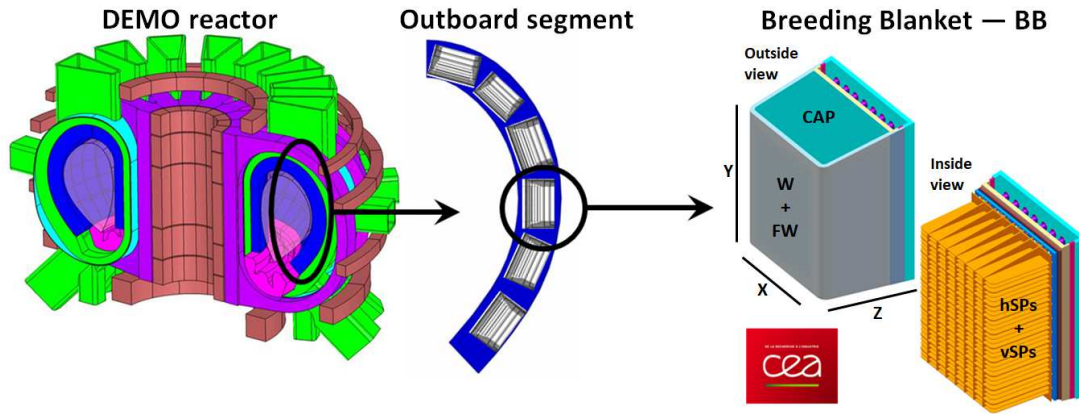


Fig. 1. Breeding Blanket concept in DEMO reactor

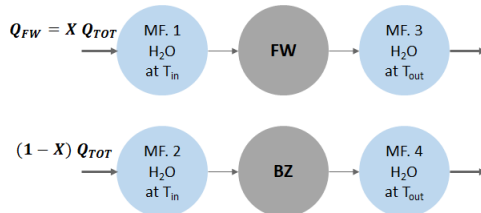


Fig. 2. WCLL Breeding Blanket water flows

No matter the configuration chosen, the WCLL BB in DEMO is attached along the poloidal direction on a Back Supporting Structure (BSS) which is crossed by a network of pipes at the rear of the segment for in-segment fluid as well as breeder supplies. The standard design scheme which has been followed is described in Fig. 1.

The BB structural material is the reduced activation ferritic-martensitic steel Eurofer97. Liquid Lithium-Lead Pb-15.7Li is used as breeder, neutron multiplier and carrier. Water is used as coolant with inlet/outlet temperatures of 295 / 328 °C with a pressure of 155 bar (typical Pressurized Water Reactors (PWR) conditions). Water is chosen for its high capability for heat extraction and for the Return of eXperience (RoX) from its extensive use in nuclear technologies as well in and fossil power plants. Structurally, in the case the MMS configuration (cf. Fig. 1), the WCLL BB is composed of several boxes attached to a Back Supporting Structure (BSS): this option has been chosen in SYCOMORE. All the boxes have the same design concept. Indeed each one is externally covered by a First Wall (FW) directly in front of the plasma and Caps at the top and the bottom. Internally the box is composed by a set of Stiffening Plates (horizontal hSPs and vertical vSPs) in order to withstand the pressure in the case of a Loss Of Coolant Accident (LOCA) in the Breeding Zone (BZ). The BZ is actively cooled by Double Wall Tubes (DWTs) – immersed in the PbLi liquid metal between vSPs and hSPs which constitutes a Breeding Unit (BU) – in which the water coolant circulates. The WCLL BB structure is closed on its back by Back Plates (BPs) that act as Manifolds (MF) – see Fig. 2 – for the water flow distribution and breeder routing through the BB. Note that these design principles are the same for the SMS configuration [4] which consists finally in a big module along the poloidal direction with a banana shape.

The WCLL BB model in SYCOMORE derives from the HCLL BB model previously implemented, but some important modifications have been done: #1 at this stage of system code development, the water-cooled FW has been implemented which is clearly representative of the WCLL BB concept, #2 no DWTs have been inserted in the Breeding Zone (BZ) area, the previous structure (coming from the HCLL BB module in SYCOMORE) is maintained with vSPs and hSPs in flow series with Cooling Plates (CPs) in the BZ at the scale of BU. The global flow path however follows the same scheme as the reference WCLL DEMO blanket with a parallel cooling scheme between the FW and the BZ (cf. Fig. 2).

3. WCLL BB design module in SYCOMORE

In the SYCOMORE system code, dedicated modules calculate important reactor values using models whose level of implementation depends on the code objective: each module is composed of calculation blocks subdivided in sub-blocks – see Fig. 3. All the modules are linked together via an integrated tokamak modeling platform via SYCOMORE allowing to establish the plasma physics and to define the various reactor subsystems: thus system design workflow is creating by chaining the execution of the various sub-modules with optimization loops. Moreover a major preliminary work has been done previously to define cause-and-effect links and inputs/outputs of each module. This approach allows several advantages:

- Modules describe a physic or a technology. They can be unitary replaced that makes collaborative development easier. Moreover in a pre-design phase simple models are used to accelerate code processing.
- The reactor design workflow is adapted to change: the type of constraint applied can be modified speedily as well as the way to chain modules and finally converge to a global solution.

The Breeding Blanket module in SYCOMORE is constituted by several blocks (left part of Fig. 3) such as:

- Reactor reassembly geometry block;
- Neutronic block;
- Reactor reassembly power block;
- WCLL BB design block.

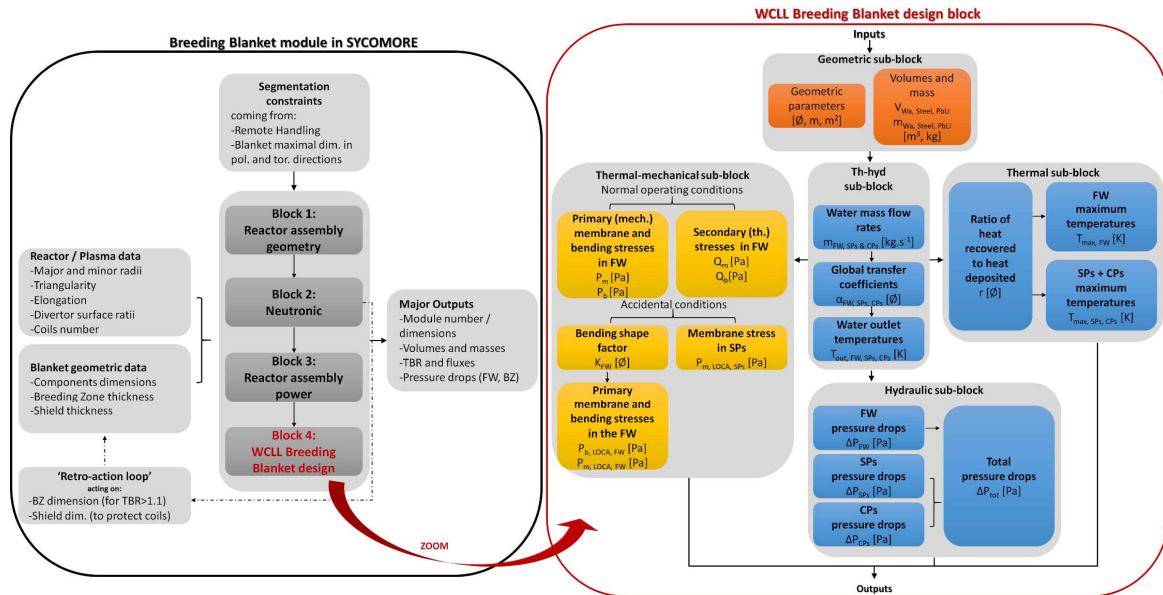


Fig. 3. WCLL Breeding Blanket design block (right) within the global BB module in SYCOMORE (left)

The WCLL BB design block (block 4 in Fig. 3) uses the same global architecture than the one developed for the HCLL BB configuration (cf. [2] to [5]). In this block, the different elementary analyses are segmented in sub-blocks in terms of geometry, mass calculation, thermic, hydraulic, pressure drops and thermo-mechanic; each one regrouping dedicated functions (see Fig. 3):

- A geometry check is performed in the geometric sub-block in order to ensure the coherence between inlet data. Then geometrical parameters are calculated such as hydraulic diameters, pitches between channels, surfaces of thermal exchanges evaluation.
- The volume of each material per component is computed again via rough estimation performed in the reactor geometry assembly module. The mass evaluation taking into account the specific mass at the initial temperature for Eurofer and Pb-Li and at the average temperature for water.
- In the thermal analyses sub-block, the power recovered in each part of the two water cooling circuits in parallel (#1 FW and #2 BZ = SPs + CPs – cf. fig. 2) is estimated starting from the power fraction deposited in each component. The water mass flow rates in the WCLL BB per sub-components (FW and BZ) are evaluated: see Fig. 3. After, in each part, relevant inlet/outlet temperatures are calculated via a simple enthalpy balance using as input the power deposited in various components from reactor assembly power block (block 3 in Fig. 3). Maximum temperatures in the FW as well in the SPs and in the CPs are estimated to check whether steel maximum temperature limit is respected.
- In the hydraulic sub-block, pressure drops in the BB are estimated combining friction losses in straight channels and pressure drops in singularities such as elbows. Pressure drops will be input parameter for the energy conversion system SYCOMORE sub-module which is being developed in parallel for the

predesign of the primary heat transfer system and the calculation of thermo-dynamic cycle efficiency.

- In the thermo-mechanical sub-block, more particularly via a Python function dedicated to the FW analyses, membrane and bending stresses are evaluated analytical formulations and compared to allowable limits for RCC-MRx [7] damages

4. WCLL BB FW design block strategy

4.1 WCLL BB operating conditions and design limits

For the two hydraulic circuits in parallel i.e. #1 FW and #2 BZ, the input/output temperatures are respectively 295°C / 328°C.

Two operating conditions are precisely studied:

- In Normal condition (A-level in RCC-MRx [7]), the mechanical loadings are the water pressure is 155 bar in the water hydraulic circuits and the pressure on surfaces wetted by PbLi is taken at 0.5 bar. Moreover, the thermal loadings are (#1) the HF deposited on the FW (which depends essentially on the reactor configuration), (#2) the neutronic power deposited in the FW structure and (#3) the HF on the FW backside at boundary with the BZ. The (#2) and (#3) contributions cannot be exactly determined without knowing respectively the geometry and the interaction between the FW and the BZ. Thus in SYCOMORE, these quantities are calculated iteratively starting from the total power deposited in the WCLL BB module.
- In accidental condition (D-level RCC-MRx [7]): a Loss Of Coolant Accident (LOCA) is supposed, all the WCLL BB is considered as over-pressurized at 186 bar on all surfaces wetted by PbLi.

Concerning the design limits, the operating cases are analyzed with different stress limits [7], depending on the probability of the condition occurring, and the willingness to return the component to service. Moreover the temperature of the Eurofer structures shall not exceed

550°C; indeed above this value, the thermo-mechanical properties in particular decreases quickly. Furthermore the flow conditions in water has to remain below the Critical Heat Flux to not severely affect heat transfer in the FW channels. Moreover, always on the thermo-hydraulic aspects but this time linked with the Balance of Plant (BoP), the pressure drops have to be calculated in order to assess the reactor efficiency. At last, the design has to comply with the RCC-MRx criteria [7].

4.2 FW geometry: major dimensions

Table 1. Variables used

Variable	Description
Q_{FW}	Water mass flow rate in the FW [kg/s]
C_p	Water specific heat [J kg ⁻¹ K ⁻¹]
ΔT	Range of temperature in the FW and BZ [K]
T_{in}	FW inlet temperature [K]
T_{out}	FW outlet temperature [K]
P_{FW}	Total power deposited in the FW [W]
ρ	Water density in the FW [kg/m ³]
v	Water velocity in the FW with $v = v_{corro} \cdot f_{corro}$ [m/s]
S	Total section of the FW channels [m ²]
S_c	Section of one FW channel [m ²]
n_c	Number of FW channel
f_d	Ratio between d_1 and d_2 - dimensionless parameter (cf. [3])
f_r	Ratio between $2r$ and d_1 - dimensionless parameter (cf. [3])
T_w	Wall temperature of the FW [K]
T_{sat}	Temperature of water saturation [K] - $T_{sat} = 344.76^\circ\text{C}$ at 155 bar
D	Inner diameter of the tube [m]
D_0	Maximum bubble diameter = 12.7 mm
μ	Dynamic viscosity of water [kg m ⁻¹ s ⁻¹]
ρ_{in}	Density of water at inlet temperature [kg/m ³]
ρ_{out}	Density of water at outlet temperature [kg/m ³]
ρ_{gsat}	Density of steam at saturation temperature = 101.931 kg/m ³
H_{out}	Enthalpy of water at outlet temperature [J/kg]
H_{sat}	Enthalpy of water at $T_{sat} = 1630.75\text{E}^3$ [J/kg]
H_{fgsat}	Enthalpy of steam at $T_{sat} = 969.55\text{E}^3$ [J/kg]
P	Pressure of water in the hydraulic circuit [Pa]
P_0	220.9 bar
$F_{l,max}$	Real heat flux through the FW channel wall [W/m ²]
q''	Heat flux applied on the FW [W/m ²]
D	Hydraulic diameter [m]
f	Darcy-Weisbach friction factor for straight tube
L	FW channel length $L = X + 2Z$ [m]
K	Concentrated pressure loss coefficient
$d_{1,DNB}$	Poloidal dimension of the FW at which the DNB occurs [m]
f_p	Calculated fraction of the thermal power used for the PP [%]
f_p	Limit fraction of the thermal power used for the PP [%]
X	FW toroidal length [m]
Y	FW poloidal length [m]
Z	FW radial length [m]

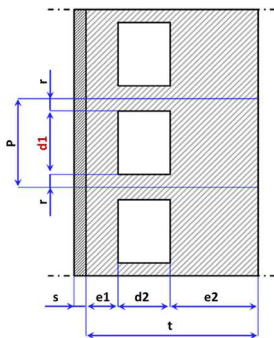


Fig. 4. FW section in the poloidal-radial plane.

The WCLL FW is made by a big U-shape Eurofer plate where water flows in n_c spare channels which are in parallel (see Fig. 4 extracted from [9]) with the BZ heat extraction components. In Fig. 4, a section of the FW in the poloidal-radial direction is shown and this scheme will serve as a basis for the discussions that will

follow. The geometry of FW is characterized by several parameters: the radial tungsten thickness s the overall FW thickness t , the plasma facing wall thickness e_1 , the BZ facing wall thickness e_2 , the poloidal channel dimension d_1 , the radial channel dimension d_2 , the distance between two channels ($2r$, the rib) and the pitch between two channels P . The additional variables are given in Table 1.

4.3 WCLL BB FW calculation strategy

The WCLL BB FW design sub-block is included in the WCLL BB design block. The calculation strategy is: Step #1 to pilot the resolution via the water velocity (due to corrosion); Step #2 to verify a posteriori that the dimensions of the FW channels are greater than those obtained via the DNB formula (else a retroaction is done in the sub-block); finally Step #3 to analyze the impact of the FW design defined on the reactor efficiency.

Step #1: the approach for the evaluation of the FW dimensions is to introduce a limitation on the water velocity in channels or tubes due to corrosion. Two parameters are imposed as inputs of the block: a maximal velocity v_{corro} (taken at 8 m/s as a limit coming from the PWR RoX) is imposed as an input parameter in the FW block and a reduction coefficient f_{corro} symbolizing the margin before corrosion becomes significant in the hydraulic circuit. The water velocity in the FW is defined by: $v = v_{corro} \cdot f_{corro}$. This strategy comes in particular from the RoX on the PWR nuclear plants as well as fossil power ones in which the aqueous corrosion is a major threat for the degradation of the hydraulic circuit whose local losses of thickness are monitored and analyzed precisely at each maintenance stops of plants. In imposing the velocity as an input data, the main target is firstly to evaluate the FW channels poloidal dimension d_1 (cf. red value on Fig. 4). All the FW geometric parameters can be evaluated via the thermo-mechanical and thermo-hydraulic via the same calculation strategy than in [3].

The enthalpy balance in the FW is given:

$$Q_{FW} \cdot C_p \cdot \Delta T = P_{FW} \quad (1)$$

And the Mass Flow Rate in the FW is defined via:

$$Q_{FW} = \rho \cdot v \cdot S \quad (2)$$

Where $S = S_c \cdot n_c$ the total water section in the FW.

And with: $S_c = d_1 \cdot d_2 = d_1^2 \cdot f_d$ and $n_c = \frac{Y}{d_1 \cdot (1 + f_r)}$

Finally, the poloidal FW channel dimension d_1 can be expressed by (3) in combining (1) and (2):

$$d_1 = \frac{(1 + f_r) \cdot P_{FW}}{\rho \cdot v \cdot Y \cdot f_d \cdot C_p \cdot \Delta T} \quad (3)$$

Step #2: concerning the thermal exchange in case of water, the Departure from Nuclear Boiling (DNB) has to be finely analyzed in order to prevent the degradation of the heat exchange in the FW: the goal is that, at the scale of a FW channel, the heat flux does not reach the critical heat flux – in any case. The Rohsenow correlation (4)

extracted from [8] is used in order to prevent the FW of any DNB. This equation is valid for circular channels. At the moment, no correlation exists for rectangular channels: for lack of better, equation (4) is used here. However, tests will have to be developed in the future to establish the correlation for rectangular channels.

$$\frac{8}{Re^{0.6}} \left(\frac{D}{D_0} \right)^{0.32} (0.23 \rho_{in} \cdot v \cdot H_{f_{gsat}}) \left(1 + 0.00216 \left(\frac{P}{P_0} \right)^{1.8} Re^{0.5} \frac{(H_{sat} - H_{out}) \rho_{out}}{H_{f_{gsat}} \rho_{gsat}} \right) = F_{l_{max}} \quad (4)$$

With D the hydraulic diameter given by:

$$D = \frac{2 \cdot f_d}{1 + f_d} d_{1_{DNB}} \quad (5)$$

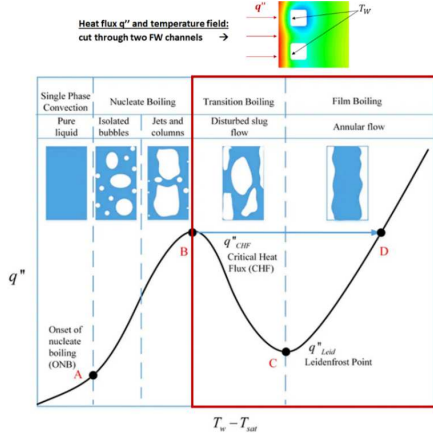


Fig. 5. DNB principles of occurrence [9]

Indeed, if the Heat Flux near a FW channel is above the value of the Critical Heat Flux, then the bulk fluid may boil. Thus large bubbles form, sometimes blocking the passage of the fluid. These results in a DNB – see Fig. 5 whose curve is extracted from [9]. In the calculation process, the goal is to find via the DNB equation the value of d_1 at which the DNB occurs: this value is called $d_{1_{DNB}}$.

First, an equilibrium between the HF on the FW and the one at the scale on the channels walls can be written:

$$n_C \cdot d_{1_{ONB}} \cdot F_{l_{max}} = Y \cdot q'' \quad (6)$$

$$\text{And geometrically: } d_{1_{DNB}} \cdot n_C = \frac{Y}{(1 + f_r)} \quad (7)$$

$$\text{Thus } F_{l_{max}} = (1 + f_r) \cdot q'' \quad (8)$$

And moreover in re-combining (1) to (3):

$$\rho_{in} \cdot v = \frac{(1 + f_r) \cdot Q_{FW}}{Y \cdot f_d \cdot C_P \cdot d_{1_{DNB}}} \quad (9)$$

Therefore, by replacing equations (6) to (9) in (4):

$$d_{1_{ONB}} = \left(\frac{8}{Re^{0.6}} \left(\frac{2f_d}{Re^{0.6} D_0 (1+f_d)} \right)^{0.32} \left(0.23 \frac{(1+f_r) Q_{FW}}{Y f_d C_P} H_{f_{gsat}} \right) \left(1 + 0.00216 \left(\frac{P}{P_0} \right)^{1.8} Re^{0.5} \frac{(H_{sat} - H_{out}) \rho_{out}}{H_{f_{gsat}} \rho_{gsat}} \right) \right)^{\frac{1}{0.68}} \frac{1}{(1+f_r) \cdot q''} \quad (10)$$

In the FW block code, the FW channels dimensions at which the DNB occurs is evaluated via (10): if the value obtained is below the one obtained via step 1, the step 1 value is conserved; else the dimensions at the limit of the DNB concurrency are chosen. The test can be formulated as: if $d_{1_{DNB}} < d_1$ then $d_1 = d_{1_{DNB}}$.

Step #3: for finally producing electricity with a consequent global efficiency, energy losses due to the pumping of the coolant must be limited. This aspect is precisely verified a posteriori regarding the Pressure Drops (ΔP) and the Pumping Power (PP) too. Indeed the calculation strategy is to determine the ratio that represents the PP necessary for cooling the FW divided by the heat recovered by the FW: this ratio has to be below 5% (limit fixed in SYCOMORE).

The Pressure Drops ΔP can be formulated via two different equations: in the first one, the Pressure Drops are directly obtained via this standard formula i.e.:

$$\Delta P = \rho \cdot \frac{v^2}{2} \cdot \left(\frac{f \cdot L}{2 \cdot \frac{f_d}{1+f_d}} + K \right) \quad (11)$$

The second one is used to calculate f_p' the fraction of the thermal power used for the pumping power obtained in the configuration which has been calculated:

$$\Delta P = \frac{f_p' \cdot \rho \cdot P_{FW}}{Q_{FW}} \leftrightarrow f_p' = \frac{Q_{FW} \cdot \Delta P}{\rho \cdot P_{FW}} \quad (12)$$

Finally the value of f_p' is compared to the limit f_p given in the main program in SYCOMORE. Note that in the system code, other retro-action loops are present in particular concerning manufacturing aspects [3].

5. Interaction with the neutronic BB module

A coupling between thermo-mechanical and neutronic blocks is implemented, several iterations are necessary to obtain a converged design. Neutronic block evaluates the BB tritium production, the neutronic fluxes in the structures of the tokamak (especially magnets) and the nuclear heating in the FW and the Breeding Zone (used by thermo-mechanical block). Moreover the neutronic block calculates integral quantities such as TBR (Tritium Breeding Ratio) and Me (energy multiplication factor). Thermo-mechanical module gives the design data (FW thickness, compositions, etc.) to the neutronic block.

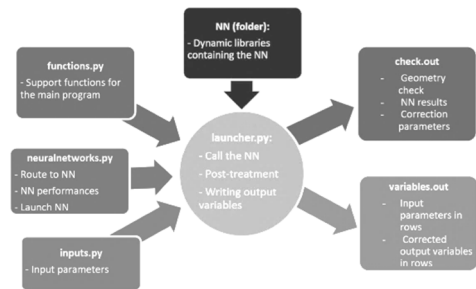


Fig. 6. Neutronic Neural Network in SYCOMORE

At first, the same calculation strategy than for the HCLL neutronic module (see [5][6]) has been used for the WCLL BB in SYCOMORE. The activities have been particularly focused on the development of simplified neutronic models for the WCLL concept: a new neutronic model has been developed in order to obtain faithful results via simplified 3D models of the tokamak with TRIPOLI-4@. The simulations have been performed in coupled neutron-photon transport mode. To easily integrate this neutronic module and to propose

simulation times compatible with the constraints of the system code (total SYCOMORE "run" less than one minute), Neural Network (NN) meta-models (Fig. 6) replicating the results have been built using the URANIE [11] platform. The selected NN have been encapsulated in a Python program allowing their exploitation quickly, it constitutes the WCLL neutronic module of SYCOMORE [6] and can be used for the BB design. Furthermore, the results obtained have been compared to the DEMO WCLL reactor case (2014 baseline). WCLL neutronic sub-module produces results with right orders of magnitude and shows rather small differences with the DEMO WCLL reactor case.

6. Benchmark with the WCLL BB model in DEMO

Table 2. Comparison between the SYCOMORE WCLL BB module vs. the DEMO WCLL BB FE analysis

Parameter	Units	DEMO WCLL BB FE analysis (cf. results in [12])	WCLL BB module in SYCOMORE
Major Radius, R0	[m]	9.072	→ Input
Minor radius, a	[m]	2.297	→ Input
Elongation, el		1.59	→ Input
Triangularity		0.333	→ Input
Plasma volume	[m ³]	2502	→ Input
Plasma surface	[m ²]	1428	→ Input
FW water velocity	[m/s]	1.922	→ Input for test
FW ch. dimensions	[mm ²]	7 * 7	7.4 * 7.4
FW front th.	[mm]	3	2.1
Total FW th.	[mm]	25	28
FW pressure drops	[bar]	0,14	0,17
Number of FW ch.		108(*)	131
Max. FW Temp.	[°C]	417	391
Max. hSPs / vSPs Temp.	[°C]	409	332 (#)
TBR		1.13	1.12

Leg. 1: (*) Value recalculated in the MMS configuration to compare

Leg. 2: (#) Calculated in SYCOMORE but not representative, SPs cooled

The thermo-mechanical and thermo-hydraulic physics of the WCLL BB has been coded in SYCOMORE using Python language. Moreover, as described in Fig. 3, a feedback loop on the neutronic block in SYCOMORE acts on the BZ dimensions for the TBR optimization (target above 1.1 for tritium self-sufficiency): thus a TBR evaluation is done via SYCOMORE on the design iteratively calculated. Nonetheless, the design rules of C&S have been coded too [3] and criteria can be checked: for the case studied in Table 2, the criteria are fulfilled.

In Table 2, WCLL FW design obtained with SYCOMORE is finally compared to Finite Elements (FE) analyses [12]. The results between the FE model versus the one calculated in SYCOMORE are similar: in particular, the maximum temperature in the FW Eurofer structure is respectively 417°C vs. 391°C and moreover the TBR obtained are very similar with respectively 1.13 vs. 1.12 which is very encouraging for a system code. The global dimensions of the FW calculated via SYCOMORE are clearly in the same order of magnitude of the DEMO design established with FE analyses [12]. However some gaps remain concerning the temperature in the SPs that can be easily explained: in the configuration chosen in SYCOMORE, the SPs are cooled internally which is not the case in the FE model.

Besides the pressure drops in the FW are slightly different due to global geometric differences between the two models (MMS vs. SMS).

7. Conclusions

The development of the BB module in SYCOMORE has been continued for the WCLL concept in introducing thermo-hydraulic and thermo-mechanic sub-blocks in order to define the deductive optimal design in accordance with the WCLL BB performance targets and the C&S criteria. Geometric, thermo-hydraulic and thermo-mechanical blocks coupled to the neutronic one allow a complete calculation and very encouraging results for a system code are obtained in particular concerning TBR evaluation. Indeed the WCLL BB calculation via SYCOMORE has shown that the developed methodology reproduces quite well the behavior of 3D model providing a useful automatic pre-design tool to designers.

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