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Investigation of the DEMO WCLL Breeding Blanket Cooling Water Activation

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ABSTRACT

Within the framework of the activities foreseen by the EUROfusion action on the cooling water activation assessment for a DEMO reactor equipped with a Water Cooled Lithium Lead Breeding Blanket (WCLL BB), the University of Palermo is involved in the assessment of dose rates induced by the decay of nitrogen radioisotopes produced by water activation, nearby the main components (e.g. isolation valves) of both First Wall (FW) and Breeder Zone (BZ) cooling circuits. In particular, the aim of this work is to evaluate the spatial distribution of nitrogen isotopes (^{16}N and ^{17}N) in the WCLL BB cooling circuits. To this purpose, a coupled neutronic/fluid-dynamic problem is solved following a theoretical-numerical approach and adopting an integrated computational tool mainly relying on the use of MCNP6 and ANSYS CFX codes. The operative procedure adopted foresees the assessment of the production rate distributions of nitrogen isotopes within FW and BZ cooling channels and tubes by means of totally heterogeneous neutronic analyses. A fully 3-D fluid-dynamic approach is, then, used to compute the nitrogen isotope concentrations within the In-Vessel complex flow domain, while a 1-D lumped parameters approach is adopted to calculate their distribution along the Ex-Vessel BB Primary Heat Transfer System. The results obtained, herewith presented and critically discussed, provided the necessary data to perform dedicated neutronic and photonic transport analyses and, hence, to assess the dose rates in the aforementioned target locations.

1. Introduction

Within the framework of the activities foreseen by EUROfusion action on the "Cooling water activation assessment", the University of Palermo is involved in the assessment of the absorbed dose around both First Wall (FW) and Breeder Zone (BZ) cooling circuits (e.g. isolation valves, hot and cold legs) of the DEMO reactor equipped with a Water Cooled Lithium Lead Breeding Blanket (WCLL BB).

2. Description of the method

The operative procedure adopted is based on a multi-physics method previously developed and it foresees the assessment of the spatial distribution of nitrogen isotope concentration production rates within FW an BZ cooling channels and tubes by means of completely heterogeneous neutronic models. A fully 3-D CFD approach is, then, used to compute the nitrogen concentrations within the In-Vessel complex flow domain, while a lumped parameters, 1-D approach, is adopted to calculate the nitrogen isotope concentrations along the Ex-Vessel BB PHTS.

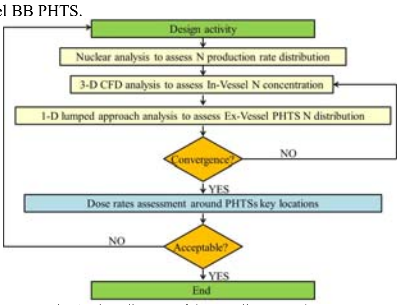

Fig. 1. Flow diagram of the coupling procedure set-up.

3. Assessment of the volumetric density of ^{16}N and ^{17}N production rates

The first step of the procedure described above foresees the assessment of the spatial distribution of ^{16}N and ^{17}N volumetric density production rates, therefore, neutronic analyses have been carried out for the cooling circuits of OB and IB FWs and for the OB BZ circuit while results have been extrapolated for the IB BZ circuit, which has not been considered as its design is not still mature enough.

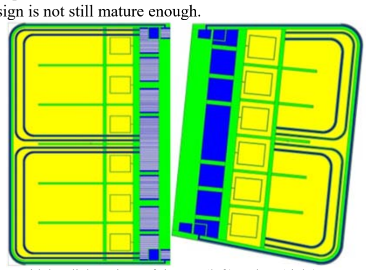

Fig. 2. Toroidal-radial sections of the OB (left) and IB (right) MCNP models.

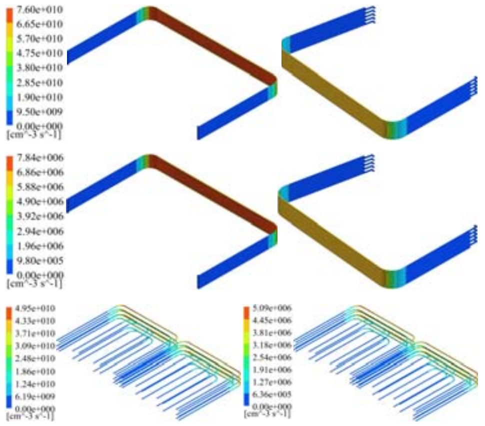

Fig. 2. Spatial distribution of ^{16}N and ^{17}N volumetric density production rates in the OB and IB FW and in the OB BZ.

4. ^{16}N and ^{17}N volumetric densities

The assessment of ^{16}N and ^{17}N volumetric densities in the FW channels of the 26 OB and 55 IB slices has been performed by CFD analyses. As far as BZ tubes are concerned CFD analyses have been performed in one OB slice and results have been extrapolated to the whole segment scaling the values in accord to NWL neutron profile. Nitrogen isotopes concentrations of the IB BZ water domain have been obtained from the OB BZ ones using scale factor taking into account both the ratios between the different NWL values and the mass flow rates related to the IB and OB segments.

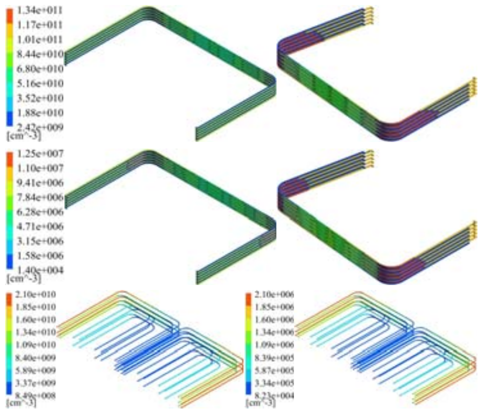

Fig. 3. Spatial distribution of ^{16}N and ^{17}N volumetric density in the FW and BZ.

The assessment of ^{16}N and ^{17}N concentration spatial distributions in the Ex Vessel components has been carried out by a numerical method based on a 1-D lumped parameter approach that foresees a nodalization of the system. As nitrogen isotopes move from the single slice to the entire cooling system, it is necessary to account for the mixing of water streams in the collector pipes that transfer the coolant water to the PHTS, modifying the nitrogen concentration distribution along the cooling system. So, each slice, pipe and component of the cooling system is modelled as a node. Basically, for each node, it has been considered the balance between what enters from the previous nodes and what exits to the next nodes, decreased by the amount of nitrogen lost due to decay during the transit.

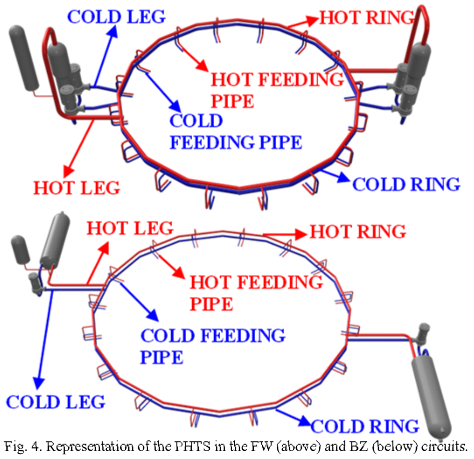

Fig. 4. Representation of the PHTS in the FW (above) and BZ (below) circuits.

Table 1. Nitrogen concentration in the FW circuit [cm^{-3}].

NODE	^{16}N	^{17}N
Hot Feeding Pipe	3.809E+10	2.338E+06
Hot Ring	3.031E+10	1.616E+06
Hot Leg	2.922E+10	1.518E+06
Cold Leg	5.248E+09	8.077E+04
Cold Ring	5.060E+09	7.589E+04
Cold Feeding Pipe	4.928E+09	7.257E+04

Table 2. Nitrogen concentration in the BZ circuit [cm^{-3}].

NODE	^{16}N	^{17}N
Hot Feeding Pipe	4.516E+09	3.008E+05
Hot Ring	3.519E+09	2.012E+05
Hot Leg	2.578E+09	1.182E+05
Cold Leg	1.692E+09	5.758E+04
Cold Ring	1.627E+09	5.387E+04
Cold Feeding Pipe	1.577E+09	5.107E+04

CONCLUSIONS

Within the framework of EUROfusion action, at the University of Palermo a research campaign has been performed in order to assess the dose absorbed in some key components of the WCLL BB PHTS in the DEMO reactor. As first step of this research activity the main activation products of water (^{16}N and ^{17}N) volumetric densities have been evaluated in some relevant component of DEMO PHTS. To this purpose it has been developed a multi-physics method whose underlying idea is to evaluate the spatial distribution of nitrogen isotopes concentrations as precisely as possible in order to assess the spatial distribution of the absorbed dose in a realistic and accurate way. Therefore, the nitrogen isotopes production rates have been evaluated by neutronic analyses and their concentrations in the BB hydraulic circuits and in the PHTS system have been assessed by CFD analyses and 1-D lumped parameter calculations respectively. Then, results obtained have been used as input data to implement the neutronic and photonic sources necessary to assess the dose in the neighborhood of the PHTS in a further work.

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