# Assessment of DEMO WCLL Breeding Blanket Primary Heat Transfer System Isolation Valve Absorbed Doses due to Activated Water

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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 investigation of the absorbed dose induced by the decay of nitrogen radioisotopes produced by water activation, in the main components (e.g. isolation valves) of both First Wall (FW) and Breeder Zone (BZ) cooling circuits.

The aim of this work is to assess the spatial distribution of the absorbed dose in the DEMO Upper Pipe Chase (UPC), focusing the attention on the space neighbouring a typical isolation valve of the Primary Heat Transfer System (PHTS), taking into account a period of 7 full power years. To this end, a computational approach has been followed adopting MCNP5 Monte Carlo code. In particular, a totally heterogeneous neutronic model of a portion of the UPC has been set up, including the valve and the main FW and BZ PHTS piping, and the spatial distribution of nitrogen isotopes concentrations, previously assessed, have been used to model the photonic and neutronic sources.

The results obtained, herewith presented and critically discussed, provided some information on the nuclear issues of the WCLL BB PHTS, to be considered as hints for the blanket design optimization.

Keywords DEMO, WCLL blanket, dose, neutronics.

## 1. Introduction

Within the framework of the activities foreseen by EUROfusion action (TS Ref. PMI-3-T011) on the "Cooling water activation assessment", the University of Palermo is involved in the dose assessment 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) [1,2].

In such a nuclear system the endothermic charged-particle reactions $^{16}O(n,p)^{16}N$ (with a threshold energy of ~10.2 MeV) and $^{17}O(n,p)^{17}N$ (with a threshold energy of ~8.4 MeV) are the principal sources of water radioactivity during operation [3,4]. $^{16}N$ decays by emission of $\beta$ particle and emits $\gamma$ rays with the half-life of 7.13 s while $^{17}N$ decays by $\beta$ particles and emits neutrons with the half-life of 4.173 s.

The aim of this research activity is to assess the spatial distribution of the absorbed dose, due to the decay of nitrogen isotopes produced by coolant activation, around some key components of WCLL BB cooling circuit, focussing the attention on the Primary Heat Transfer System (PHTS), in the Upper Pipe Chase (UPC) of the reactor and taking into account a period of 7 Full Power Years (FPYs). The neutron and photon dose maps have been evaluated starting from the spatial distribution of the activity volumetric densities of nitrogen isotopes, obtained in a previous work [5], as they allow the set-up of photon ($^{16}N$) and neutron ($^{17}N$) sources for the related nuclear analyses. Indeed, in [5] a coupled neutronic/fluid-dynamic problem was solved following a theoretical-numerical approach and adopting an integrated computational tool mainly relying on the use of robust and well validated commercial codes. Neutronic calculations were performed to evaluate the spatial distribution of the production rates of nitrogen isotope concentrations and 3D computational fluid-dynamic analyses were performed to assess the nitrogen isotope concentrations.

A 3-D map of the absorbed dose in the volume under investigation is of considerable interest in order to be able to evaluate the conditions influencing devices whose availability is undermined by intense ionizing radiation fields. To this regard the assessment of the dose absorbed in such components as valve electronic actuators and hydraulic seals, if made of organic materials, is of uttermost importance.

As far as the PHTS and the UPC are concerned, attention has been focused on 2018 design [6-8]. Photonic and neutronic calculations, to evaluate the spatial distribution of the absorbed dose, have been

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performed following a computational approach based on the Monte Carlo method and adopting the Monte Carlo N-Particle (MCNP5-1.60) code [9] along with the JEFF-3.2 transport cross section libraries [10].

## 2. Model

In the current pre-conceptual phase, DEMO WCLL BB design is arranged in a Single Module Segment lay-out adopting two parallel and distinct cooling circuits for FW and BZ [8]. So, its PHTS foresees four heat exchangers, two for the Outboard Blanket (OB) and two for the Inboard Blanket (IB) and it is located in a reactor building with a peculiar lay-out [11] (fig. 1).

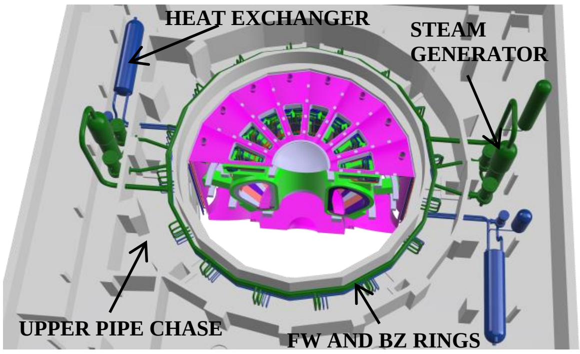

Fig. 1. View of DEMO PHTS in the UPC.

Attention has been focussed on the PHTS piping arranged in the UPC where important devices as isolation valves could be located. In particular, a slice of 22.5° (corresponding to one blanket sector) has been considered as it is shown in figure 2 where it is possible to notice the borated heavy concrete walls of the UPC, the pipes (AISI 316 LN) in which the radioactive water flows and the considered model of valve, that is a simplified version of a gate valve (DN 150, rating 1500).

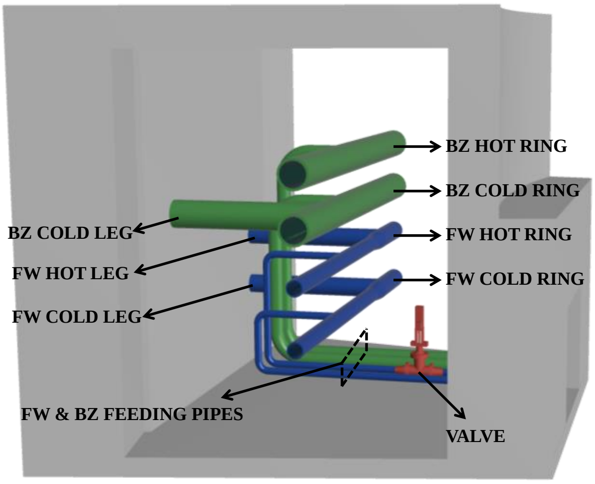

Fig. 2. Isometric view of the UPC slice.

Then, a completely heterogeneous 3-D MCNP model of such a slice has been set up adopting McCad code [12] for converting the CAD geometry representation into the MCNP constructive solid geometry representation. Reflecting surfaces have been used in the toroidal direction to take into account the geometric continuity of the calculation domain in that direction (Figs. 3,4).

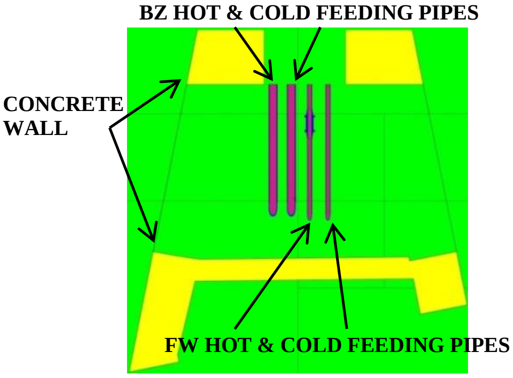

Fig. 3. Toroidal-radial section of the MCNP model of the UPC.

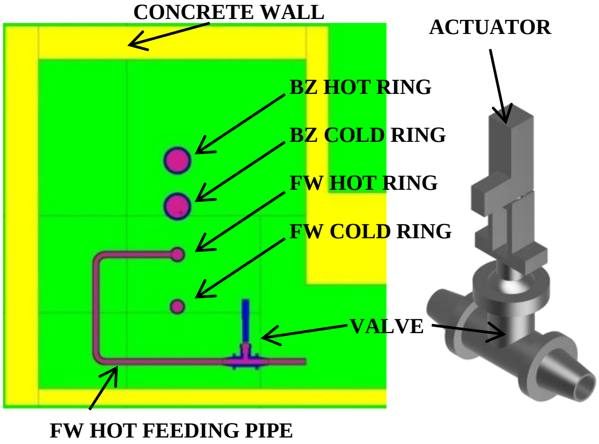

Fig. 4 Poloidal-radial section of the MCNP model of the UPC.

As far as the photon and neutron sources are concerned, they were modelled as diffuse sources, since water of each tube, in the considered portion of UPC, was conceived as a uniform volume source. Therefore, the emission probability of each source has been calculated from its relative activity (Tabs. 1,2) with reference to the total activity of the water present in the domain [4].

Table 1. Nitrogen activity in the FW circuit [GBq].

| NODE | $^{16}$N | $^{17}$N |
|---|---|---|
| Hot Feeding Pipe | 4.893E+02 | 5.132E-02 |
| Hot Ring | 2.089E+03 | 1.903E-01 |
| Hot Leg | 9.368E+02 | 8.316E-02 |
| Cold Leg | 1.683E+02 | 4.425E-03 |
| Cold Ring | 3.488E+02 | 8.937E-03 |
| Cold Feeding Pipe | 5.826E+01 | 1.466E-03 |
| Valve | 6.973E+01 | 7.313E-03 |

Table 2. Nitrogen activity in the BZ circuit [GBq].

| NODE | $^{16}$N | $^{17}$N |
|---|---|---|
| Hot Feeding Pipe | 2.718E+02 | 3.093E-02 |
| Hot Ring | 6.941E+02 | 6.781E-02 |
| Hot Leg | 1.484E+02 | 1.163E-02 |
| Cold Leg | 9.741E+01 | 5.664E-03 |
| Cold Ring | 3.261E+02 | 1.845E-02 |
| Cold Feeding Pipe | 8.526E+01 | 4.717E-03 |

Regarding the energy distributions of both $^{16}$N photons and $^{17}$N neutrons they have been biased taking into account their discrete spectra with the related branching from each energy level [13]. Furthermore, a compromise has been reached between the need to obtain a detailed spatial distribution of the dose and the extent of the computational time by implementing a super-imposed mesh (500 ×500 × 500) with a uniform voxel size of 2.52 × 5.56 × 1.86 $cm^3$.

## 3. Results

Detailed 3D photonic and neutronic analyses have been carried out for the assessment of the dose nearby FW and BZ cooling circuit key-points, due to γ radiation from $^{16}N$ and neutron emission from $^{17}N$. A period of 7 FPYs has been considered as it is assumed to be the expected life of the breeding blanket of DEMO taking into account an availability factor of ~33% [14].

A steady state scenario has been taken into account considering the plasma flat-top phase of the reactor.

Analyses have been carried out by simulating $10^{11}$ histories for photon transport and $6 \cdot 10^{10}$ for neutron transport, so that the results obtained are affected by relative errors lower than 1% in the most of the calculation domain.

### *3.1 γ dose assessment*

Figure 5 and 6 show the spatial distribution of the γ absorbed dose in the slice of the UPC taken into account. The full-scale of 2 MGy has been selected, in the most of the images, as it represents the reference figure for the qualified valves in NPP in order to verify their suitability for DEMO. It can be observed that a large part of the volume is characterized by a dose above the threshold value identified while, clearly, maximum values are localized in the water, that is, the source volumes.

It is also possible to notice shaded areas to the radiation due to the mutual shielding effect of the pipes. The outcomes related to the valve, of course, imply that some design modifications of the BB and/or the PHTS must be foreseen.

Figure 6 suggests some solutions as the location of the most rad-sensible equipment away from the highest dose (e.g. the valve actuators), as well some R&D to replace such components or materials with other more rad-resistant capability in order to have less constraint for the location of valves in such complex and crowded layout.

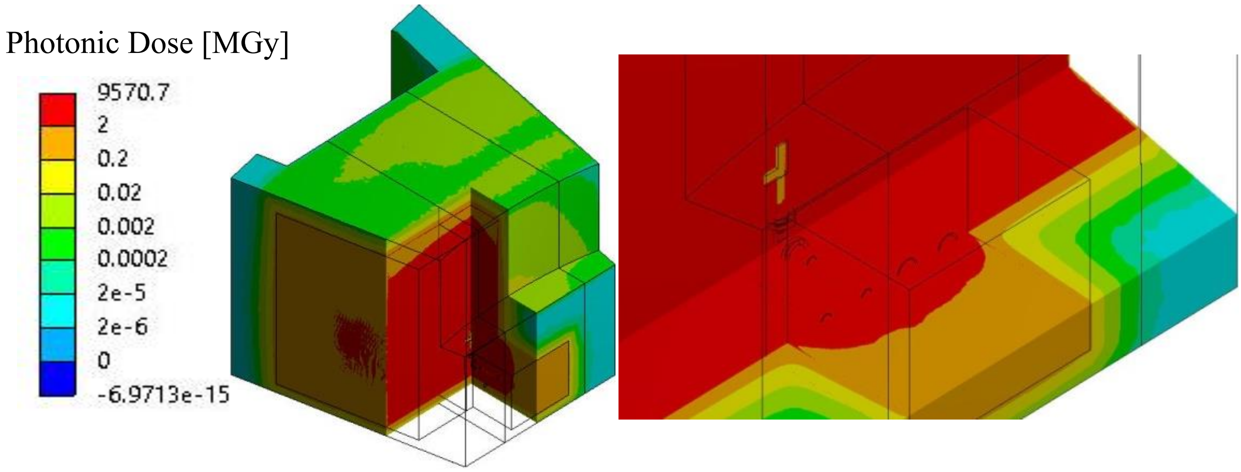

Fig. 5. Absorbed γ dose spatial distribution in the UPC slice (left) and an enlarged detail (right).

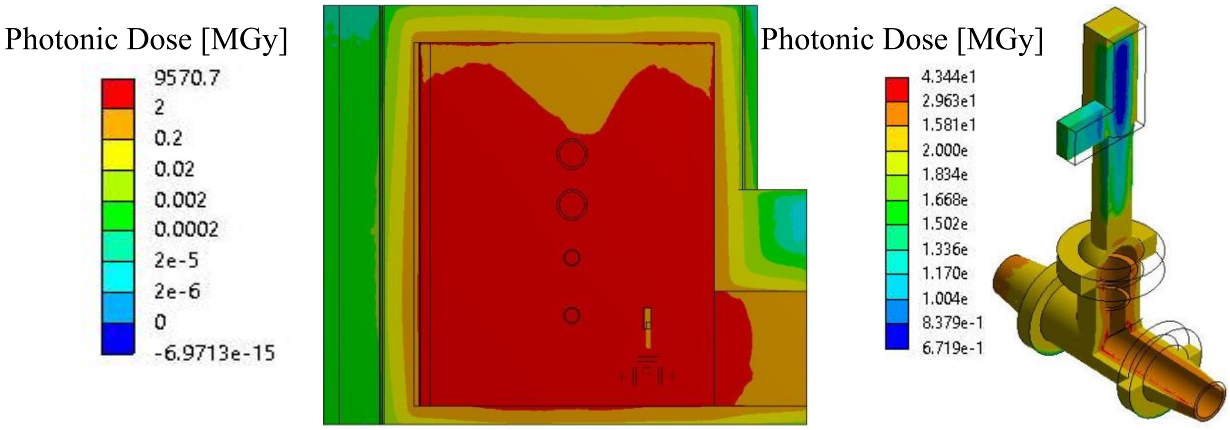

Fig. 6. Absorbed γ dose spatial distribution in a UPC slice detail (left) and in the valve (right).

### *3.2 neutron dose assessment*

The spatial distribution of neutron absorbed dose in the UPC slice is shown in figures 7 and 8. The dose due to neutron radiation is several order of magnitude lower than photon dose, nevertheless, $^{17}N$ activity during the DEMO pulse (tabs. 1,2) deserves, for completion, further neutron transport studies to evaluate the inventory of activation products and to evaluate their effects on the radiation field in the UPC.

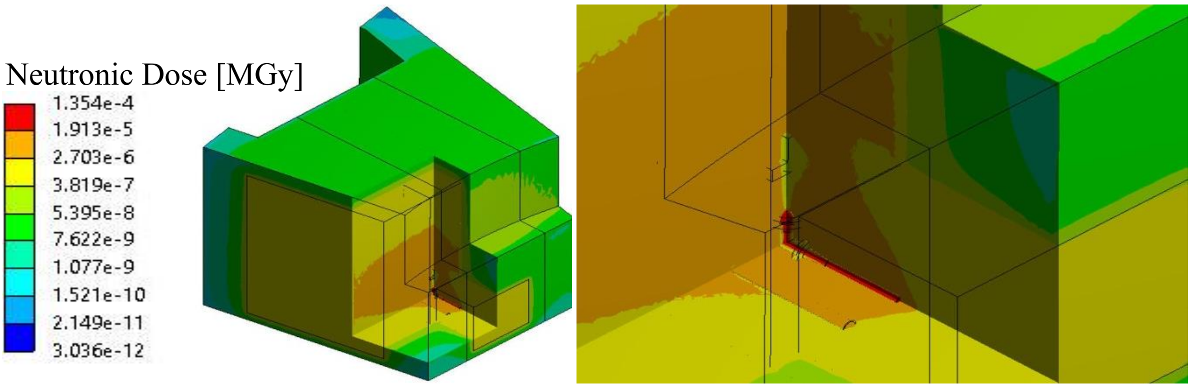

Fig. 7. Absorbed neutron dose spatial distribution in the UPC slice (left) and an enlarged detail (right).

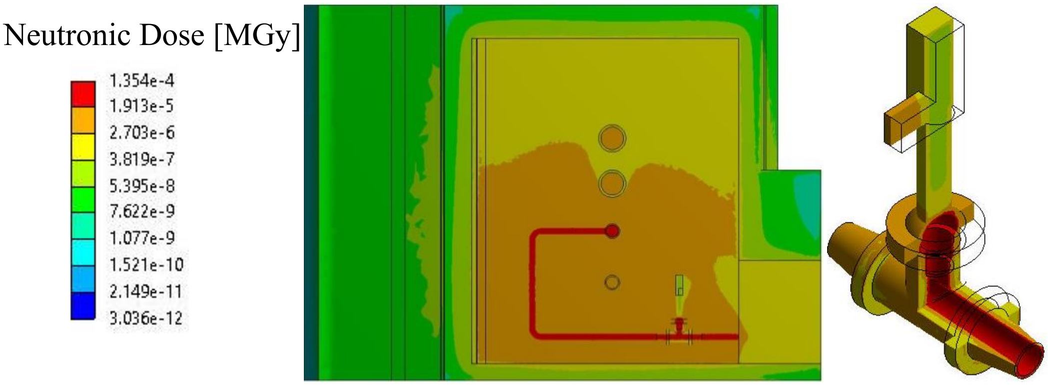

Fig. 8. Absorbed neutron dose spatial distribution in a UPC slice detail (left) and in the valve (right).

## 4. Conclusion

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. The results obtained show, as expected, that the main contribution to the absorbed dose by matter in the UPC comes from the photons emitted by the $^{16}N$ decay and that, on the other hand, the estimated $^{17}N$ activity leads to consider specific analysis for the evaluation the extent of neutron activation in the pipes.

Furthermore, these outcome lead to a further development of the present research activity aimed at developing PHTS design changes in order to lower the dose absorbed by the valve. In particular, the peculiarities of the spatial distribution of dose found suggest some simple modifications such as the use of bulkheads to shield the valve and/or change the lay-out of the pipes and/or develop more rad-resistant material for specific cases.

## Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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