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Shutdown dose rate assessment with the Advanced D1S method for the European DCLL DEMO

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ABSTRACT

The present paper is devoted to the shutdown dose rate assessment, one of the most important safety issues in fusion power plant design and operation. The characterization of the radiation environment after the shutdown is fundamental to plan safe operation and maintenance in a fusion machine in order to guarantee the dose limits are not exceeded. In this paper the shutdown dose due to the radionuclides generated by neutron activation of reactor components have been assessed for the design of the European DCLL v3.0 developed during 2016 integrated into the generic DEMO baseline 2015 fusion reactor. The shutdown dose rate calculations from 1 day to 1 year after shutdown have been performed through the Advanced D1S method coupling the particle transport MCNP5 and ACAB inventory codes. 3D maps of shutdown dose rates, decay fluxes for the whole reactor and decay gamma heating for Eurofer structures have been provided as well as specific values at relevant positions. Results are presented and discussed also in terms of the different nuclides contributions from the various activated components. Two different divertor compositions have been also used demonstrating the importance of this component not only locally but in the global radiation field inside the plasma chamber.

1. Introduction

The assessment of the radiation environment in a fusion machine like the future demonstrative reactor DEMO is essential to demonstrate a safe and economically viable operation of such machines.

The radiation field and nuclear loads during operations are typically calculated by the use of standard particle transport codes. Besides the loads during the reactor operation, neutrons generated from the deuterium–tritium (DT) reaction inside the plasma cause significant activation of the surrounding structures which radioactive products continue to decay also after the shutdown of the machine. Hence, the gamma field generated by the decay of the radioactive nuclides needs to be characterized after the shutdown in areas where personnel access could be required for operations and maintenance purposes.

Over the past decade, two different methodological approaches have been developed in the frame of the fusion technology for the three-dimensional calculation of the shutdown dose rate: the Rigorous two-step (R2S) [1] and the Direct one-step method (D1S) [2,3]. Both tools, although with different approaches, are based on the combined use of radiation transport and inventory codes.

Advanced D1S [4,5] is a D1S tool recently developed by ENEA based on MCNP5 Monte Carlo code [6] and FISPACT [7] inventory code with novel unique features. In this work the calculations have been performed by implementing an Advanced D1S version based on the use of use of ACAB inventory code [8] instead of FISPACT.

The study has been performed for a Dual-Coolant Lithium Lead (DCLL) Breeding Blanket (BB) model [9], one of the 4 BB options conceived for the future European DEMO reactor. The procedure (model, material compositions, irradiation scenario, correction factors calculation, codes and recommendations) applied for the execution of the activity is described in Section 2. The results of the analyses after the shutdown are detailed in Section 3.

2. Methodology, assumptions and input data

2.1. Advanced-D1S method

Original Direct 1-Step method (D1S) was developed by ENEA and ITER team more than fifteen years ago for fast 3D calculations of the shutdown dose rates in fusion devices [2,3]. It is based on the use of a modified version of the MCNP5 Monte Carlo code with specially prepared nuclear cross-section data. In this approach the decay gammas of the radioactive nuclides are emitted as prompt and thus, the neutron and decay gamma, treated as prompt, are transported in a single MCNP run.

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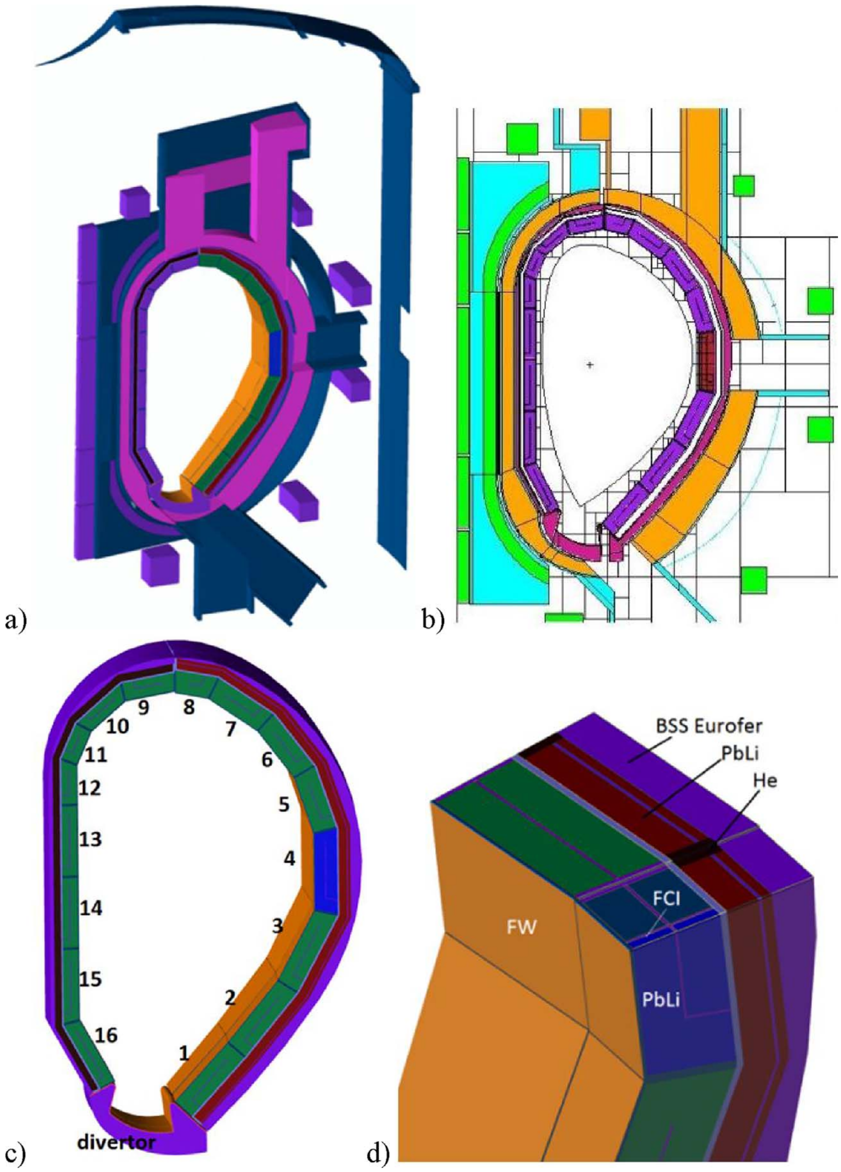

Fig. 1. DCLL DEMO2015: a) whole reactor; b) MCNP geometry plot; c) BB segment, BSS and divertor; d) detail of OB BB module (partially heterogenized) and its fully-heterogenized BSS, version 3.0.

Time correction factors, calculated with a proper activation code, are applied to the scored quantities to take into account the build-up and the decay of the radionuclides considered. The “Advanced-D1S” [4,5] is an improved version of D1S in which new computation capabilities have been introduced, such as the dose rate spatial mesh maps and cooling time dependence. Time correction factors take into account the production and decay of each radionuclide. For mesh tally maps they are internally applied to each generated photon according to its parent and multiplied by the corresponding flux-to-dose conversion coefficient to provide directly, as an output result, the dose rate in Sv/h [5].

2.2. Application to the DCLL DEMO design analyses

The DEMO baseline 2015 design [10] consists of 18 sectors each one of 20∘ and equipped with six main components: blanket modules, divertor, back supporting structure (BSS), vacuum vessel (VV), ports (Upper, Lower and Equatorial) for maintenance procedures and toroidal field (TF) coil. In the present application, an MCNP 10∘ half sector [11] of the 360° torus tokamak has been used with reflective boundary conditions on the lateral sides to take into account full 3D transport.

Blanket modules and back supporting structure are modelled in detail using MCAM CAD-to-MCNP software [12] with separated regions for its different components according to the specific design of the DCLL concept.

The development of a DCLL BB among the EUROfusion Programme to be integrated inside the common DEMO generic reactor is currently lead by CIEMAT [13]. The DCLL concept is basically characterized by the use of self-cooled breeding zones with the liquid metal PbLi serving as tritium breeder, neutron multiplier and coolant and the ferritic–martensitic steel Eurofer-97 as structural material. In Fig. 1 the neutronic model of the DEMO reactor with integrated DCLL blankets (a); its plotting in MCNP5 (b); the specific BSS and BB modules' segmentation inside a sector (c); and the main structures inside the equatorial outboard (OB) blanket module (d) are shown. The model is a 3D *quasi*-heterogenized design in which most of the details are included and with the equatorial OB module fully heterogenized (stiffening plates, flow channel inserts (FCI), breeder channels, walls are all separately described).

The chemical compositions for all the materials include relevant impurities because often they give rise to significant additional activation compared to the base material. The compositions considered for Eurofer, W, PbLi, are given in [14,15] and [16] respectively and