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# Neutronics analysis of the ITER Collective Thomson Scattering system

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ABSTRACT

The Collective Thomson Scattering (CTS) will be the ITER diagnostic responsible for measuring the alpha-particle velocity distribution. Using mirrors, a powerful microwave beam is directed into the plasma via an opening in the plasma-facing wall. The microwaves will scatter off fluctuations in the plasma, and the scattered signal is recorded after transmission through a series of mirrors and waveguides. Several components of the CTS system will be directly exposed to neutron radiation from the plasma which can change the properties of the components and reduce their lifetime. In this paper, a neutronics analysis is presented for the CTS system. A study on the influence of different materials on the nuclear heat loads in the launcher mirror is also presented, along with the design of a simple cooling system. All the studies were conducted using the Monte Carlo program MCNP6. The outputs, in particular the nuclear heat loads, will be used to perform the thermal analysis of the system.

## 1. Introduction

The Collective Thomson Scattering diagnostic (CTS) [1] will be implemented in ITER. It is based on characterizing mm-waves scattered by the interaction between a 1 MW injected source beam and ion-driven fluctuations in the plasma. The primary role of the diagnostic is to deliver spatially resolved information on the alpha-particle velocity distribution, with supplementary roles regarding measurements of the ion temperature and plasma rotation [2–4].

The front-end components of the ITER CTS diagnostic system are installed in the Drawer #3 of the Equatorial Port Plug #12 in the vacuum vessel partly exposed to the direct radiation plasma through apertures in the Diagnostic First Wall. They are thus subjected to nuclear loads from the plasma neutrons and from the gammas generated in nuclear interactions with the surrounding materials. The ionizing radiation will contribute to the thermal loads in the system and may cause irradiation-induced changes in the material properties, namely thermal and mechanical, which can compromise the integrity of the components during the lifetime of ITER.

The system, shown in Fig. 1, consists of a high-power and a lower-power transmission line with a solid wall in between. The high-power transmission line makes use of a powerful 1 MW 60 GHz gyrotron source, which through a system of waveguides and mirrors delivers the probing radiation from the closure plate of the equatorial port plug into the plasma via a cut-out in the diagnostic first wall [5].

In the low-power transmission line, the scattering signal is collected through a receiver cut-out in the diagnostic first wall and via mirrors and waveguides transmitted through the port cell and to the diagnostic building. Due to the large openings in the plasma facing first wall, the in-vessel port plug based CTS components will be subjected to significant loads by neutron and gamma radiation.

This paper presents the outcome of the nuclear analysis performed for the main components of the CTS system. The nuclear thermal loads obtained in this work will contribute to the loads specification of the CTS system and serve as input to the thermal analysis and stress analysis of the CTS in-vessel components. Such a thermal and stress analysis was presented for the originally proposed but later abandoned CTS receiver mirror on the high-field side [6].

## 2. Neutronics model

In this paper we distinguish three types of neutronics models:

1 **Reference model**: standard ITER neutronics model, featuring a 20-degree portion of the most up-to-date global design information of the ITER machine;
2 **System-specific model**: detailed input of the system which is the subject of the nuclear analysis (the CTS in-vessel components);
3 **Integrated model**: System-specific model integrated in the reference model.

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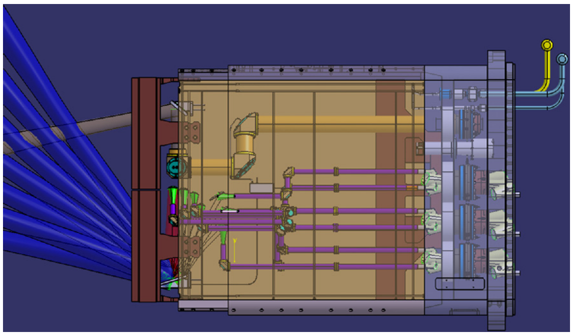

**Fig. 1.** CAD drawing of the ITER CTS diagnostics system.

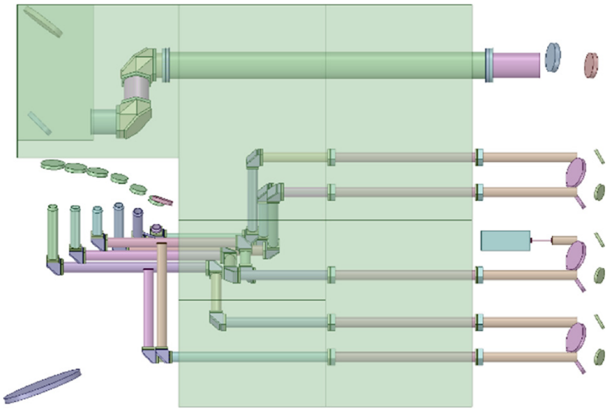

**Fig. 2.** Simplified neutronics CAD model of the CTS system. The green, transparent boxes represent cells to be filled with a $B_4C$ shielding mixture (for interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

The input for the neutronics model is a CAD Model in which some simplifications were made allowing simpler structured meshes. During the creation of the system-specific model mainly spline surfaces, doubled surfaces and round edges were removed, which, in most cases, were replaced by sharp edges. The probe waveguide, in particular – which is seen at the top of Fig. 2 – was greatly simplified, due to the complexity of the original model, which featured several layers with a series of internal rings separating them. The inner radius of the waveguide was kept unchanged and the outer radius was adjusted to ensure volume conservation. In the remaining components – mitre bends, waveguide connectors, mirrors and waveguides – the simplifications consisted of removal of round edges. In the simplification process, the deviations between the volumes in the original model and the volumes in the simplified model were kept below 0.1%, to make sure that the simplifications do not influence the results significantly.

In order to calculate the heat loads for the different mirrors and other components of the system, the neutronics CAD model was divided into separate cells, which are shown in Fig. 2 with different colours.

The neutronics simulations were performed using the Monte Carlo simulation program MCNP6, 1.0 [7]. The CAD model of the CTS system was simplified in order to avoid overlapping components in the most recent neutronics reference model of ITER – the C-model v2.1. The simplified CAD models were then converted to the STEP format, edited in ANSYS SpaceClaim [8] and imported into the CAD-based modelling program MCAM [9,10] for a final conversion to the MCNP input format. This workflow is outlined in Fig. 3.

Fig. 4 shows a vertical cross-section of the ITER reference MCNP model used in this work. The system-specific MCNP model was created following the procedures illustrated in Fig. 3 and later integrated in this reference model. The system-specific model is shown in Fig. 5, which shows a sectional cut at y = 55 cm of the integrated MCNP model at the location of the CTS system.

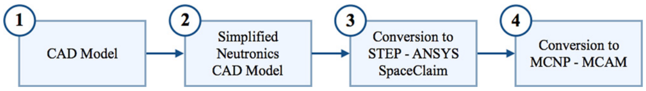

**Fig. 3.** Conversion steps from the CAD models in ENOVIA to the MCNP system-specific input.

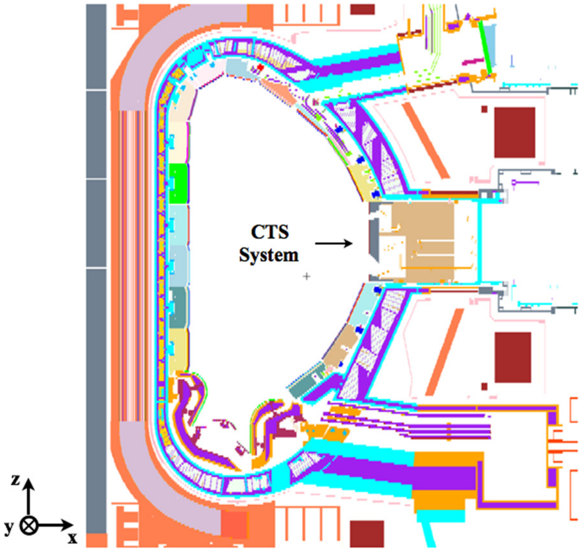

**Fig. 4.** Integrated MCNP model vertical cross-section, plane y = 55 cm.

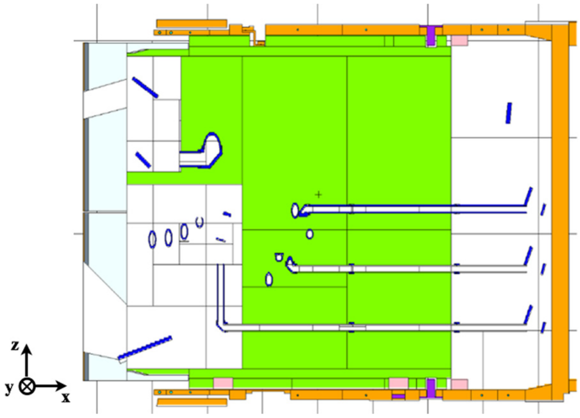

**Fig. 5.** System-specific MCNP model of the CTS system, plane y = 55 cm.

The integrated MCNP model was then used to perform the simulations. The parameters used for the simulations can be summarized as follows:

- The standard ITER D–T neutron source provided in the ITER reference model was used, normalized to 500 MW of fusion power;
- The source is characterized by a Gaussian fusion energy spectrum with a mean value of 14.0791 MeV and a FWHM of 0.889 MeV;
- The simulations include both neutron and gamma transport and the nuclear heat loads are reported separately. No other load combinations were considered;
- The ITER-grade steel 316 L(N)-IG was the material used in the mirrors, waveguides and mitre bends of the CTS system, with a density of 7.93 g/cm$^3$. The material used in the shielding blocks, shown in Figs. 2 and 5, consists of a mix of Stainless Steel (31%), boron carbide ($B_4C$) with a density of 2.52 g/cm$^3$ (41%), void (27%), water (1%) and other metals ($< 1\%$) with an effective density of 3.26 g/cm$^3$;