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Characterization of JET Neutron Field for Material Activation and Radiation Damage Studies

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ABSTRACT

A new Deuterium-Tritium campaign (DTE2) is planned at JET in 2017 with a proposed neutron budget, corresponding to the neutron fluence on the first wall of JET of up to about 10^{20} n/m². This will offer the opportunity to irradiate samples of functional materials and of in-vessel structural materials used in ITER to assess the degradation of the physical properties and the neutron induced activities, respectively. The present work is aimed at the characterization of the neutron field inside the JET device during DT plasma operations in preparation of the planned experiments. Several possible irradiation positions are studied and characterized with their appropriateness for irradiation and activation studies during the DT campaign. The neutron spectra are studied and the total neutron fluence at the specified positions is calculated.

1. INTRODUCTION

A new Deuterium-Tritium campaign (DTE2) is planned at JET in 2017, with a proposed 14MeV neutron budget nearly an order of magnitude higher than any previous DT campaigns [1, 2]. With this proposed budget, the achievable neutron fluence on the first wall of JET will be up to about 10^{20} n/m², comparable to that occurring in ITER at the end of life in the rear part of the port plug, where several diagnostic components are located. At the expected plasma performance, the neutron flux on the first wall achieves levels comparable to those expected in ITER between the blanket and the vacuum vessel ($\sim 10^{17}$ n/s · m²). This level of neutron flux/fluence will offer the opportunity to irradiate samples of functional materials used in ITER diagnostics, and of materials used in the manufacturing of the main in-vessel ITER components, to assess the degradation of the physical properties and the neutron induced activities, respectively.

The purpose of the present work was to characterize the neutron field inside the JET device during DT plasma operations. An analysis of the neutron flux and energy spectrum is performed at selected irradiation locations, such as the neutron activation irradiation ends, new long term irradiation stations located inside the vessel and inside a circular horizontal port, where samples would be exposed to the maximum neutron flux or fluence. Other locations are considered around the vacuum vessel and inside a lower vertical port where active tests on fiber optics and on dielectric materials would be performed. The neutron flux and spectrum at different irradiation ends are calculated and compared.

2. IRRADIATION POSITIONS STUDIED

The positions studied are presented in Figure 1 and can be summarized as:

- Internal irradiation holder, mounted next to the poloidal limiter (octant 4) – Figure 1a)
- External irradiation holder, mounted inside the small, circular, horizontal ports (oct. 7) – right in Figure 1b)
- Outside-inner irradiation end and underlying vertical port – upper left in Figure 1b)
- Inside-middle irradiation end – upper right in Figure 1b) – both irradiation ends are used also as a diagnostics for neutrons
- Lower vertical port, Figure 1 c)

Several parametric studies have been performed in order to examine the local changes in flux and energy spectrum in the proposed locations, in particular for the internal/external irradiation holders and outside-inner irradiation end locations. Additionally it was desirable to know the relative difference in the fluence among different irradiation locations in order to exploit the maximum total neutron fluence available during the DT campaign.

3. CALCULATIONS

3.1. MCNP MODEL

Monte Carlo transport calculations have been performed to provide the necessary information on the neutron fluence and energy spectra in order for the correct planning of the exposure time and location of the samples.

There exist a few existing MCNP models of the JET tokamak, which differ with respect to their purpose of use. For the present calculations a model, optimized for in-vessel calculations was used [3]; it was upgraded from the original model, described in [4]. The components, needed specifically for the present calculations – i.e. the internal/external irradiation holder and outside-inner irradiation end – were modeled mostly with help of the MCAM conversion tool [5] and inserted and into the model. A schematic view of the MCNP model is shown in Figure 2.

A typical DD JET plasma neutron source [3] was used with a major radius of 290cm and minor radius of 80cm. The neutron transport cross sections have been taken from FENDL-2.1 library and from ENDFB/VII in the cases, for which the FENDL data are not available.

4. RESULTS

The comparison of calculated fluxes in the irradiation ends is presented in Figure 3 and for the external irradiation holder cylinder in Figure 4. The location of the studied regions is also presented in the figures. In case of the outside-inner irradiation end, the parametric study is performed also for the underlying positions inside the vessel port (cells 1 – 4 in Figure 3a). It can be observed from the results in Figure 3, that the fast neutron flux is larger, as expected, in the inside-middle irradiation end, which is directly exposed to the plasma, and the smallest in the outside-inner irradiation end, with the possible other irradiation locations – below this irradiation end – exhibiting intermediate fast neutron fluxes. The variations in the thermal flux range are small.

In the case of the external irradiation holder the neutron flux is calculated at several distances from the plasma center with a 10cm interval (Figure 4a).

The results, given in Figure 4b, show that neutron fluxes do not vary significantly with distance from the plasma inside the holder.

The in-vessel holder is mounted at midplane close to the wide poloidal limiter at Octant 4 (Figure 5). A second in-vessel holder is also available at Oct.8, identical to the one considered in the present analysis. The spectrum calculated in different positions (Figure 5a) inside the holder is shown in Figure 5b. The flux is higher than that found in the external irradiation holder station.

Finally, two different positions were considered in the lower main vertical port to study the shielding effect due to the presence of the divertor: one just below the divertor and the other one further to the low field side of the divertor at a position, in which it is not shielded from the plasma by the divertor. The calculated neutron spectra (Figure 6) show that the flux of uncollided neutrons is reduced by a factor 2.5 below the divertor.

The total DT neutron budget during the upcoming DT campaign is proposed to be $1.7 \cdot 10^{21}$ neutrons. For all previously described locations the corresponding total neutron fluences have been calculated and are presented in Table 1 in three energy groups: $> 10\text{MeV}$, $100\text{keV} - 10\text{MeV}$ and total.

It can be observed from Table 1, that in the fast neutron region the most favorable position is the inner irradiation station, which exhibits a fast neutron fluence for a factor of cca. 1.6 higher than any other position. The total fast neutron fluence at this position is expected to be $3.2 \cdot 10^{19} \text{n/m}^2$ and a total neutron fluence of $7 \cdot 10^{19} \text{n/m}^2$ can be achieved. It is worth stressing that a net surface of about 125cm^2 is available to locate samples (250cm^2 in the two holders that will be available), all exposed at the same neutron fluence and energy spectrum. Although the distance from the plasma in the case of the internal and external irradiation holders is very similar, the local neutron fluence in the external holder is 40% lower. It was found that the reason for the lower fast flux in the external irradiation holder is almost entirely due to its thicker casing, which is assumed to amount to 2mm of beryllium shield and 6mm of stainless steel due to double holder containing. On the contrary the irradiation locations in the internal irradiation holder are assumed to be covered only by a 0.5mm thick layer of beryllium. With an equal thickness of the casing both positions would exhibit fluxes of a similar value. It is worth noting that the available net surface at the external irradiation holder is 150cm^2 for sample exposure.

The fast neutron fluence (neutrons with energies higher than 10MeV) at the positions of the internal irradiation holder will amount to $1.8 \cdot 10^{19} \text{n/m}^2$; it is the highest value for any of the locations studied. The results also show that total neutron fluences up to $7 \cdot 10^{19} \text{n/m}^2$ can be achieved. In general, apart from the position below the divertor, the total and the fast neutron fluences are almost constant in the studied positions, while the neutron fluence at $E > 10\text{MeV}$ varies within a factor of three. A careful choice of irradiation position and holder configuration allow to vary the fraction of fast neutron over the total neutron fluence and therefore providing the possibility of investigating the effect of spectral details on radiation damage effects.

5. CONCLUSIONS

The planned DT campaign at JET will offer the opportunity to irradiate samples of functional materials used in ITER to assess the degradation of the physical properties and the neutron induced activities, respectively. The present work was aimed at the characterization of the neutron field inside the JET device during DT plasma operations in preparation of the planned experiments. Monte Carlo transport calculations were used in order to study several possible irradiation positions and parametric studies were performed for the estimation of the flux gradient at these locations.

It was found that in the fast neutron region the most favorable position is the inner long term irradiation station, which exhibits a fast neutron fluence, which is for a factor of 1.6 higher than in the case of the external irradiation holder or any other position. The reason for this difference between the internal and external irradiation holder was found to lie in the proposed design of the irradiation stations at both positions – the former is covered only by a 0.5mm layer of Be while the latter is covered by 2mm of Be and 6mm of stainless steel. With equal thicknesses of the casing both positions would exhibit similar fluxes.

The expected total DT neutron budget during the DT campaign is $1.7 \cdot 10^{21}$. In this case the total fast neutron fluence at the most favorable position (the internal irradiation holder) is expected to be $1.8 \cdot 10^{19}$ n/m² and a total neutron fluence in excess of $6 \cdot 10^{19}$ n/m² can be achieved. With a careful choice of irradiation position and holder configuration the possibility of investigating the effect of spectral details on radiation damage effects is given.

ACKNOWLEDGMENTS

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energy range	irradiation position						
	inside-middle irr. end	outside-inner irr. end	Below out-inn irr. end, sphere 2	external irradiation holder sphere 1	external irradiation holder sphere 4	internal irradiation holder	lower port position 2
10 MeV - 20 MeV	1.0E+19	5.6E+18	6.7E+18	1.1E+19	1.1E+19	1.8E+19	2.0E+18
0.1 MeV - 10 MeV	3.1E+19	2.7E+19	3.0E+19	3.1E+19	3.1E+19	3.2E+19	1.8E+19
total	6.3E+19	4.8E+19	5.4E+19	6.6E+19	6.7E+19	7.0E+19	3.2E+19

Table 1: Comparison of fluences for candidate irradiation positions in three energy groups: > 10MeV, 0.1MeV – 10MeV, total. Normalized to the expected $1.7 \cdot 10^{21}$ total DT neutron budget. Values in n/m².

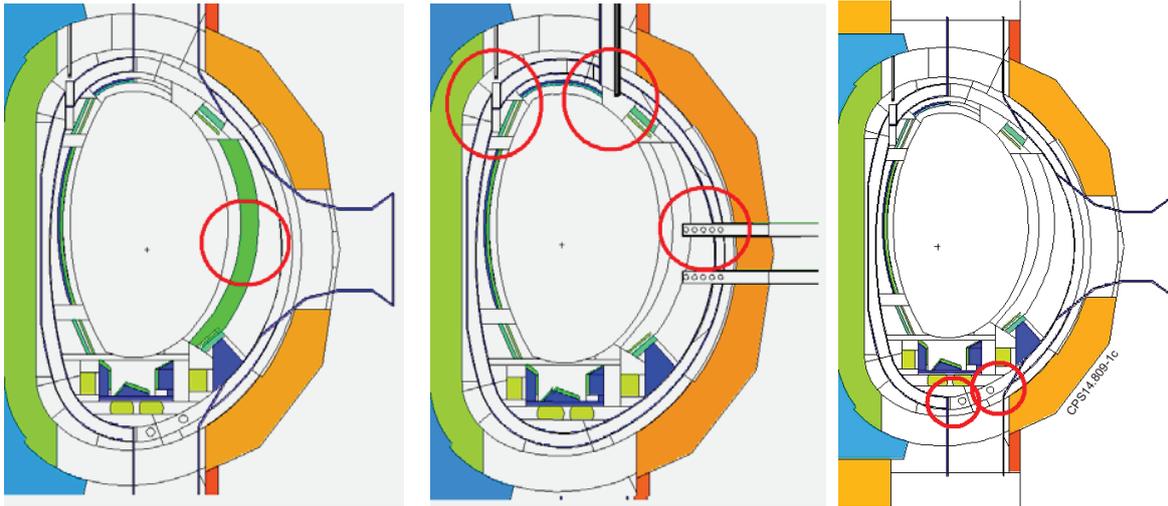


Figure 1: The candidate positions in which the neutron flux was calculated: a) internal irradiation holder b) external irradiation holder (right), outside-inner and inside-middle irradiation ends c) lower vertical port.



Figure 2: Geometrical model of JET in MCNP – the presentation of the level of detail.

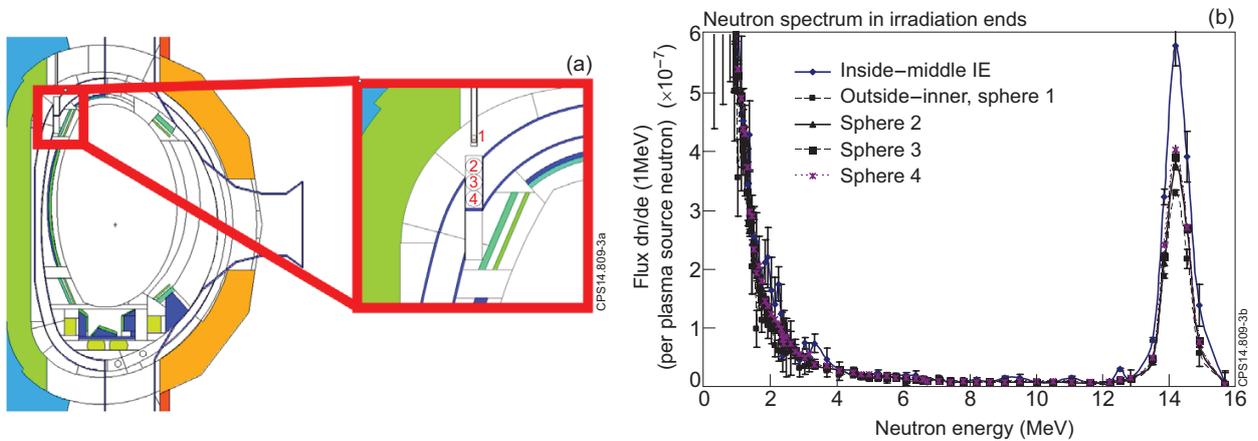


Figure 3 a): Outside-inner irradiation end and scoring regions in the underlying vertical port. b) Comparison of the neutron fluxes in the regions shown in Figure 3a and in the inside-middle irradiation end (Figure 1b), irradiation ends.

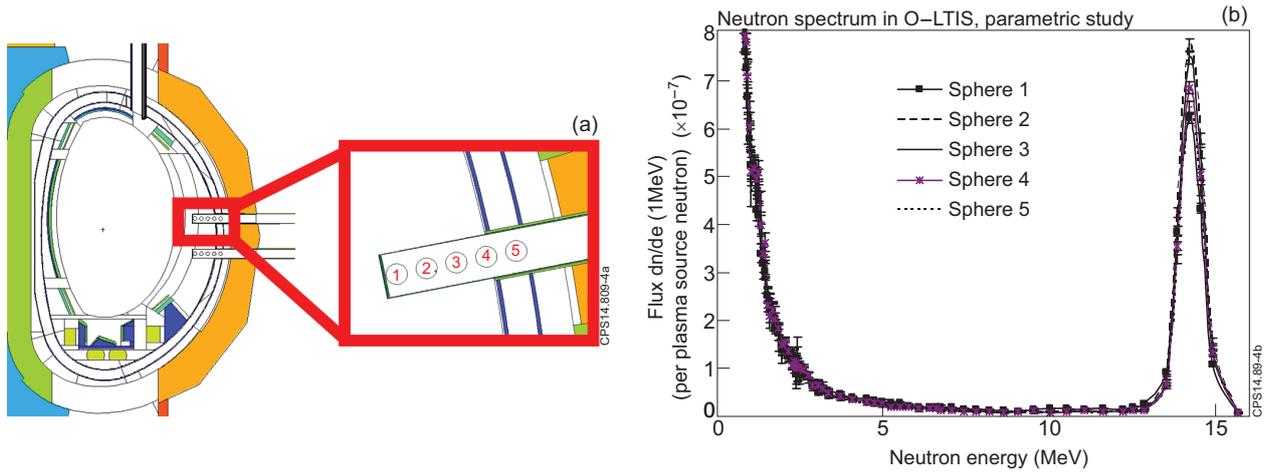


Figure 4 a): Location of the studied region in the external irradiation holder. b) Parametric study of neutron fluxes in the external irradiation holder cylinder; sample spheres at a distance of cm.

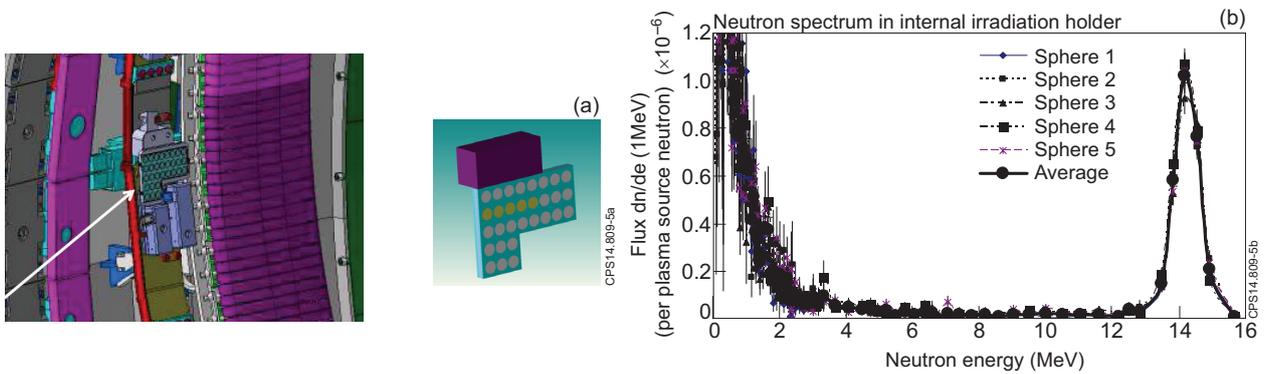


Figure 5 a): Internal irradiation holder: the CATIA drawing (left) and the MCNP model [5] (right). b) Spectrum in five positions in the internal irradiation holder and the average spectrum.

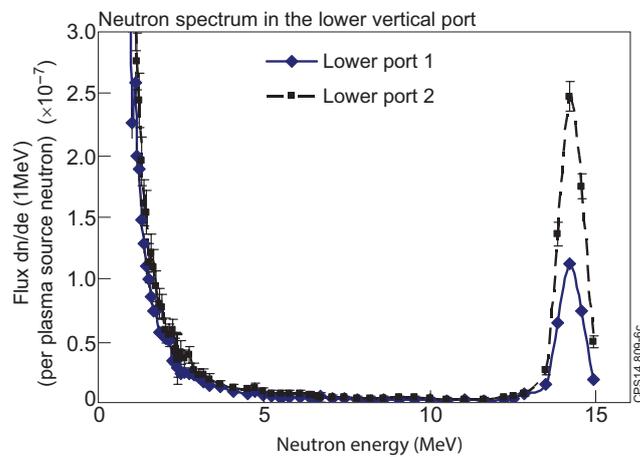


Figure 6: Neutron spectrum in two locations in the lower vertical port – positions marked in Figure 2 c): denoted with “lower port 1” is the right position in Figure 2c) and “lower port 2” the left position.