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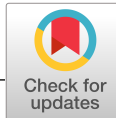
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Estimation of 14 MeV neutron rate from triton burn-up in future W7-X deuterium plasma campaigns

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Abstract

Fast ion confinement is of major importance for the ignition of a burning fusion plasma. In future deuterium plasma campaigns of the Wendelstein 7-X stellarator, W7-X, the amount of triton burn-up is one possible measure for fast ion confinement. A well-established technique to observe triton burn-up is the 14 MeV neutron rate. In this paper, it is estimated whether an existing scintillating fibre neutron detector is also suited to measure triton burn-up in W7-X with sufficient accuracy. An estimation is presented, which can be applied to any tokamak or stellarator design and is one-dimensional in the minor radius. The inputs are profiles of density, temperature, and differential volume element as well as the triton slowing-down time. The estimation calculates the thermal deuterium fusion rate and the associated deuterium-triton fusion rate; thus, the triton burn-up generated 14 MeV neutron rate. It neither takes triton diffusion nor explicit losses into account. This thermally generated fusion rate is compared to the neutral beam injection heating induced beam-plasma fusion rate.

KEYWORDS

deuterium plasmas, fast ion physics, neutron diagnostics, triton burn-up, W7-X

1 | INTRODUCTION

The optimized stellarator W7-X has achieved the highest triple product for stellarators. In the next operational campaigns, the reactor capability of a W7-X-like stellarator will be studied by trying to conduct steady-state plasma discharges of 30 min duration with a reactor-relevant triple product for the first time.^[1]

So far, hydrogen and helium plasma discharges were performed in W7-X. It is planned to start deuterium plasma operation to study differences of the plasma transport in stellarators, as it is expected to differ from current hydrogen discharges due to the isotope effect, which is already investigated in the Large Helical Device (LHD).^[2,3] Beneficially for the plasma heating, deuterium will increase the maximum achievable heating power in W7-X, as the neutral beam

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injection (NBI) heating will transfer more power per particle to deuterium compared to the currently used hydrogen, which only has half the mass of deuterium.^[4] Moreover, the fusion processes in deuterium plasmas will enable to study plasma and fast ion physics with neutron detectors.

In deuterium plasmas, there are two equally probable fusion channels, one yielding a 2.5 MeV neutron and a Helium-3 nucleus, and the other producing a 1 MeV triton and a proton. The tritons will fuse with the surrounding deuterium plasma again, resulting in a 14 MeV neutron and a 3.6 MeV α -particle. Studying the energetic neutrons from the deuteron-triton (DT) reaction, called triton burn-up, allows to infer the confinement and slowing-down properties of the tritons, which was done in, for example, the ASDEX Upgrade, JET, PDX, PLT, and TFTR tokamaks as well as recently in the LHD heliotron.^[5–10] Since the α -particles and tritons are both emitted isotropically and have similar gyroradii at their production energies, predictions of the α -particle confinement can be assessed, which is of major interest for future fusion reactors.^[5] These fast ions are meant to be the main heating source in burning DT fusion plasmas.

A plastic scintillating fibre detector, called *SciFi*, was developed and operated in the 1990s with the goal of detecting the energetic 14 MeV neutrons and determining triton burn-up as well as triton diffusion with temporal resolution in the order of 10 ms.^[11–14] As the fibres are separated by aluminium and the scintillation light is detected by a photomultiplier tube using pulse height discrimination, this detector design features an intrinsic directionality and a gamma ray background suppression in the 14 MeV neutron signal even at high counting rates.^[11] Recently, similar detectors were operated at LHD, yielding reasonable statistics for 14 MeV neutron rates above 10^{12} s^{-1} .^[10,15–19] In order to study the capability of *SciFi* at W7-X, a one-dimensional diffusionless estimation has been developed that does not take losses into account explicitly.

2 | 14MEV NEUTRON RATE ESTIMATION IN THERMAL DEUTERIUM PLASMAS

The estimation is based on a technical report,^[20] which assesses the upper limit of the neutron rate in W7-X for a radiation safety study. The procedure of the technical report is modified here to obtain a lower limit of the neutron rate, as the achievable accuracy of measurements with *SciFi* is meant to be investigated conservatively. Since NBI beam interactions with the plasma will bias the study of fusion and confinement physics in a purely thermal plasma, it is of special interest, whether the 14 MeV neutron rate generated in exclusively electron cyclotron resonance heating (ECRH) heated W7-X plasmas is sufficient to be measured with *SciFi*. Note that, in contrast to other large magnetic confinement fusion devices, ECRH is the main heating source in W7-X. Consequently, the estimation is carried out for an exclusively ECRH-heated deuterium plasma scenario in thermal equilibrium.

For the subsequent estimates, W7-X is approximated to be toroidally symmetric. Thus, the estimation is reduced to one dimension, namely s

$$s = \left(\frac{r}{a} \right)^2, \quad (1)$$

$$\begin{aligned} dV &= d(2\pi R \cdot \pi r^2) \\ &= 2\pi R \cdot \pi a^2 ds \end{aligned} \quad (2)$$

where a is the radius of the last closed flux surface, r is the minor radius, and R is the major radius of W7-X. s is used here, since the volume element of a torus, dV given in Equation (2), is constant in s , which simplifies the calculations. Moreover, the deuteron (DD) fusion rates are only calculated for thermal interactions, thus excluding beam–plasma (and beam–beam) interactions, which would be present in an NBI-heated plasma. For DT fusion, high energetic fusion-born tritons interact with the thermal deuterium plasma. Furthermore, the plasma parameters are assumed to be stationary and diffusion is not taken into account. For simplicity, triton losses are not considered explicitly. Instead, they are implicitly introduced via the triton slowing-down time, limiting the triton density as discussed later and given by Equation (5).

The overall DD and DT fusion rates in W7-X are calculated via the following formula

$$\begin{aligned} R_{AB \rightarrow CD} &= \int_0^1 \langle \sigma v \rangle_{AB \rightarrow CD} \cdot \frac{n_A n_B}{\delta_{AB} + 1} \cdot \frac{dV}{ds} ds \\ &\approx \frac{1}{q} \cdot \sum_{k=1}^q \langle \sigma v \rangle_{AB \rightarrow CD}^k \cdot \frac{n_A^k n_B^k}{\delta_{AB} + 1} \cdot \frac{dV^k}{ds}, \end{aligned} \quad (3)$$

where $\langle\sigma v\rangle_{AB\rightarrow CD}$ [m^3/s] equals the velocity distribution-averaged reactivity of particles of species A and B fusing and generating particles of species C and D . σ [m^2] is the cross-section of the fusion process and v [m/s] is the velocity of the interacting particles. $n_{A/B}$ [m^{-3}] are the densities of the respective species and δ_{AB} denotes the Kronecker Delta. The differential volume element along s , dV/ds , is obtained from the three-dimensional magnetohydrodynamic equilibrium code VMEC2000^[21] for the standard configuration of W7-X, where dV/ds is indeed constant in s . Therefore, the integral over s is approximated by a sum over $q = 98$ equidistant bins matching the VMEC2000 output.

First, the fusion rate of the DD channel yielding a triton and a proton has to be calculated to obtain the source distribution of the tritons. In this case, $\langle\sigma v\rangle_{DD\rightarrow Tp}^k$ equals the thermal reactivity of the plasma deuterons averaged over their velocity distribution, which is assumed to be a Maxwellian, whose temperature T^k [keV] is dependent on the radial position k in the plasma. An approximating parameterization of the reactivity given in eq. 12 of [Bosch and Hale, 1992] ref. [22] is inserted here and plotted in Figure 1.

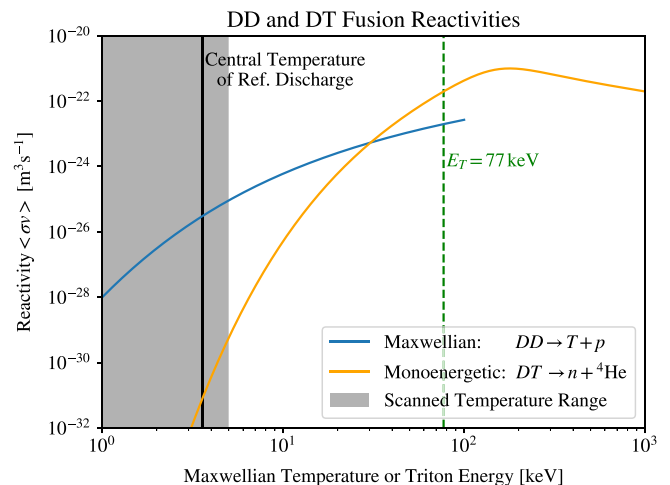
Both T and n_D profiles are taken from a high performance phase during the hydrogen discharge 20171207.006, $t = 2.13$ s, in the latest uncooled divertor campaign of W7-X^[23] assuming that the profiles will be the same in a future deuterium plasma discharge. This discharge was chosen as it features simultaneously a good confinement with a confinement time of above 200 ms at a high central β -value, a thermal equilibration of electron and ion temperatures at a high central temperature of $T^{\text{Ref.}} \equiv T_H \approx T_e \approx 3.6$ keV, and a high central electron density of $n_e \approx 8 \cdot 10^{19} \text{ m}^{-3}$ ^[24] Moreover, this discharge provided a new triple product record for stellarators and was heated exclusively with 5 MW of ECRH power.^[25] The density and temperature profiles are given in figs. 13 and 14 of ref. [25]. Since also ion and electron density are approximated to be the same in this paper $n_D^{\text{Ref.}} \equiv n_H \approx n_e$, though Z_{eff} equals about 1.5 in the core assuming the main impurity to be carbon,^[25] the DD fusion rate is overestimated by about 20%. For an order of magnitude estimation, which is attempted here, this is accurate enough. Still, Z_{eff} is only measured in the core and expected to be larger at the plasma edge, which is neglected here as the fusion rates are strongly dependent on density and temperature such that the contributions from the edge are negligible. Since the chosen reference discharge features more peaked profiles compared to standard W7-X discharges whose central profile plateaus typically exceed the core region, the fusion rates are underestimated, which is conservative.

To scan the operational regime of W7-X in the (n_D, T) space, the profiles are normalized and multiplied by a scaling. Thus, all bins of the profile are divided by the profile's central maximum value, that is, $n_D^{\text{Ref.}} = 8 \cdot 10^{19} \text{ m}^{-3}$ and $T^{\text{Ref.}} = 3.6$ keV, respectively, and multiplied by the desired scaling in the range of $(10^{19} - 10^{21}) \text{ m}^{-3}$ and $(1 - 5)$ keV, respectively. The profiles for the extreme cases and the reference discharge are plotted in Figure 2. Note that the thermal DD reactivity changes over three orders of magnitude within the scanned central temperature range as shown in Figure 1.

In order to obtain the DT fusion rate and thus the 14 MeV neutron rate, the monoenergetic DT reactivity $\langle\sigma v\rangle_{DT\rightarrow n\alpha}^k(E_T)$ is calculated approximating the plasma deuterons to be at rest compared to the fast tritons

$$\langle\sigma v\rangle_{DT\rightarrow n\alpha}^k(E_T) = \sigma \left(E_T \cdot \frac{m_D}{m_T + m_D} \right) \cdot \frac{\sqrt{2E_T m_T}}{m_T + m_D}, \quad (4)$$

FIGURE 1 Plot of deuteron (DD) and deuteron-triton (DT) reactivities as function of Maxwellian temperature and triton energy, respectively. A Maxwellian velocity distribution is assumed for the thermal DD reactivity, which is calculated via eq. 12 of [Bosch and Hale, 1992] ref. [22]. This parameterization is plotted below 100 keV as it is not valid for higher ion temperatures.^[22] The monoenergetic DT reactivity is calculated via Equation (4) using the parameterization in eq. 8 of [Bosch and Hale, 1992] ref. [22], assuming the plasma deuterons to be at rest and the tritons to be monoenergetic. The vertical lines mark the central temperature of the W7-X reference discharge ($T_e \approx T_i$) at 3.6 keV and at 77 keV the energy at which the monoenergetic DT reactivity equals the one at the initial triton energy of 1 MeV. The area shaded in grey highlights the considered temperature range for W7-X



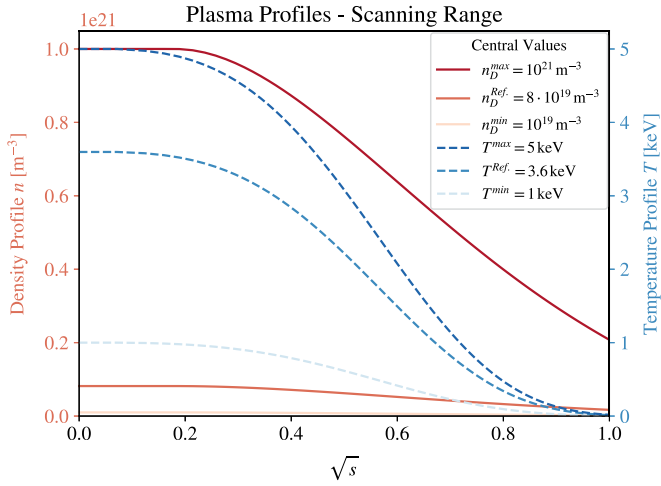


FIGURE 2 Reference density and temperature profiles of the W7-X discharge 20171207.006, $t = 2.13$ s, and scaled extreme cases of the W7-X profile scan. Note that the reference discharge is treated as a deuterium discharge though it is a hydrogen discharge

where E_T equals the triton energy, $m_{D/T}$ are the masses of deuterium and tritium, and the cross-section σ is calculated for the center of mass energy via the parameterization in eq. 8 of [Bosch and Hale, 1992] ref. [22]. The monoenergetic DT reactivity is plotted in Figure 1 and features a maximum at a triton energy of about 180 keV decreasing by almost one order of magnitude towards the initial triton energy of 1 MeV. At 77 keV, the reactivity reaches again the same value as at the initial triton energy of about 10^{-22} m³/s and decreases steeply for lower triton energies. In order to keep the estimation fast and not to introduce a time dependence, the triton energy is kept constant at the initial energy, $E_T = 1$ MeV, to calculate the reactivity via Equation (4). This assumption becomes conservative and underestimates the DT fusion rate if only tritons of equal or higher reactivity are considered. Therefore, tritons that slowed down below 77 keV are not considered anymore.

The loss of tritons below 77 keV is implemented implicitly via the triton slowing-down time, which limits the triton density. Explicit physically induced losses such as prompt losses as well as losses due to triton orbit effects, like large pitch angles and trapped orbits, are not taken into account. The triton density is calculated from the DD fusion rates at each s -bin k . The following equation is used as an approximation

$$n_T^k \approx \tau_{sd}^k \langle \sigma v \rangle_{DD \rightarrow Tp}^k \frac{(n_D^k)^2}{2}, \quad (5)$$

where $\tau_{sd}^k(E_T, T^k, n_D^k)$ equals the slowing-down time of tritons with the initial energy $E_T = 1$ MeV at the position k in the deuterium plasma. The slowing-down time is defined as the time it takes for tritons to decelerate from the initial energy of 1 MeV to 77 keV. It is calculated for each s -bin k by integrating the energy loss given in eq. 12 of [Batistoni and Barnes, 1991] ref. [26].

$$\frac{dE_T^k}{dt} = -\frac{\alpha^k}{\sqrt{E_T}} - \beta^k E_T, \quad (6)$$

over the energy interval (1 MeV, 77 keV) as follows

$$-\int_{77 \text{ keV}}^{1 \text{ MeV}} \left(\frac{dE_T^k}{dt} \right)^{-1} dE_T = \int_0^{\tau_{sd}^k} dt \iff \frac{2 \log(\alpha^k + \beta^k E_T^{1.5})}{3\beta^k} \Big|_{77 \text{ keV}}^{1 \text{ MeV}} = \tau_{sd}^k, \quad (7)$$

which neglects energy diffusion as well as pitch angle scattering.^[26] α and β are proportional to n_D and $n_D \cdot T^{-3/2}$, respectively.^[26] Hence, τ_{sd}^k is approximately proportional to $T^{3/2} \cdot n_D^{-1}$. Due to this proportionality and the shape of the used n_D and T profiles, τ_{sd}^k is largest in the centre of the plasma at $s = 0$ and decreases monotonically for larger values of s .

Multiplying this τ_{sd} profile with the triton birth profile, which is equal to the rate of the DD fusion process generating a triton, as given in Equation (5), yields the triton density profile. Consequently, triton diffusion is not considered. The DT fusion-induced 14 MeV neutron rates can be calculated for each (n_D, T) pair by integrating over the s -bins as given in Equation (3).

3 | THERMALLY INDUCED DD AND DT FUSION RATES

The radial profiles of the thermal DD to triton and proton fusion channel as well as the resulting DT fusion rate are plotted exemplarily for the reference discharge in Figure 3. Note that the 2.5 MeV neutron rate equals the plotted DD fusion rate, as the two DD fusion channels are equally probable. Compared to the n_D and T profiles in Figure 2, the fusion rate profiles feature a much stronger peaking in the plasma centre, which is caused by the squared density dependence of the fusion rates in Equation (3) and especially by the strong temperature dependence of the DD reactivity in the investigated temperature regime as visible in Figure 1.

Integrating over the thermal DD to triton and proton fusion rate profile of the reference discharge in Figure 3 yields W7-X's overall rate of this DD fusion channel, which is plotted in Figure 4 as a function of the scaled density and temperature profiles. On x -axis and y -axis, the central densities and temperatures of the respective profiles are plotted. Note that fusion rate and central density are plotted on a logarithmic scale. Moreover, contour lines for the fusion rate are plotted and the vertical white line highlights the maximum achievable density in ECRH-heated W7-X plasmas, which amounts to about $2.4 \cdot 10^{20} \text{ m}^{-3}$ due to the second harmonic ordinary cutoff.^[1] Realistically, a maximum density of about $1.8 \cdot 10^{20} \text{ m}^{-3}$ can be achieved due to the reduced ECRH absorption close to the cutoff.^[23]

The corresponding DT fusion rates, and thus the 14 MeV neutron rates, are shown in Figure 5. For the used reference discharge, the 2.5 MeV neutron rate plotted in Figure 4 equals about $4.0 \cdot 10^{14} \text{ s}^{-1}$ while the 14 MeV neutron rate amounts to about $1.5 \cdot 10^{12} \text{ s}^{-1}$ yielding a triton burn-up ratio of about 3.8 per mille, which is calculated by dividing the 2.5 MeV neutron rate by the 14 MeV neutron rate. Overall, the triton burn-up ratio changes from 0.8 per mille at lowest densities and temperatures to 5.8 per mille at the highest densities and temperatures. Both, DD and DT fusion rate, show the

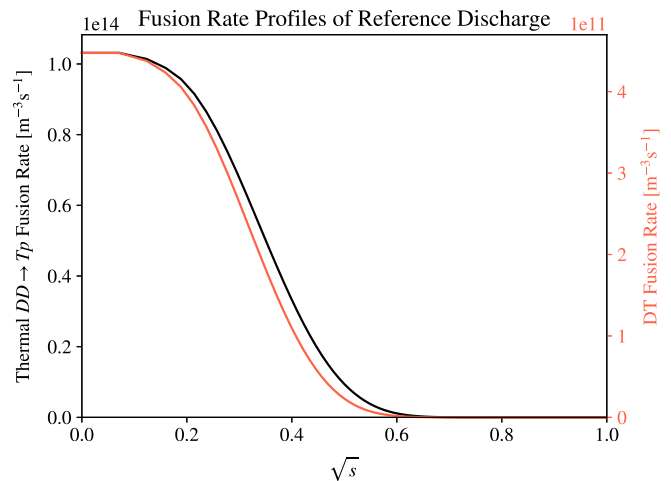


FIGURE 3 Estimated deuteron fusion rate ($DD \rightarrow Tp$ channel) profile and resulting deuteron-triton fusion rate profile for the reference discharge of W7-X with central density and temperature of $n_D^{\text{Ref.}} = 8 \cdot 10^{19} \text{ m}^{-3}$ and $T^{\text{Ref.}} = 3.6 \text{ keV}$, respectively

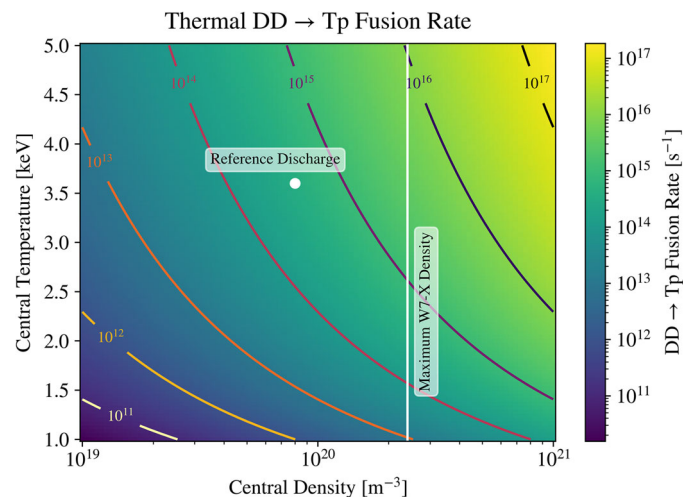


FIGURE 4 Plot of the W7-X $DD \rightarrow Tp$ fusion rate channel, which is equal to the 2.5 MeV neutron rate. Central deuteron density and temperature are given on x -axis and y -axis, respectively. The plasma is assumed to be purely ECRH heated as it is the case in the reference discharge. The upper density limit in ECRH-heated W7-X plasmas is labelled

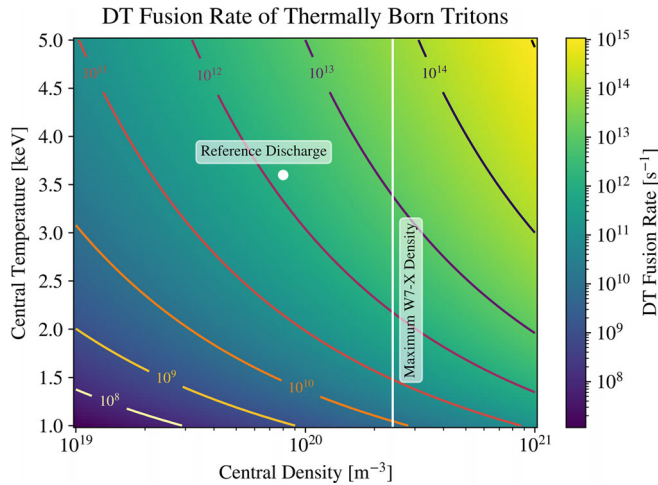


FIGURE 5 Plot of the W7-X 14 MeV neutron rate, which corresponds to the deuteron-triton fusion rate resulting from tritons generated by the deuteron fusion rate channel in Figure 4. Assuming deuterium instead of hydrogen as main fuel, the W7-X reference discharge would result in a 14 MeV neutron rate of about $1.5 \cdot 10^{12} \text{ s}^{-1}$

expected squared dependence on density and the dominating temperature dependence, which is stronger in the DT case, since the triton slowing-down time introduces an additional $T^{3/2}$ dependence.

As stated in the introduction, deuterium plasmas in LHD generating an overall 14 MeV neutron rate of 10^{12} s^{-1} yield sufficient statistics for measurements with *SciFi* detectors that are similar to the one, which is considered for measurements at W7-X.^[16,18] In these LHD measurements, the major radius of the plasma amounts to 3.6 m and the used *SciFi* detectors are placed about 4 m from the plasma centre, thus 7.6 m from the torus centre.^[16,18] To approximate the geometrical fraction of neutrons hitting the active area of the detector via the solid angle coverage, the 14 MeV neutron source of LHD is assumed to be an isotropically emitting ring along the major radius. Absorption and scattering effects during the neutron propagation from the plasma to the detector are not considered. Moreover, the radius of *SciFi*'s circular active area, which consists of 91 scintillating fibres of each 1 mm diameter and 10 cm length, is calculated to be 0.477 cm. Taking the 15° full-width half maximum viewing angle of the detector into account,^[13] the geometrical fraction of the 10^{12} s^{-1} 14 MeV neutrons reaching the detector is about 10^4 s^{-1} . A considered position for *SciFi* at W7-X is in 8 m distance to the torus centre. There, the same fraction of neutrons, 10^4 s^{-1} , is expected using the same approximations as for LHD and the major radius of W7-X of 5.5 m. It is concluded that an overall 14 MeV neutron rate of 10^{12} s^{-1} will be sufficient for time dependent triton burn-up studies with the *SciFi* detector at W7-X. Currently, a sophisticated neutron propagation Monte Carlo model of the *SciFi* detector inside of the W7-X torus hall is set up to study the effect of 14 MeV neutron absorption and scattering on the performance of *SciFi*.

Resulting from the estimation shown in Figure 5, the reference discharge would exceed the requirement with a 14 MeV neutron rate of $1.5 \cdot 10^{12} \text{ s}^{-1}$. To reach exactly the required 10^{12} s^{-1} 14 MeV neutron rate, the reference discharge of W7-X could have a lower central density of about $7 \cdot 10^{19} \text{ m}^{-3}$ and the same central temperature of 3.6 keV or a lower central temperature of 3.3 keV at the same central density of $8 \cdot 10^{19} \text{ m}^{-3}$. This requirement on central density and temperature is compatible with the goal of W7-X to simultaneously achieve 4 keV and above 10^{20} m^{-3} .^[1] Thus, the sensitivity of the currently available *SciFi* detector is sufficient to study the time dependence of the 14 MeV neutron rate and triton burn-up in purely ECRH-heated plasmas of high performance.

The above given estimate neglects diffusive plasma transport of tritons. Triton diffusion potentially reduces the 14 MeV neutron rate. Therefore, to estimate the maximum effect of diffusion, the tritons are assumed to be equally distributed in the s -space during their slowing-down process. Thus, the triton birth profile is assumed to flatten out to a constant, which is equal to the mean value of the triton birth profile. Consequently, also the mean value of the slowing-down time profile is calculated and both mean values are inserted in Equation (5) in place of the profiles. The resulting 14 MeV neutron rate equals $3.7 \cdot 10^{11} \text{ s}^{-1}$ for the reference discharge. In this case and over the whole scanned operational regime of W7-X, the 14 MeV neutron rate is about a factor of four less than in the diffusionless estimation. In this maximum diffusion scenario, the required 14 MeV neutron rate of 10^{12} s^{-1} would be exceeded with the same temperature as in the reference discharge of 3.6 keV and a slightly higher density of about $1.4 \cdot 10^{20} \text{ m}^{-3}$, which is below the realistically achievable maximum density in ECRH-heated W7-X plasmas.

At these high densities and temperatures, the estimated triton burn-up ratio is in the per mille range. This is the same order of magnitude as measured with *SciFi* at JT60-U^[13] and recently at LHD^[19] in deuterium plasmas of similar temperatures but with a dominant beam-plasma neutron production rate driven by NBI heating.

4 | COMPARISON WITH NBI HEATING BEAM-PLASMA-INDUCED DT FUSION RATE

NBI heating was successfully commissioned in W7-X in the last campaign and will be expanded for the upcoming campaigns.^[27] To estimate the neutron rate generated by the beam-plasma interaction of the W7-X NBI deuterium beams with 60 keV energy, an adapted version of the FBURN code is used,^[19] which also does not take diffusion or triton losses into account and calculates the NBI beam and triton slowing-down in 1 ms steps for a 1 s long lasting NBI beam scenario using the same density and temperature profiles as before. The beam power is assumed to be 5 MW, which equals the ECRH heating power during the considered reference discharge with a Z_{eff} of about 1.5 and carbon as main impurity.^[25] In FBURN, Z_{eff} is required to be an integer and conservatively approximated to be two while the only impurity is carbon such that the ion density is underestimated compared to the previous estimations by about 20%, where ion and electron density were assumed to be the same. It is known that FBURN overestimates the DT fusion rate by about a factor of four in the case of LHD as pointed out in ref. ^[19]. As the amount of overestimation is not predictable for W7-X, it will not be taken into consideration for the qualitative comparison here.

Figure 6 gives the resulting DT fusion rates of tritons, which were generated by the fusion of NBI beam deuterons with plasma deuterons, in the same density and temperature range as previously shown in Figure 5, where the DT fusion rate originates only from thermal DD fusion of plasma deuterons. With $2.5 \cdot 10^{12} \text{ s}^{-1}$, the NBI beam-induced DT fusion rate exceeds the corresponding thermal rate by less than a factor of two in the case of the reference discharge. Nevertheless, summing NBI-induced and thermal DT fusion rate, the 14 MeV neutron rate is more than doubled compared to the purely thermal ECRH heated case. Therefore, the *SciFi* detector is especially suited for NBI-heated deuterium plasmas.

Note that the NBI beam power is not scaled with the power needed to generate plasmas of different (n_D, T) configurations. Instead, the NBI beam power is kept constant at 5 MW, which matches the ECRH power in the reference discharge, such that the neutron rates in Figure 6 are underestimated for lower central densities and temperatures compared to the reference discharge and overestimated for higher ones, respectively. The beam power was not adapted as there is no experience in W7-X yet on how the NBI beam power will scale with the plasma densities and temperatures.

5 | CONCLUSIONS AND OUTLOOK

A fast one-dimensional estimation has been developed, which calculates the expected neutron rates in W7-X in future deuterium plasmas, in order to gain information on the feasibility of the *SciFi* 14 MeV neutron detector for triton burn-up studies. The estimation can be applied to any magnetic confinement nuclear fusion device and calculates the thermal fusion rates in purely ECRH-heated plasmas. For simplicity, it does not take diffusion into account and only introduces triton losses implicitly via their slowing-down time.

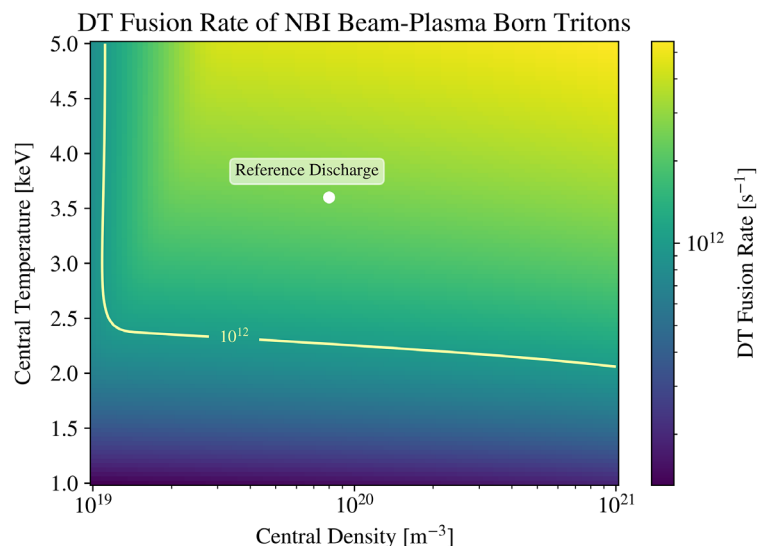


FIGURE 6 Plot of the FBURN calculated deuteron-triton fusion rate of tritons, which were born by the fusion of neutral beam injection (NBI) beam deuterons with plasma deuterons. Note that the NBI beam power is kept constant at 5 MW for all central density and temperature pairs, which matches the ECRH heating power of the reference discharge. Assuming deuterium instead of hydrogen as main fuel, the W7-X reference discharge would result in a 14 MeV neutron rate of about $2.5 \cdot 10^{12} \text{ s}^{-1}$

The resulting DT fusion rates, and thus 14 MeV neutron rates, are promising for *SciFi*'s application at W7-X, since they exceed the required value of 10^{12} s^{-1} for central densities of about $7 \cdot 10^{19} \text{ m}^{-3}$ and central temperatures of 3.6 keV, which were already achieved in previous W7-X campaigns and are expected to be increased in future campaigns with more heating power. Even for a maximum diffusion scenario, the required 14 MeV neutron rate is exceeded at the same central temperature and a central density of $1.4 \cdot 10^{20} \text{ m}^{-3}$, which is below the realistic upper density limit in ECRH-heated W7-X plasmas.

Using profiles from a purely ECRH-heated reference discharge of the latest W7-X hydrogen campaign yields 14 MeV neutron rates above $1.5 \cdot 10^{12} \text{ s}^{-1}$, which is slightly above the requirement for *SciFi* measurements, assuming the same plasma density and temperature would have been achieved in a deuterium plasma. For the reference discharge, the DT fusion rate of tritons generated by NBI heating induced beam-plasma DD fusion yields a 14 MeV neutron rate, which is less than a factor of two higher than the thermally induced rate.

Therefore, the *SciFi* detector is expected to be feasible for triton burn-up studies in ECRH-heated W7-X deuterium plasmas of high performance.

To study triton burn-up also at lower neutron rates, the *SciFi* detector could be upgraded with more scintillating fibres, which increases the detection sensitivity. This is currently investigated in LHD.^[28]

Currently, a more sophisticated simulation, using the Monte Carlo orbit following code ASCOT,^[29] is developed to produce neutron source distributions from the DD and DT fusion processes in W7-X deuterium plasmas. The sources will be five dimensional in space, energy, and pitch angle. In a later step, these neutron sources will be fed into a neutron propagation Monte Carlo model of the W7-X torus hall to complete a universal simulation of the *SciFi* detector at W7-X.

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