Integration of Lost Alpha-Particle Diagnostic Systems on ITER

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Abstract

Time-resolved measurement of lost alpha particles on the first wall is demanded on ITER, because it is anticipated that various kinds of collective instability are driven by alpha particles. Moreover, localization of alpha-particle loss on the first wall is one of the problems for the safe operation of ITER. However, the severe thermal/radiation environment of measurement location and the difficulties on the access and installation, limit the application of conventional measurement tools.

The ITER integration are studied for some candidates of lost alpha-particle measurement, such as the camera imaging of scintillators on the first wall, a scintillator probe, a Faraday-cup, and an imaging bolometer. An orbit calculation of escaping alpha particles is inevitable, and the orbit characteristics are considered in the conceptual design of these systems.

1. Introduction

The self-heating of a DT plasma by fusion-produced alpha particles is the key to the realization of self-sustainable ignition of a thermonuclear plasma for fusion reactors. The loss of alpha particles means the deterioration of the heating input power. Moreover, the localization of alpha particle bombardment on the first wall surface might induce a serious damage. Confinement of alpha particles is one of the key issues on ITER. Even before the real DT experiments lot of studies have been performed experimentally and theoretically, in these two decades, by using energetic beam particles for heating and fusion produced energetic ions from DD and D^3He reactions. As a result of the accumulation of these researches, it has been understood that the confinement of fast ions is governed by a number of processes, not only the magnetic structure, q-profiles and the energy and pitch angle diffusion originated in Coulomb collisions, but interaction with instabilities driven by themselves, and the other stochastic processes [1]. Especially some MHD events can transport alpha particles to the outer region of the plasma, and cause giant losses spiky in time and localized in space. Studies that combine alpha particles losses and characteristics of MHD activities are needed to identify the mechanisms responsible for alpha particle transport and loss.

In consideration of such a background, the diagnostic systems for the lost alpha particles prepared for ITER can be categorized into two groups. One is the energy and pitch-angle resolved probes for the study of characterization of lost alpha particles, and the other one is the loss imaging on the surface of the first wall. Good time resolution is needed for systems of both groups.

However, the severe thermal/radiation environment of measurement location and the difficulties of access and installation, limit the application of conventional measurement tools. The typical neutron and γ flux on the first wall are 3 $x10^{18}$ n/m^2 /s, and $2x10^3$ Gr/s, respectively, at the maximum fusion power operation.

This paper describes the anticipated features of escaping alpha particle orbits, loss location (section 2), integration of several candidate systems of lost alpha-particle measurement (section 3), development and test of new type ceramic scintillator materials (section 4), and issues to be worked in future.

2. Features of alpha particle loss on ITER

The major origin of alpha particle loss is that of locally trapped in ripples, and banana particle loss. The former depends mostly on the ripple structure and is not so substantial in ITER, while the loss fraction of the latter is substantial and strongly depends on tokamak operation scenarios, the birth profile and the diffusion rate, as well as the ripple structure and strength. The poloidal distribution of the loss is ranging in 200 to 250 degree in angle from the inner mid-plane [2]. The typical heat load due to the alpha particle loss is expected in few kW/m^2 to several hundreds kW/m^2. The typical distribution under the standard operation is shown in Fig. 1. Under the operation of the reversed shear mode, it is anticipated that the loss might increase substantially. The MHD activities might also increase the loss.

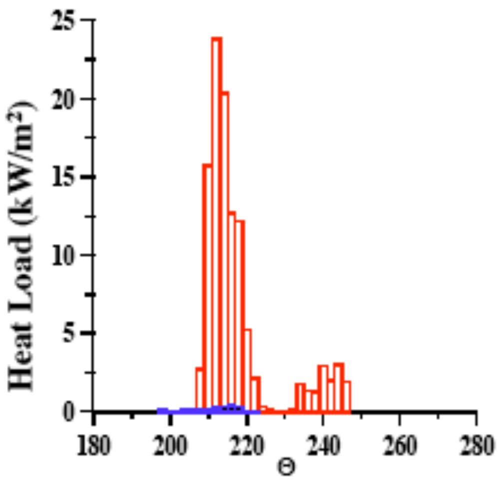


Fig. 1 Poloidal distribution of the heat load in the standard operation. Red histogram corresponds to banana particle loss and blue one shows locally trapped α loss [2].

The head load shown in Fig. 1 is smaller than the average 14 MeV neutron wall loading of 0.57 MW/m^2. But the effect of alpha bombardment on the first wall is severe because the energy deposit concentrates in a thin surface layer of the alpha particle range (in the range of few micro meters), while the neutron wall loading is received by the whole blanket materials.

3. ITER integration

Candidate methods of loss imaging are the IR camera imaging, camera imaging of scintillators fixed at various locations on the FW (scintillator imaging) [3, 4], and gamma ray imaging using $^{10}B(\alpha,p\gamma)^{13}C$ reaction [5]. Candidate methods of point measurement with energy and pitch-angle resolutions are faraday-cup detectors, Scintillator probes, and bolometric imaging [6]. In this paper, the ITER integration of scintillator imaging and the integration of various lost alpha probes are studied.

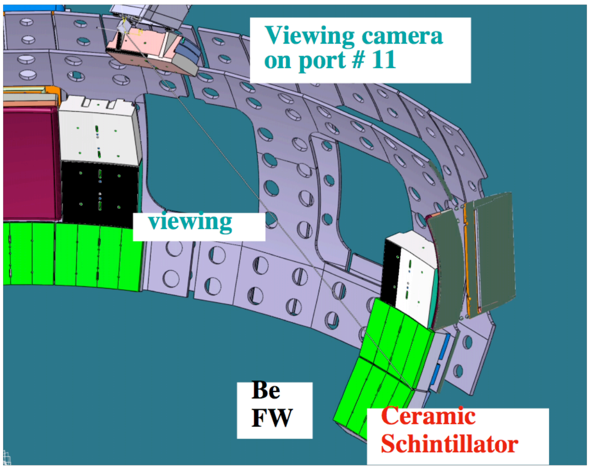
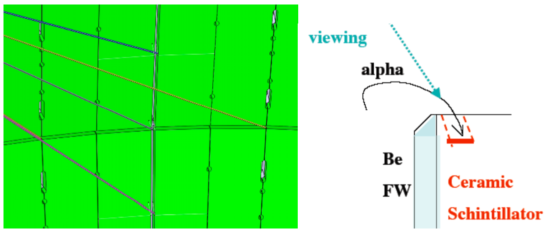


Fig. 2 Integration of the scintillator imaging system on a CAD drawing. The upper port 11 is used for the viewing camera, and the ceramic scintillators are fixed behind the edge of FW of BM #16, and #17 (Detector poison A).

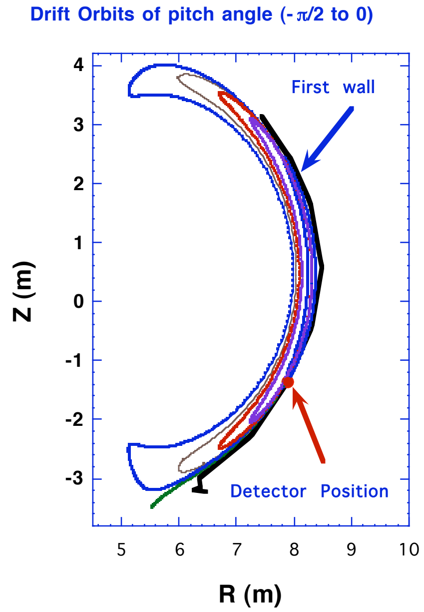


(a) (b)

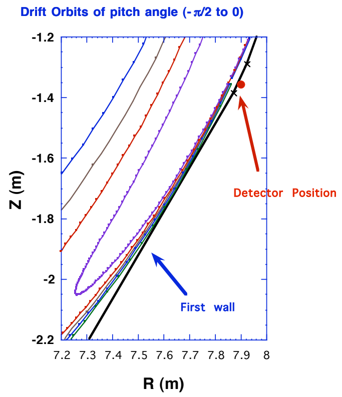
Fig. 3 (a) The area viewed by the camera at the upper port 11. Extra holes on the slit of the first wall panels will be used for installation of various lost alpha probes.
Fig. 3 (b) A conceptual image of the scintillator imaging system.

Fig. 2 shows the geometry of the scintillator imaging system on a CAD drawing of ITER. Ceramic schintillators are fixed in holes on the edges of first wall (Cu backing) of the blanket module #16 and #17, and viewed by a camera with filters in the upper port. Fig. 3 shows the area view by the camera (a) and the conceptual image of the system.

Drift orbit calculations for escaping alpha particles have been performed starting from the detector position on the upper edge of the blanket module #17 (Fig. 4) with the time inverse. Only orbits with the pitch angle from $-\pi/2$ to 0 are shown because those with 0 to $\pi/2$ do not go back to the plasma. These drift orbits have turning points only in the peripheral region in the plasma, and they are not the best to monitor particles resonating with MHD excited in the inner region. Moreover, the drift orbits are too close wall surface as shown in the Fig. 4b. The straight lines in the Fig. 4b are connecting the outmost corners of the blanket module. The actual shape the corner is rounded and the module itself is curved poloidally and toroidally. It is necessary to carry out the full gyro-orbit calculation including the actual shape of the modules, in order to judge whether orbits starting from the detection

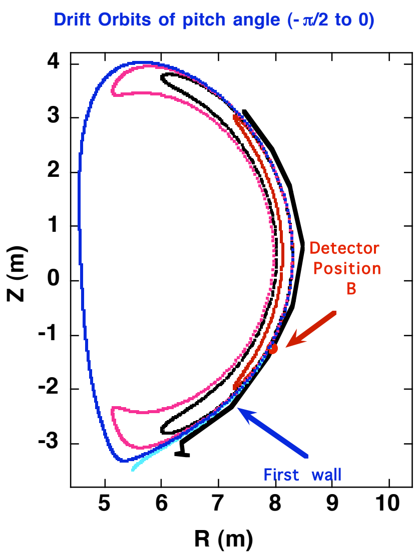


(a)

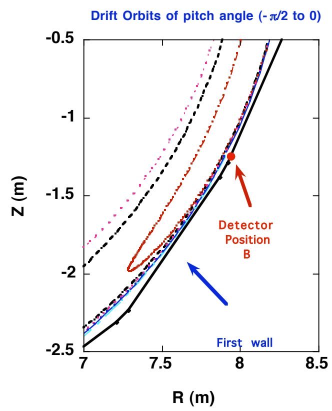


(b)

Fig. 4 (a) Drift orbits of escaping alpha particles calculated from the detector position on the upper edge of the blanket module #17 with the time inverse. (b) The closed up view of (a).



(a)



(b)

Fig. 5 (a) Drift orbits of escaping alpha particles calculated from the detector position on the slit of front panels of the blanket module #16 with the time inverse. (b) The closed up view of (a).

position really go back to plasma or not. Fig. 5 shows the drift orbit starting from the upper detection position, on the slit of front panels of the blanket module #16. These drift orbits have turning points in a wider region in the plasma, and include passing orbits. This detection position is better to monitor particles resonating with MHD excited in the inner region, and is considered to be used for point measurement probes with energy and pitch-angle resolutions, such as faraday-cup detectors, scintillator probes, and bolometric imaging probes. Signals from these probes are transferred electrically (faraday cups) or optically (scintillators and bolometers).

4. Development and test of new type ceramic scintillator

New types of ceramic scintillator which are usable for lost alpha measurement under severe environment of high temperature have been developed [7]. It has been known that most of ceramic scintillator show thermal quench of luminescence at the temperature higher than 100 C. New ceramic plates were manufactured from inorganic ceramic compounds and various kinds of scintillation material. The ceramic scintillators thus made were bombarded by a 7 keV He^+ beam, extracted from a bucket-type source, and the scintillation spectra were measured with the PMA-11, changing the scintillator temperature with a sheath heater. Among four kinds of scintillation material tested, ZnS(Ag), ZnO(Zn), $Y_3Al_5O_{12}$(Ce), and $Y_3Al_5O_{12}$(Cr), the ceramics made from $Y_3Al_5O_{12}$(Cr) emit luminescence of the longest wave length. Considering the transmission degradation due to the neutron irradiation, the luminescence in the region of larger wave length is preferable.

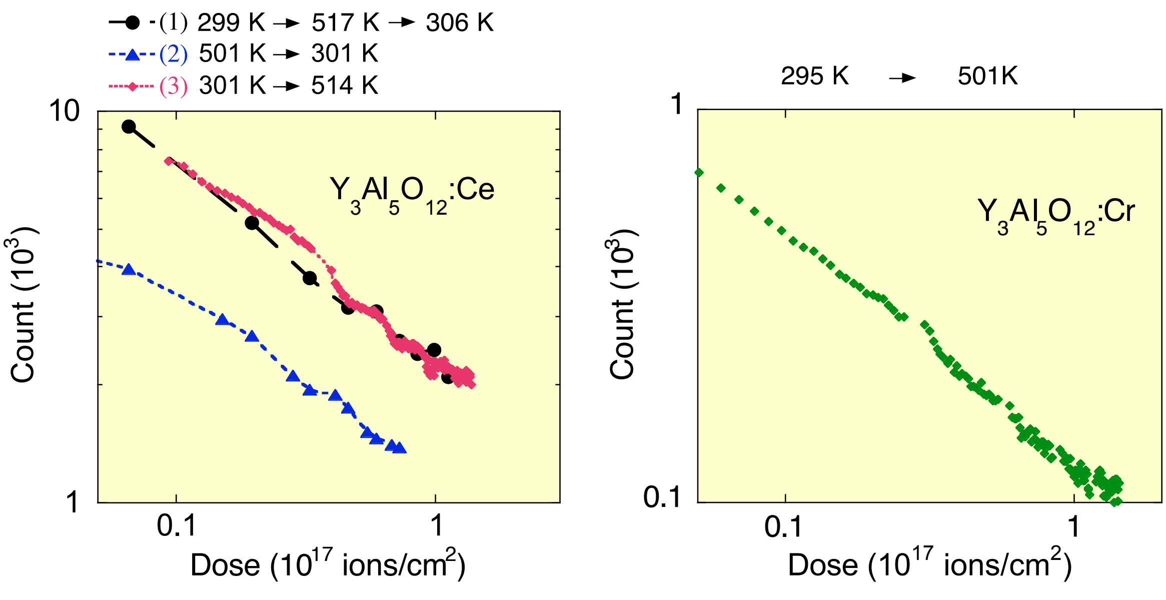


Fig. 6 Changes in scintillation efficiency of $Y_3Al_5O_{12}$(Ce) (a) and $Y_3Al_5O_{12}$(Cr) (b) with dose by 7 keV He^+ beam bombardment.

Figure 6 shows the changes in the scintillation efficiency of $Y_3Al_5O_{12}$(Ce) (a) and $Y_3Al_5O_{12}$(Cr) (b) during continuous bombardment by a 7 keV He^+ beam as a function of with dose. The three results shown in the figure (a) are those of different thermal history. In case (1) , the bombardment and the measurement was started when the heater was turned on to increase the temperature, and the heater was turned off at T = 517 K. In case (2), the a new scintillator sample was preheated up to T = 501 K and then ion beam bombardment and measurement were started during the cooling down. The decay curves in figure 3(a) indicate that the change in scintillation efficiency during measurement is not due to the temperature. Moreover, the exponential decay indicates that the scintillation centers are destroyed by the incidence of the ion beam.

5. Conclusion and Issues to be worked in future

The integration of some candidate measurement tools of lost alpha-particles on ITER, such as the camera imaging of scintillators on the first wall, a scintillator probe, a Faraday-cup, and an imaging bolometer, have been studied, while the severe thermal/radiation environment of measurement location and the difficulties on the access and installation, limit the application of conventional measurement tools. The distribution of the loss is ranging in 200 to 250 degree in poloidal angle. It is proposed to fix ceramic scintillators in holes on the edges of first wall (Cu backing) of the blanket module #16 and #17, and viewed by a camera with filters in the upper port 11. The drift orbit calculation shows that detection position of the gap between the blanket module #16 and #17 catches some banana orbits but turning points are in the peripheral of the plasma. Upper positions on the gaps and slits of the blanket module #16 catch some passing particles and banana particles which have turning points are in the inner part of the plasma. Full-gyro orbit calculations including realistic detector designs and detailed 3D first wall shapes, are needed, and now under preparation. Here, we consider only detection of typical and standard escaping particles. The interaction with MHD has possibility to eject specific orbits, such as resonating passing particles. More studied focused on this aspect is waited.

New type of ceramic scintillators have been developed and tested at a temperature of T = 514 K. They had high scintillation efficiency and could potentially be used at ITER. The changes in scintillation efficiency due to continuous bombardment were studied, showing the exponential decay, and indicating that the scintillation centers are destroyed by the incidence of the ion beam. Further developments and experiments are planned, including the testing of new scintillation materials, and bombardment with 1–3 MeV alpha particles.

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