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Measurements of carbon, deuterium and boron deposition in DIII-D

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Abstract

An experiment was recently conducted in DIII-D in which ^{13}C methane ($^{13}CH_4$) was injected from the upper divertor plenum into 22 identical lower single null divertor L-mode plasmas. Twenty-nine graphite tiles were subsequently removed and analyzed to determine the spatial distribution of ^{13}C deposited on the main chamber wall and divertor. ^{13}C coverage was mapped by ion beam analysis using the $^{13}C(^3He,p)^{15}N$ nuclear reaction. This technique also measures deuterium, boron and ^{12}C content in the near-surface region of the tiles. The measurements show the ^{13}C is deposited mainly at the inner divertor.

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1. Introduction

Codeposition of tritium with carbon can potentially lead to large inventories of retained tritium in a fusion reactor [1]. In tokamaks with carbon walls, hydrocarbons from chemical erosion at the wall dissociate in the plasma edge and redeposit back onto plasma facing surfaces. The location and form of this redeposited carbon affects tritium retention and strategies for its mitigation. Models are being developed to simulate and predict erosion, transport and deposition of carbon in tokamaks [2,3] and experiments are needed to test the models. Such an experiment was recently conducted in DIII-D in which $^{13}CH_4$ was injected from the upper divertor plenum into lower single null divertor L-mode deuterium fuelled plasmas, as illustrated in Fig. 1 [4]. This plasma geometry and location of injection far from the divertor, were chosen to simulate methane originating from plasma interactions with the main chamber wall. A set of graphite tiles was subsequently removed and analyzed to determine the spatial distribution of ^{13}C deposition on the main chamber wall and divertor. ^{13}C coverage was mapped by ion beam analysis using $^{13}C(^3He,p)^{15}N$ nuclear reaction analysis. This technique also measures deuterium, boron and ^{12}C content in the near-surface region of the tiles. This paper describes the ion beam analysis method used and presents the results of the measurements. The distribution of ^{13}C shows the pattern of carbon deposition with the well-defined plasma

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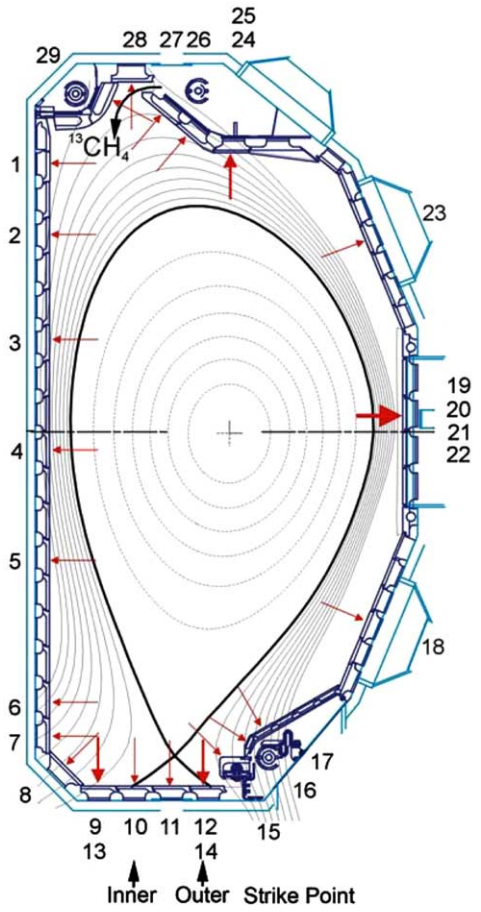

Fig. 1. Illustration of the plasma configuration and location of $^{13}CH_4$ injection. Red arrows and numbers indicate tiles analyzed. Heavy red arrows indicate tiles from multiple toroidal angles. The lines indicate magnetic field contours (dotted) and the last closed flux surface (heavy). Radii of the inner and outer wall at the midplane are 1.01 and 2.38 m respectively from the center of the machine (For interpretation of the refrences in colour in this figure legend, the reader is referred to the web version of this article).

conditions during the $^{13}CH_4$ injection, while the distributions of boron and deuterium indicate the wall composition resulting from erosion and deposition during prior exposure to various plasmas and wall conditioning procedures. The measurements show the ^{13}C is deposited primarily at the inner divertor.

2. Experimental methods

$^{13}CH_4$ was injected from a distributed gas system located in the upper divertor plenum providing a high degree of toroidal symmetry to the $^{13}CH_4$ flow into the plasma. The $^{13}CH_4$ was injected for 3 s intervals during constant plasma conditions, at a rate chosen to be as high as possible without significantly perturbing the plasma conditions [4]. Plasma conditions are described in references [4,5]. Tiles were near room temperature except at the strike point where the temperature rose during the plasma exposure but remained below 100 °C during the low power L-mode plasmas used in this experiment [6]. In order to obtain a sufficient total quantity of ^{13}C for measurements of deposition, the $^{13}CH_4$ injection was repeated for 22 consecutive identical plasmas, for a total of 314 Torr-liters or 1.00×10^{22} atoms of injected ^{13}C. The $^{13}CH_4$ injection was done on the last day of the experimental campaign, and no baking or cleaning were performed afterwards. At the beginning of the subsequent machine vent, 29 carbon tiles were removed for analysis. These tiles were located both in the divertor and main chamber, as illustrated in Fig. 1. The tile set included 23 tiles within ±10° of the same toroidal angle, plus 6 from other toroidal angles to check toroidal symmetry.

^{13}C coverage on the tiles was measured by ion beam analysis at Sandia National Laboratories, using a large chamber capable of analyzing whole tiles. An analysis beam of 2.5 MeV ^3He was directed onto the tiles, and energy spectra of charged particles from resulting nuclear reactions were recorded. Measurement of ^{13}C coverage required a specialized detector geometry optimized for this purpose. A large diameter annular silicon surface barrier detector 3 cm from the target was used to obtain a large solid angle without excessively broadening the energy resolution due to the range of scattering angles subtended. A large depletion depth of 1500 μm is necessary to stop the energetic protons.

Fig. 2 shows spectra of protons from the $^{13}C(^3He,p)^{15}N$ reaction for a graphite sample, a thin film ^{13}C reference sample, and two of the tiles from DIII-D. The ^{13}C thin film reference has a narrow peak at 10.6 MeV. This peak is also present for graphite because it contains 1.1% natural abundance of ^{13}C. The broadening of the peak for graphite results mainly from the kinematics of the reaction and the fact that the ^3He loses energy as it penetrates into the target. The lower energy ^3He at greater depths yields lower energy protons. The detector must therefore have good energy (and thus depth) resolution to distinguish ^{13}C deposited on the tile surface from natural ^{13}C in the graphite. The energy resolution indicated by the width of the ^{13}C reference peak in Fig. 2, corresponds to a depth resolution for the ^{13}C analysis of about 0.6 μm.

Nuclear reactions with other light isotopes present on the tiles produce energetic particles at many other energies. Thin film references were used to link peaks in the energy spectra to isotopes and check for overlapping peaks. Yields from proton peaks at 11.4, 9.2 and 3.2 MeV were used to determine near-surface content of deuterium, boron and ^{12}C respectively.