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Applicability of β-ray-induced X-ray spectrometry to in situ measurements of tritium retention in plasma-facing materials in ITER

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Abstract

Applicability of β-ray-induced X-ray spectrometry (BIXS) for in situ measurements of tritium retention by plasma-facing materials in ITER was examined using two γ-emitters and a divertor tile with metallic supports employed during D–T fusion experiments in JET. Measurements of the tile with a γ-emitter showed that the presence of the γ-field has no influence in the shape of the β-ray-induced X-ray spectra, although the whole intensity in the observed energy region was dependent on radioactivity of the γ-emitters. To simulate more accurately the in-vessel environment of PFMs, one of the divertor tiles with metallic supports was subjected to BIXS measurements. Although the metallic supports were gamma active, no significant effect was observed on the recorded X-ray spectrum. These results clearly indicate that BIXS can be applied to in situ measurements of tritium retention by PFMs with a simple shielding of the X-ray detector.

Keywords: Tritium retention; In situ measurement; BIXS; Plasma-facing materials; ITER

1. Introduction

It is of a great importance to assess the amount of tritium retained by the surface and/or in the bulk of plasma-facing materials (PFMs) of fusion devices from viewpoints of control of fuel particle balance in

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the reactor core as well as safety and economy of tritium. For this purpose, the applicability of the newly developed technique of β-ray-induced X-ray spectrometry (BIXS) has been previously examined [1–4]. This technique is based on the measurement and analysis of X-ray spectra induced by the β-rays from tritium trapped in/on materials, and main features are as follows: non-destructive measurements, discrimination of surface layers and bulk, and depth profile analyses of tritium are possible. Feasibility of BIXS was examined using graphite samples irradiated with a given amount of tritium ions [2], and it was found that BIXS can measure the tritium amounts retained on the surface layers and in bulk of graphite independently. In addition to this, it was shown that the depth profile of tritium in the bulk could be clarified by computer simulation.

Application of BIXS to non-destructive measurement of the tritium amounts was further extended based on the above results. The amount and distribution of tritium retained on/in the carbon fiber composite (CFC) tiles exposed to tritium plasmas in the JET machine during the DTE1 campaign were measured in detail [3,4]. It was concluded from this examination that the present technique is significantly useful for in situ evaluation of tritium retention on/in PFMs as well as metallic impurities deposited on PFMs.

To apply BIXS for in situ measurements of tritium retained by PFMs in ITER, effects of γ- and X-rays emitted from the neutron-activated structure materials on the BIXS spectra must be elucidated in advance. Since X-rays induced by tritium β-rays appear in the low energy region below 18.6 keV and have intensity and spectral shapes that give information about the amount and depth profile of tritium, an important issue is to examine the changes in a shape of the observed X-ray spectra with the coexistence of X- and γ-rays. In the present study, therefore, changes in the X-ray spectra induced by tritium β-rays were examined using emitters of γ-rays and a CFC tile attached with the activated metallic supports.

2. Experimental

Three kinds of tests were carried out to examine the effects of ambient radiations in a fusion device on measurements of X-ray spectra induced by interactions between β-rays of tritium and materials: (1) measurements of radiation spectra in an energy region below 18.6 keV by using two γ-emitters (^{137}Cs and ^{60}Co) as models of activated materials, (2) preliminarily tests using both the cylindrical carbon fiber composite (CFC) sample contained a given amount of tritium and ^{137}Cs, and (3) measurements of X-ray spectra emitted from a CFC tile with the activated metallic parts, which were exposed to neutrons produced by D–T fusion experiments in the JET machine. All the measurements of CFC tiles were performed in a glove box of the hot cells in the Forschungszentrum Karlsruhe.

A semiconductor detector equipped with a high purity Ge crystal was used for measurements of radiation spectra such as γ-rays and β-ray-induced X-rays. Energy resolution of the present X-ray detector was determined to be 129 eV at 5.9 keV by using a ^{55}Fe source. The radiation entrance window of the X-ray detector was made of a specially designed thin beryllium plate (8 μm in thickness) to gain an effective transmittance of low energy X-rays. The size of the Ge crystal employed for the present detector was 8 mm in diameter and 5 mm in thickness.

The activities of ^{137}Cs and ^{60}Co sources used were 2.2 MBq and 1.5 TBq, respectively. In the first measurement, since activity of the former γ-emitter was not so high, it was fixed near the X-ray detector surrounded with a few lead bricks in the glove box and the radiation spectrum from the ^{137}Cs source was measured. However, radiation spectrum from the ^{60}Co source could not be measured by a similar way owing to the large activity. That is, the ^{60}Co source was usually stored in a thick lead-cell. Thus, radiation from the latter γ-emitter was measured by opening slightly a protection window of a specially designed lead-cell. In addition to a slight opening of the protection window, the X-ray detector was placed at outside of the lead-cell as shown in Fig. 1. The rear side of the X-ray detector was also surrounded with a number of lead bricks for safety.

In the second series of tests, a cylindrical sample used was cored out from the 1IN1 CFC tile that was one of the divertor tiles exposed to D–T plasmas in the DTE1 campaign of JET. Size of the cylindrical sample was 6 cm in diameter and 3 cm in length. X-ray spectra were measured by placing the ^{137}Cs source just behind the cylindrical sample.