Abstract

The C/O monitor is a dedicated diagnostic system designed to monitor impurity content in the Wendelstein 7-X (W7-X) plasma. It was designed to measure the intensity of Lyman-α lines of hydrogen-like ions of four low-Z impurities - boron (B^{4+} - 4.9 nm), carbon (C^{5+} - 3.4 nm), nitrogen (N^{6+} - 2.5 nm) and oxygen (O^{7+} - 1.9 nm). It is an optical spectroscopic system whose construction is based on Johann geometry with cylindrically curved dispersive elements. It is constructed as two independent vacuum chambers, each designed to measure the intensity of two spectral lines: the first one is dedicated to measuring the C and O lines, and the second one to B and N. During the next operational phase (OP2.1), the first sub-spectrometer dedicated to the measurement of C and O lines will be commissioned.

The main goal of the system is to provide information on the intensities of radiation. However, the shape of their spectral lines will not be investigated. Therefore, it is extremely important to understand thoroughly the origin of the measured output signals with respect to its dependence on the main plasma kinetic parameters, i.e., temperature (T_e) and electron density (n_e), or the impact of impurity transport on the radial impurity distribution, hence radiated photon intensities. These dependencies, however, turn out to be non-trivial due to the large observed plasma volume and its complicated shape, including the edge plasma layers, from which most of the radiation is emitted.

To answer these questions, a numerical code in Python dedicated to determine the emissivity and the total intensity of radiation reaching the detectors' surfaces was developed. Its purpose is to precisely reproduce the system's geometry with respect to the W7-X and to determine the output signals originating from the investigated lines. Consequently, mainly qualitative information on the emitted photon flux intensities is obtained, but in the future, after an absolute calibration of the system, it will also be possible to obtain quantitative results.

To examine the response of the system to the experimental conditions qualitatively, a series of simulations was performed, assuming various T_e and n_e profiles in the W7-X plasma (with the use of corona equilibrium model). The aim of this analysis was to estimate the expected radiation fluxes and to determine the sensitivity of the system to the changes in impurity

levels, as well as plasma kinetic parameters. The results of analysis demonstrated complexity of the output signals including a high correlation between e.g., increasing temperature (especially in the edge region) and decreasing intensity of the emitted photon fluxes. The problem of impurity transport is also important. For example, their accumulation in the central plasma region can lead to a decrease (and in the case of oxygen lines, over a certain temperature range, also increase) in the emitted photon flux, even though the total impurity content in the plasma remained unchanged.

A case study was then performed for the experimental results registered during the previous operational phase OP1.2b, where carbon accumulation was observed in the central plasma region. The radial distribution of impurities from the C^{6+} line was measured using the Charge Exchange Recombination Spectroscopy (CXRS). Based on these measurements, the distribution of all C ions along minor plasma radius was calculated using the pySTRAHL code. Then, using the developed code, the time evolution of the potential signals was determined. These calculations illustrated photon flux which would be observed if the C/O monitor system was in operation during the previous experimental phase. The results were subsequently compared with the 'flat' impurity profile, assuming exact kinetic parameters and a constant average impurity content in the plasma. A similar procedure was also used for the oxygen line. The obtained results match previous findings.

Finally, it was concluded that the system will fairly accurately reflect the changes of impurity level in the plasma, which confirms that the diagnostic will be crucial from the safety point of W7-X operation.