

OPEN ACCESS

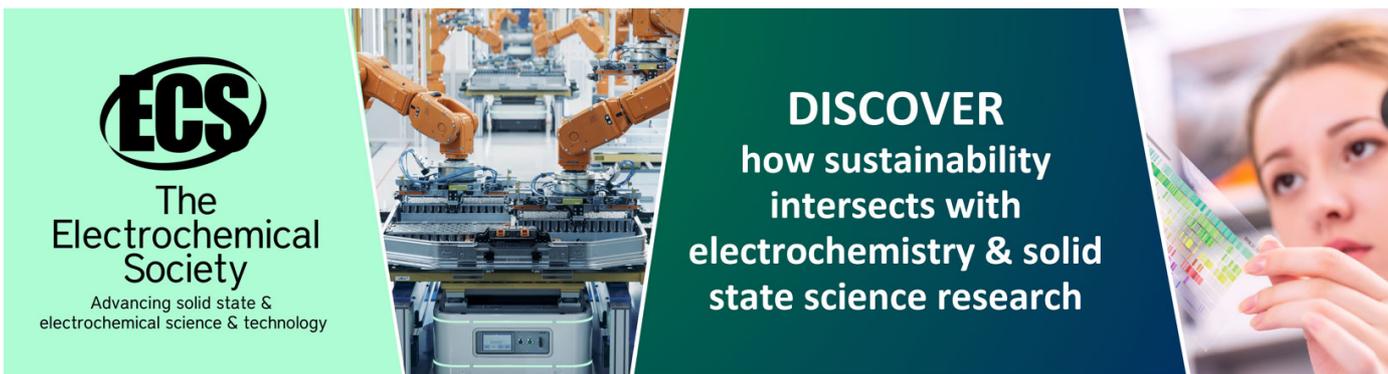
## Laboratory tests of the Pulse Height Analysis system for Wendelstein 7-X

To cite this article: M. Kubkowska *et al* 2015 *JINST* **10** P10016

View the [article online](#) for updates and enhancements.

### You may also like

- [Preparation of thermostable PBO/graphene nanocomposites with high dielectric constant](#)  
Yi Chen, Qixin Zhuang, Xiaoyun Liu *et al.*
- [Direct Electrochemical Reaction of Phytohemagglutinin Adsorbed at the Multi-Walled Carbon Nanotubes Modified Glassy Carbon Electrode](#)  
Tayyeb Madrakian, Habibollah Bagheri, Abbas Afkhami *et al.*
- [Preparation of novel mcl-PHA by green synthesis: influence of active small molecule via esterification effect on side chain](#)  
Kun Li, Wen-Wen Zhang, Xiao-Juan Shi *et al.*



**ECS**  
The  
Electrochemical  
Society  
Advancing solid state &  
electrochemical science & technology

**DISCOVER**  
how sustainability  
intersects with  
electrochemistry & solid  
state science research

1<sup>st</sup> EPS CONFERENCE ON PLASMA DIAGNOSTICS (1STECPD)  
14–17 APRIL 2015  
FRASCATI, ROME, ITALY

## Laboratory tests of the Pulse Height Analysis system for Wendelstein 7-X

M. Kubkowska,<sup>a,1</sup> A. Czarnecka,<sup>a</sup> W. Figacz,<sup>a</sup> S. Jabłoński,<sup>a</sup> J. Kaczmarczyk,<sup>a</sup>  
N. Krawczyk,<sup>a</sup> L. Ryc, <sup>a</sup> C. Biedermann,<sup>b</sup> R. Koenig,<sup>b</sup> H. Thomsen,<sup>b</sup> A. Weller<sup>c</sup>  
and W7-X team<sup>b</sup>

<sup>a</sup>Institute of Plasma Physics and Laser Microfusion, Hery 23 St. 01-497 Warsaw, Poland

<sup>b</sup>Max-Planck-Institut für Plasmaphysik, D-17491, Greifswald, Germany

<sup>c</sup>Max-Planck-Institut für Plasmaphysik, D-85748, Garching, Germany

E-mail: [monika.kubkowska@ipplm.pl](mailto:monika.kubkowska@ipplm.pl)

**ABSTRACT:** A pulse height analysis (PHA) system has been designed and manufactured for the Wendelstein 7-X stellarator, in such a way as to be already compatible with later quasi-continuous operation requirements. The diagnostic will provide X-ray spectra with energy resolution better than 180 eV. The system has three energy channels: 0.25–20 keV, 0.95–20 keV and 1.5–20 keV. For each channel a separate Silicon Drift Detector (SDD) equipped with a suitably selected beryllium foil is used. The range of the 3 energy channels can be further adapted to particular experiments by moving via a pneumatic actuator additional beryllium filters in front of the fixed ones. The PHA system is intended for measuring impurity species (e.g. C, Fe, Ni), electron temperature and for investigating possible suprathermal tails in the spectra. The system will be installed on the horizontal port AEK50 on W7-X. The SDD detectors, the replaceable filters and the adjustable piezo driven slits which allow to suitably adapt the X-ray signal intensity are mounted inside a vacuum chamber which is connected to the plasma vessel via a gate valve. The on-air diagnostic components are the preamplifiers, the Digital X-Ray Processor (XIA, U.S.A.), a computer, and an X-ray calibration source. For controlling the operation of the entire diagnostic system, as well as, for the data acquisition of the electrical pulses coming a special code was developed. The paper presents the construction of the PHA system for W7-X and the laboratory tests of its mechanical parts together with the information on the code developed to operate the diagnostic. The diagnostic was also tested and characterised by measuring Fe55 spectrum and fluorescence spectra of Ni, Fe, Cr and Cu induced by an X-ray mini-tube.

**KEYWORDS:** Plasma diagnostics - interferometry, spectroscopy and imaging; Solid state detectors; Ion identification systems; X-ray detectors

<sup>1</sup>Corresponding author.

---

## Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
<b>2</b>	<b>Concept and design of the PHA system</b>	<b>1</b>
<b>3</b>	<b>Details of the PHA system for W7-X</b>	<b>2</b>
<b>4</b>	<b>Laboratory tests of the PHA system for W7-X</b>	<b>5</b>
<b>5</b>	<b>Conclusions</b>	<b>7</b>

---

## 1 Introduction

The investigation of the soft X-ray emission from fusion plasmas has become a standard diagnostic tool used on many different fusion experiments [1–3]. The measurements of soft X-ray spectra deliver a variety of information related to impurity densities and  $Z_{\text{eff}}$ , impurity transport coefficients and electron temperatures.

The determination of the X-ray energy spectrum using PHA system requires sufficiently long acquisition times resulting in a poor temporal resolution. However, this method is particularly suited for long pulse operation envisaged for W7-X.

The combination of spectral data obtained along a single line of sight with broadband radial X-ray intensity profiles will provide a sufficiently good characterization of the impurity radiation in the plasma core. The measurements yield impurity survey spectra in the X-ray region above 0.5 keV allowing to identify the line radiation from all relevant impurities (e.g. C, Ni, Fe) and (with additional information about plasma temperature and density profile delivered by other diagnostics) to determine their concentration in the hot plasma core. The slope of the hydrogen and low-Z continuum radiation is used to determine the central electron temperature. The intensity of the continuum radiation along with additional spectroscopic data allows to assess  $Z_{\text{eff}}$  values in the plasma center.

First operation of the described PHA system at W7-X is expected in upcoming very first plasma operation phase OP1.1. The main aim of the OP1.1 is to enable an early commissioning and to demonstrate the safely operation of the device as well as to commissioning and testing installed diagnostics.

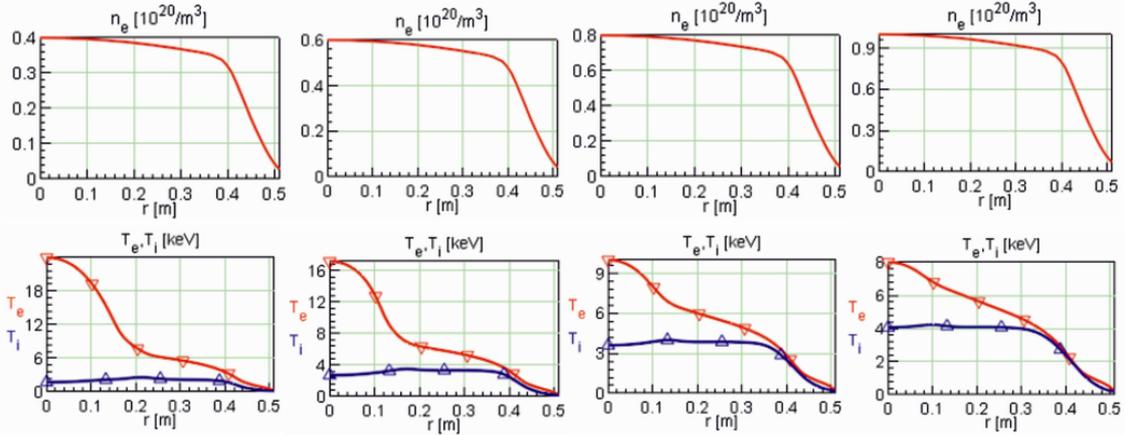
## 2 Concept and design of the PHA system

The super conducting stellarator W7-X [4, 5] will run pulses of up to 30 min duration with full heating power. Electron Cyclotron Resonance Heating (ECRH) is the main heating method for steady-state operation of the Wendelstein 7-X stellarator in the reactor relevant plasma parameters.

A heating power of about 10 MW is required to meet the envisaged plasma parameters. A wide spectrum of requirements has to be considered during design and realization of the new X-ray diagnostics.

Computer simulations of soft X-ray emission from a tokamak plasma played important role in designing of each diagnostic systems. As a tool for checking the performance of the PHA spectrometry system and optimizing filters and detectors, a special numerical code, named RayX [6] has been developed. Number of simulations have been done and the results allowed to determine the position of the particular diagnostic components.

Since ECRH auxiliary heating will be applied in W7-X, different heating scenarios, characterised by widely different electron temperature and density profiles have been taken into account. Figure 1 shows examples of electron density and temperature profiles expected to be achievable with 8 MW of ECRH power. These scenarios were used as an input data for simulations. The code allowed to investigate the influence of a geometrical configuration of the diagnostic system on the spectra intensity and shape. Radiation from the plasma with the use of different pinhole sizes, type of detectors, kind of material and thickness of filters were also calculated.



**Figure 1.** Electron density and temperature profiles for 8 MW of ECRH scenario foreseen for W7-X [7, 8] used in RayX simulations.

Simulations were performed and evaluation of the magnetic field effect on the individual elements of the system (e.g. turbomolecular pump) showed that the changeable slits must be placed at a distance of 7 m from the plasma center and detectors further 1 m behind them.

### 3 Details of the PHA system for W7-X

The soft X-ray pulse height analysis (PHA) diagnostic is routinely used to measure the electron temperature of the plasma and the content of impurities. Using the PHA system, the X-ray spectrum is obtained by the measurement of the energy carried by individual quanta (the height of a pulse measured is proportional to this energy). The intensity of radiation must be low enough to assure the condition at which the electrical signals from individual quanta do not overlap (no “pile-up” effect) either in the detector or in the electronics following the detector.

The proposed PHA diagnostic is intended to provide the spectral energy distribution with an energy resolution not worse than 200 eV along a central line of sight. The system dedicated to W-X consists of 3 energy channels with Silicon Drift Detector (SDD) manufactured by PNDetector. Their dimension is  $10 \times 10$  mm with thickness of active layer equal to  $450 \mu\text{m}$ . The nominal energy resolution given by the producer is  $132 \text{ eV}@5.9 \text{ keV}$  ( $\text{MnK}_\alpha$ ) at the operation temperature of  $-20^\circ\text{C}$ . The count rate capability is 10 kcps. As a collimator, Zr of a 3.2 mm internal diameter is used. In this type of detector Peltier cooling is applied. The detector is equipped with integrated Field-Effect Transistor (FET), which improves energy resolution.

The measurements will be taken along sightlines through the center of the plasma. In the diagnostic all detectors, operated with different filters will be installed on the horizontal port AEK50 on W7-X. Each detector has the possibility to record an X-ray spectrum in three various energy ranges by choosing one of the three Beryllium foils with different thickness (1<sup>st</sup> channel: open,  $10 \mu\text{m}$ ,  $25 \mu\text{m}$ ; 2<sup>nd</sup> channel: open,  $50 \mu\text{m}$ ,  $100 \mu\text{m}$ ; 3<sup>rd</sup> channel:  $25 \mu\text{m}$ ,  $100 \mu\text{m}$ ,  $500 \mu\text{m}$ ). This will allow to enhance the sensitivity for particular impurity species and for the investigation of suprathermal tails in the spectra.

First channel is equipped with a SD3 detector with a polymer window and aluminum light protection, to cover the energy range between 250eV and 20 keV. The second and third channel are equipped with a standard SDD detector with  $8 \mu\text{m}$  of Be window. Application of additional filter allows to record spectra in the range of 0.9–20 keV and 1.5–20 keV, respectively. All energy channels are accompanied by an individual control of pinholes size (piezo-slits) to have the possibility to increase or decrease the number of photons that reach the detectors.

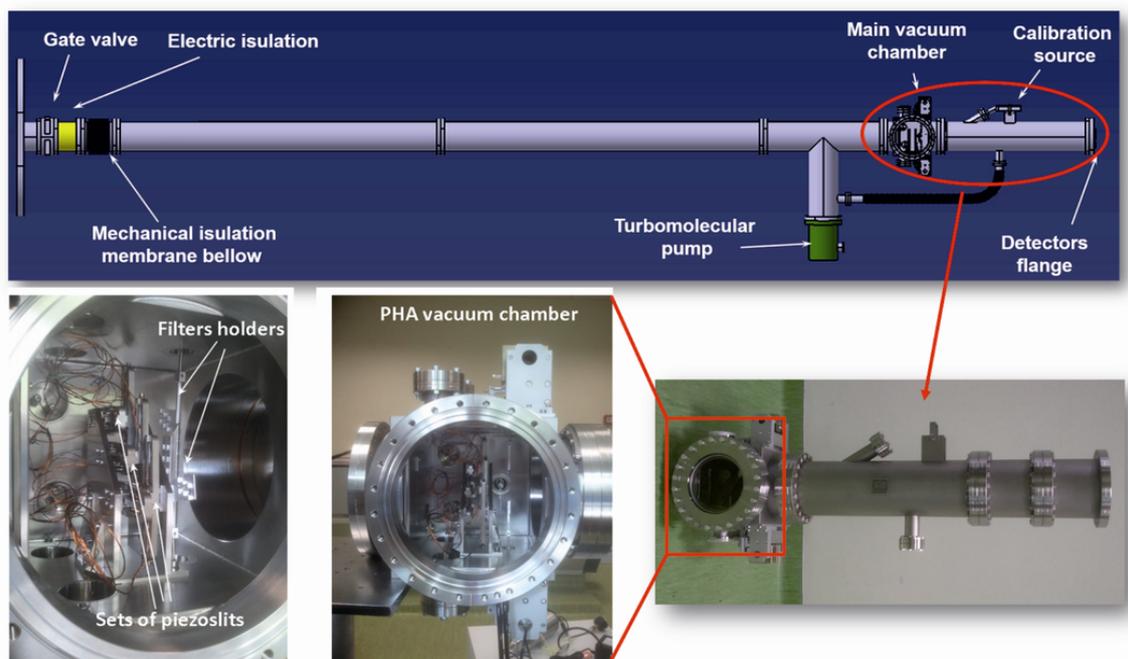
Each detectors should view equivalent plasma volumes along sightlines through the plasma center with a radial extension of up to 10 cm. Performed simulations and evaluation of the magnetic field effect on the individual elements of the system (e.g. turbomolecular pump) showed that the pinholes must be placed at a distance of about 7 m from the plasma center and detectors, 1 m behind them. Figure 2 shows the concept of the PHA system with details of the main vacuum chamber.

The detectors are mounted on a specially designed vacuum flange which provides adequate conditions for heat conduction and electric insulation (see figure 3). In order to ensure thermal contact,  $100 \mu\text{m}$  thick indium foil was used.

Each detector is equipped with an individual power supply module in order to avoid electric interaction between detection channels. Due to the high sensitivity of the preamplifier it was necessary to supply it from a non-switching power supply. It consists of classic AC transformers, rectifiers and a linear stabilizer and provides voltages to the preamplifier ( $+/- 24 \text{ V}$ ), to the Peltier cooling module (2–3 V), and to the SDD detector ( $-150 \text{ V}$ ). To prevent detectors damage, the additional protection is applied. Electronic circuit was created to immediately switch off detectors voltage in the case of losing any preamplifier voltage. Detector bias is switched on or off remotely which is realized by software.

The detectors are connected to the preamplifiers delivered by PNDetector which operate in a pulsed reset mode. The preamplifiers are connected then to the Digital Signal Analyzer (XIA, Mercury-4).

An energy calibration of the registered spectra is done by the measurements of fluorescence spectra of well know materials like Fe, Cu, Cr. In the PHA system a calibration port with mini X-ray tube from AMPTEK has been located between the main vacuum chamber and the detector

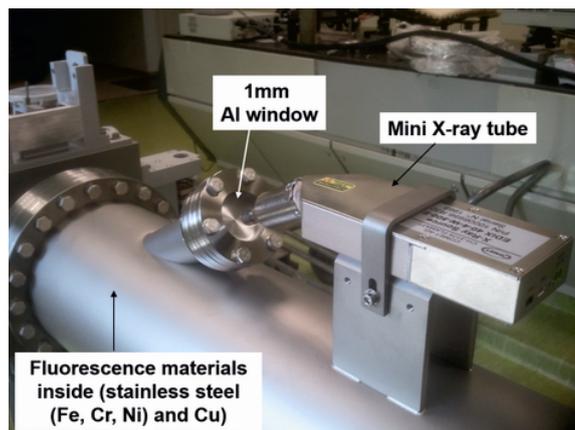


**Figure 2.** Concept of the PHA system for W7-X (top) with details of the main vacuum chamber which includes piezo-slits and filters (below).



**Figure 3.** Photo of the vacuum flange with mounted detectors.

flange. The continuum spectrum of the X-ray lamp pass through a 1mm thick of Aluminum window to induce fluorescence of Fe, Cu and Cr (stainless steel plate with addition of Cu). A photo of the PHA calibration port is presented in figure 4.

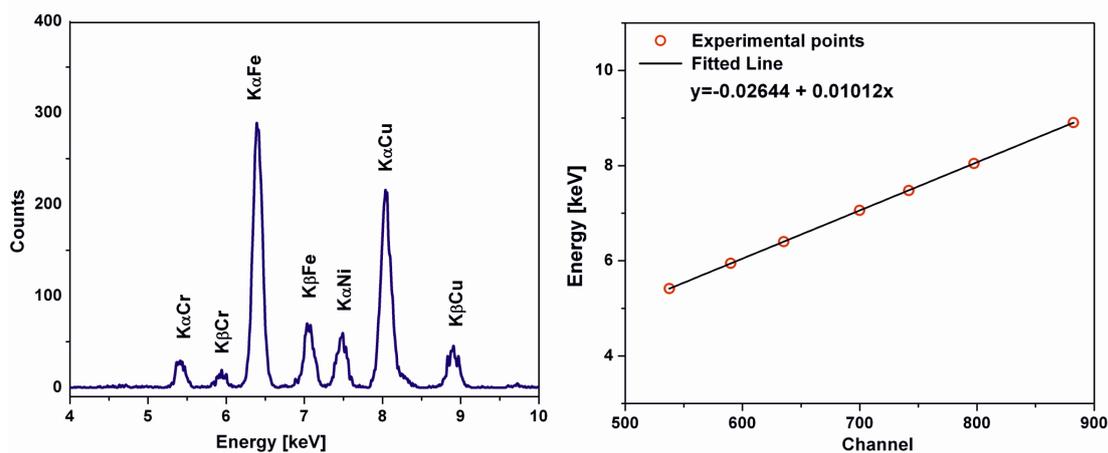


**Figure 4.** The energy calibration port of the PHA system for W7-X.

#### 4 Laboratory tests of the PHA system for W7-X

For in-situ calibration a mini X-ray tube has been integrated in the PHA system. The continuum radiation illuminates the stainless steel plate which also contains Cu, to induce a fluorescence signal, suitable for calibration over the large energy range. An example of the registered spectrum by the 1<sup>st</sup> channel (SDD with 8  $\mu\text{m}$  of Be filter) is presented in figure 5. The acquisition time was about 50 minutes. The only limitation in this case is the temperature of the mini X-ray tube which increases during the operation. Application of an additional radiator prolongs this time what has also influence on registered count number.

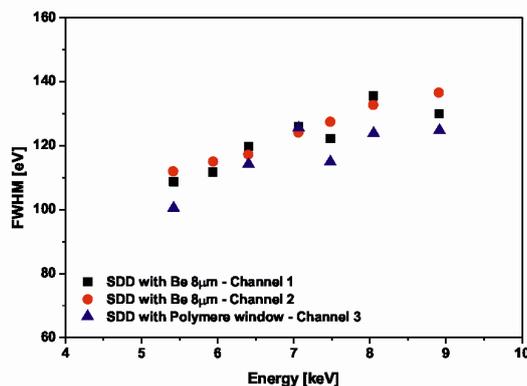
Based on 7 identified lines ( $K\alpha\text{Cr}$ ,  $K\beta\text{Cr}$ ,  $K\alpha\text{Fe}$ ,  $K\beta\text{Fe}$ ,  $K\alpha\text{Ni}$ ,  $K\alpha\text{Cu}$  and  $K\beta\text{Cu}$ ), a calibration curve has been created. It covers the energy range from 5.5 up to 9 keV and although that is a linear dependence, it is planned to introduce further elements in the future to cover much broader range.



**Figure 5.** An example of the registered spectrum by the SDD detector equipped with 8  $\mu\text{m}$  of Be filter (left) with calibration curve created based on identified lines (right).

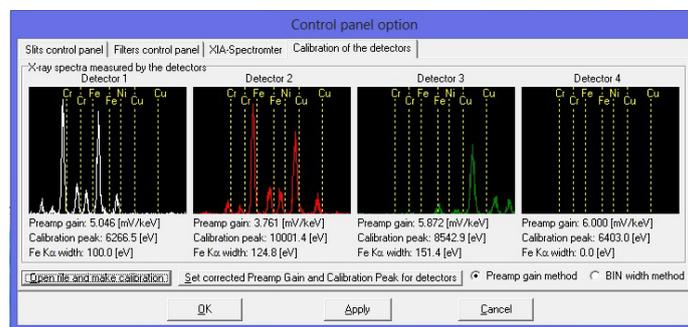
Calibration curve for each energy channel has been upload to the main acquisition software and it has been checked that the calibration is stable for a long time. This resulted in the conclusion that there is no need to perform energy calibration every day, but only at the beginning of the experimental campaign and, if needed, during longer breaks in W7-X operation.

Basing on the observed lines the energy resolution of each channel has been determined. The full width at half maximum (FWHM) in dependence of energy range is presented in figure 6. It is seen that the resolution decreases for higher energy but is on the satisfactory level of about 130 eV.



**Figure 6.** Energy resolution (FWHM) in dependence of energy range for each detector (energy channel).

All operations leading to the correct calibration of the digital signal analyser (acquisition of the spectrum and calculation of the critical values for each channel of the spectrometer: Preamp gain, Calibration peak) was made by use of the special module built-in the “PHA Control Panel”. The user interface of this module is presented in figure 7. The code provides an effective way for monitoring and management of the PHA system (checking and stabilization of the chosen filters), as well as, ensures effective regulation of the piezo-slits system (independent changing of the horizontal and vertical width of the slits and continuous stabilization of the requested values). Among others the “PHA Control Panel” code can start and stop acquisition of the X-ray spectrum, after receiving of the TTL trigger signal from the W7-X trigger system. Export of the data to the W7-X database is possible as well.



**Figure 7.** The user interface for calibration of the detectors (part of the “PHA control panel” code).

## 5 Conclusions

A number of computer simulations have been made to obtain a conceptual design of the PHA system for the Wendelstein 7-X stellarator. The system consists on 3 Silicon Drift Detectors (SDDs) covering different ranges of the spectrum, all viewing the central plasma. The diagnostics has been tested in laboratory at IPPLM, Warsaw, Poland. In order to check the system, measurements of the fluorescence spectra have been done simultaneously for each energy channel (each detector). Energy resolution of the PHA system has been measured at level of about 130 eV. According to the detectors manufacturer, the resolution should be stable up to 130 kcps (input count rate). During the operation of the W7-X to ensure a good energy resolution, piezo-slits (which allow to decrease or increase number of photons which reach the detectors) have been applied. First operation of the PHA system at W7-X is expected in OP1.1.

## Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014–2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

This scientific work was partly supported by Polish Ministry of Science and Higher Education within the framework of the scientific financial resources in the year 2014 and 2015 allocated for the realization of the international co-financed project.

## References

- [1] F. Medina, L. Rodríguez-Rodrigo, J. Encabo-Fernández, A. López-Sánchez, P. Rodríguez and C. Rueda, *X-ray diagnostic systems for the TJ-II flexible heliac*, *Rev. Sci. Instrum.* **70** (1999) 642.
- [2] B. Alper, S. Dillon, A.W. Edwards, R.D. Gill, R. Robins and D.J. Wilson, *The JET soft X-ray diagnostic systems*, *Rev. Sci. Instrum.* **68** (1997) 778.
- [3] R. Koenig, et. al., *Status of the diagnostics development for the first operation phase of the stellarator Wendelstein 7-X*, *Rev. Sci. Instrum.* **85** (2014) 11D818.
- [4] T. Klinger et al., *Towards assembly completion and preparation of experimental campaigns of Wendelstein 7-X in the perspective of a path to a stellarator fusion power plant*, *Fus. Eng. Design* **88** (2013) 461.
- [5] H.S. Bosch et al., *Technical challenges in the construction of the steady-state stellarator Wendelstein 7-X*, *Nucl. Fusion* **53** (2013) 126001.
- [6] S. Jabłonski et al., *Simulation of PHA soft X-ray spectra expected from W7-X*, to be published in *1<sup>st</sup> ECPD Special Issue in JINST*.
- [7] Y. Turkin et al., *Current Control by ECCD for W7-X*, *Fusion Sci. Technol.* **50** (2006) 387.
- [8] Y. Turkin et al., *Neoclassical transport simulations for stellarators*, *PhysPlasmas* **18** (2011) 022505.