5 JET Collaborations

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Introduction

The Polish contribution to the JET activities in 2013 concerns:

a. Participation in the JET experimental campaigns C31-C32.
b. Notification Work
c. JET projects

- Gas Electron Multiplier detector for X-ray Crystal Spectrometry (GXS)
- JW13-FT-JET (FT-4.31) Investigation of the limits of the W coatings deposited on CFC tiles for the ITER-like wall at JET using FIB and SEM/TEM techniques
- JW13-FT-JET(FT-4.36) Feasibility study for the use of JET Edge Lidar for In-situ characterisation of layers based on LIBS and LIAS
- JW12-FT-5.45 Measurements and calculations of neutron streaming through JET Torus hall ducts
- JW13-FT-JET (FT-5.48) Calculations of neutron streaming through JET Torus Hall ducts
- JW13-FT-5.53 Activation measurements at JET in DD plasma and assessment of activation reactions for DT calibration and operation
- JW11-FT-4.21 The activation measurements in support of the JET neutron camera

The main research results obtained in 2013 are summarized below.

Results

Gas Electron Multiplier detector for X-ray Crystal Spectrometry (GXS)

The KX1 X-ray diagnostic has been upgraded at JET. Two diagnostic channels were prepared for tungsten and nickel impurity monitoring. In May 2013 two mechanically modified more stable T-GEM detectors with a detection area of 206x92 mm^2 for Ni channel and 204x90 mm^2 for W one (considering He buffer frame at the spectrometer arm) were installed for KX1 diagnostics. The estimated detector efficiencies are 45% at 2.4 keV for W monitoring channel and 20% at 7.8 keV for Ni monitoring channel. Additionally, at the W diagnostic channel, an improved He buffer with much lower minimal gas flow rate was installed in order to optimize the X-ray transmission at 2.4 keV. It has been shown that KX1 resolves in on-line mode X-ray radiation originating from different diffraction orders and provides with the individual histograms for each 256 readout channels.

Preliminary results achieved with the GEM detectors related to Ni and W detection

Within the framework of participation in JET experimental campaign the measurements of spectra of radiation from highly ionized plasma impurities have been carried out. The spectra emitted by ions of Ni and W were collected by detectors GEM which are installed at the diagnostic port KX1. Data were collected for the different plasma parameters and various settings of the spectrometer. To measure the spectra within different energies a scan of the full energy range of spectrometer has been started to determine the target position of the crystal (the energy range of interest). Because of the damage of the crystal positioning system it has not been completed. The first interpretation was performed for Ni spectra identifying the Ar Rydberg lines in the spectra and for W ones excluding the lines not originating from W46+.

Validation of KX1 spectroscopic data of Ni26+ and W46+. Identification of the W ion charges and W x-ray lines. Energy and intensity calibration of the KX1 diagnostic

The Ni26+ and W 46+ spectroscopic data have been checked and verified. Statistical errors related to the uncertainty of the window thicknesses in diagnostic beam line were estimated. Sensitivity function of both diagnostic channels and for all diffraction orders were verified and corrected for the highest diffraction order of W diagnostic channel. The quality of the fitting procedure was checked for low and high statistics of Ni26+ spectra. The plasma parameters (Ni impurity level and ion temperature) were determined for different JET discharges by means of two procedure, with and without new functionality of the KX1 diagnostic system related to diffraction order resolution. In both procedures statistical errors of plasma parameters were also determined. Significant differences in the results obtained by two methods were found. In this way, the necessity of a new functionality of the KX1 high-resolution x-ray diagnostic related to the diffraction order resolution were confirmed for analysis. Ni impurity results obtained from the KX1 diagnostic were compared with ones obtained by other available diagnostics.

Optimization of the GEM detectors functionality under the high x-ray fluxes, determination of the optimal HV scheme to achieve stable energy resolution of the detectors

The aim of the task was to determine the dependence of the GEM detector response under the high photons fluxes of different energies. Within this task a new optimized power supply structure has been proposed and tested - reduced values of limiting current resistors in the high voltage divider, which has been implemented and verified during the last campaign on JET and resulted in reducing the effects of intense radiation on the parameters of the detector. However, this effect has not been completely eliminated and there still remains the relation, although weaker than before the changes were introduced, of the detector charge amplification on the intensity of the incident radiation, which needs further studies and optimization of detector parameters.

Verification, identification of real time signals from KX1 diagnostic and development of scheme detection of W and Ni impurities. Verification of measurement data from GEM detector by Matlab system

The system interface, based on MATLAB package, accomplishes control, communication, data processing and imaging results. This allows to study properties of the detector, measuring system diagnostics, optimization of working conditions and system development. The system interface, based on MATLAB package, is coupled with PC SERVER and CODAS system by FTP (File Transfer Protocol) data acquisition. Series of the procedures have been developed for optimization of the measurement condition, to improve quality of the acquired data and for the efficient presentation of the results. The charge range is matched to ADC signal range by the procedure analyzing the relation charge – ADC signal. Consequently the final histogram is resulting by automatic scaling for the given resolution. The energy scaling parameters are determined according to the reference Fe source and depend on the HV settings and meteo condition. The required energy range can be set by the HV auto-adjustment procedure. Small deviation of the actual energy range is compensated by the digital auto-scaling procedure. Linear calibration and auto scaling procedures have been developed to correct no uniformities and variation of channel gains for ^{55}Fe as a reference source. The individual channels characteristics for charge value distribution are considered for its parameters assessment and calibration. The table of calibration/scaling 256 coefficients is iteratively updated within a dedicated period of time applying long term charge DAQ data acquisition during night. The parameterized, variable time base algorithm is implemented to estimate diffraction orders of reflection. For a high intensity plasma pulse energy spectra are corrected by energy scaling in relation to the tungsten or nickel lines. Finally the position histogram for each determined energy range is calculated for the partial time slice respectively.

Algorithm development of data processing towards Ni and W spectra identification

Development of the algorithm leading to Ni and W data processing was leading to determination of the intensity, FWHM (Full Width at Half Maximum) and wavelength in maximum of the peak of the detected

radiation. Technical problem related to the usage of several carriers caused deformation of the signal at the beginning and at the end of each carrier's. As a first step of the code correction of acquired data was performed by averaging signal of the second and 15th channel for each carrier. The size of the detector (~10x20cm^2) and its position leads to the measurement in which part of the measured radiation passes the vacuum vessel only once and the rest of the radiation passes the vacuum vessel twice. It was taken into account in the data analysis via linear approximation of the vignetting curve (representing signal without characteristic radiation). The wavelength range of the measurement was defined by the crystal settings, which together with spectrometer settings were provided as an input parameters for the code. As a next step Gaussian fit of each peak was performed and from the Gaussian fit of each peak the intensity, FWHM and wavelength were obtained. The code was tested and verified during the experimental campaign.

Validation of hard x-ray and gamma ray data. Checks on calibrations and incorporation of the validated data in physics scenarios. Technical evaluations of apparatus

The γ-ray radiation derived from JET plasma was measured using 3"x3" BGO scintillator. The experimental γ-ray spectra recorded during JET discharges with different plasma scenarios have been analyzed. The most prominent lines in the spectrum were identified, among others: 9Be(α, nγ)12C (two lines of 3.210 MeV, 4.439 MeV) and 12C(d, pγ)13C (three lines of 3.089 MeV, 3.684 MeV and 3.853 MeV). Because of large background below the 2.4 MeV peaks from interactions of fast deuterium with impurities are not evident. The analysis of γ-ray spectra was made in order to determine the energy resolution of BGO scintillator. The shapes of peaks were fitted with Gaussian. It's worth noting that single escape (SE) peaks were taken into account in this analysis. The photopeak to single escape peak ratio and energy resolution as a function of photon energy were determined.

Calibration of the JET VUV spectrometers

Calibration of the JET KT2 spectrometer | Calibration of KT7/2 spectrometer

The VUV spectroscopy is one of the main tool for monitoring of impurities in high temperature plasma. In order to estimate quantitatively impurity concentration, it was necessary to calibrate two VUV SPRED spectrometers known at JET as KT2 and KT7/2 diagnostics. Sensitivity calibrations involved the use of Li-like and Na-like spectral line ratios to obtain a relative sensitivity curve. The analysis included preliminary survey of several thousand pulses and selection the most reliable experimental data. The absolute calibration was found in-situ, by using C branching ratios to crosscalibrate with an absolutely calibrated visible spectrometers, with a line of sight along the same beamline used by the SPRED instruments. In order to provide measurement of absolute intensities in visible range, system of COS (COmpact Spectrometer) spectrometers, covering whole range of visible spectrum, with line of sight close to KT7/2 spectrometer was recently installed on JET. COS was calibrated by applying in-vessel standard source. Relative calibration of the KT7/2 spectrometer shows that its sensitivity remains unchanged since last calibration. However, for the KT2 spectrometer the loss of sensitivity in short wavelength range was observed.

Two optical channels were added to KT1 VUV spectrometer to have the possibility of scanning plasma emission in the visible optical range. Al mirror was added to existing VUV Pt mirror for scanning plasma in the visible range. The mirrors make oscillating movement to scan plasma. Visible lines are separated by a Czerny-Turner spectrometer equipped with two PMTsas detectors. Calibration and test experiments were carried out in which the following parameters were measured: sensitivity of both channels vs. wavelength, line width (FWHM), gain vs. high voltage on the PMTs, dark current in both channels, and cross-talk between channels. Absolute calibration was carried out as well. The operation of the optical part of the KT1 spectrometer connected to the acquisition system of JET was checked out.

Numerical analyses of impurity seeded plasma discharges in JET with the help of the code COREDIV

The COREDIV code has been used for numerical analysis of JET ILW discharges. The self-consistent simulations of the core and the SOL plasma using the COREDIV code for JET H-mode and hybrid scenarios

with nitrogen seeding have been performed in order to understand the discrepancy in core radiation power and W content. The attempts have been made to adjust the parameters external to the code (e.g. T_e, n_e, P_{rad}, Z_{eff}, D and Be fluxes to divertor) in order to obtain agreement between calculated and experimental data. It was shown that the changes in electron density at the separatrix (n_{es}) lead to change in the core and SOL density profile but have very weak influence on Z_{eff}. With increase of the n_{es}, decrease the core radiation was observed. Moreover, increase of the radial transport in SOL leads to decrease of the W concentration and in consequence decrease of the plasma radiation. Calculations have been done for different levels of the beryllium (Be) fluxes in order to fit into measured Z_{eff} values. It appears that the low Z impurity Be determines the measured Z_{eff}, whereas the W impurity is responsible for the radiation losses in the core. Experimental W radiations and measured values of W concentration were sometimes much smaller than in simulations. Certainly plasma parameters in the SOL, like separatrix density, deuterium puff or radial transport have influence on W retention and in consequence on core parameters. In order to understand the reason for the differences between experimental and computation results, numerical studies have been performed to see which parameters have strong influence on the plasma parameters, in particular on the radiation level and its distribution. The dependence of the results of the modelling of JET discharges on the assumed transport coefficients profiles has been studied numerically as well. The transport coefficients profiles were taken from the standard Bohm-gyro Bohm model and from the standard simplified COREDIV model. The numerical results have demonstrated that the global parameters of plasma remain close to each other for the two different transport models.

JW13-FT-JET (FT-4.31) Investigation of the limits of the W coatings deposited on CFC tiles for the ITER-like wall at JET using FIB and SEM/TEM techniques

The main objective of the work was to determine the microstructural changes occurring in the materials employed to high temperature tests. A set of samples was subject to thermal fatigue to determine the degree of carbon diffusion and the conditions for carbide formation and the pore formation. Additionally, different coatings modification were tested to investigate their influence on the coatings thermal fatigue performance. The structure of coatings modification due to thermal fatigue was investigated using dual beam FIB/SEM device. High resolution microstructure observations were performed at dedicated STEM equipped with 200kV electron source. Detailed investigation of the level of carbidization inside the W coating depending on the heat treatment condition was performed. The shorter the heat fatigue pulse the thinner the formed carbide layer. Moreover, the level of nano porosity inside the W2C and WC follows that manner. The highest level of carbidization was identified in the sample after continuous annealing. The gradient coating seems not to prevent from carbide formation, but it should be noted that it was tested at higher temperature. Modified CMSII coating is characterized by much lower porosity at the CFC/Mo and Mo/W boundary in as deposited state. Subject to thermal fatigue, it exhibits much better properties compared to previous coatings. The level of porosity due to heat treatment was also much reduced which may be the curtail factor in their thermo-mechanical properties improvement.

JW13-FT-JET(FT-4.36) Feasibility study for the use of JET Edge Lidar for in-situ characterisation of layers based on LIBS and LIAS

- Sensitivity study of the Edge LIDAR systems for the LIBS application

The application of the LIBS method has been previously tested at the IPPLM for the components of the thermonuclear reactors (TEXTOR, AUG) and calibrated samples, however, its performance has not been tested in terms of its sensitivity for small amounts of deuterium isotopes in mixed material layers. The possibility of the estimation of the detection limits was checked with the use of the DIARC samples with calibrated deuterium contents. In the experiments with these samples, both with DLC and mixed material layers, the deuterium at the level close to 10^{18} D/cm^2 was easy to detect, however, it (deuterium) could persist only a few lasers shots and after that no traces were observed. In contrast to this, the signals obtained for pure bulk W had hydrogen indicators for a significantly larger number of

laser pulses. It can be possibly explained in a way that the layer has a very weak susceptibility for the hydrogen isotopes retention which prevents the gases from penetrating it and reaching the substrate. Based on the calibrated contents of deuterium in WAlC layers the limit of detection of hydrogen isotopes has been estimated at least as good as ~10^{17} D/cm^2 based on the SNR ratio for the signals obtained for the layers of deuterium concentration at the level of 10^{18} D/cm^2.

- Description of the procedure and involved equipment

The steps of the procedure have been defined. It should start from the measurements of the LIBS signals from precisely calibrated samples with deuterium contents in the range of the foreseen fuel retention. The research suggested that the power density of the laser beam in the interaction area should be in range of 10^9 up to 10^{10} W/cm^2. The temporal and spatial parameters of the observation of the spectroscopic signal have been defined. Various configurations of spectroscopic equipment for observation of the spectral range of interest have been analysed and possible solutions have been suggested. The optimal conditions for the dual-pulse LIBS approach have been also defined.

JW12-FT-5.45 Measurements and calculations of neutron streaming through JET Torus hall ducts

Thermoluminescence detectors (TLD) were used for dose measurements at JET. Several hundreds of LiF detectors of various types, standard LiF:Mg, Ti and highly sensitive LiF:Mg, Cu, P were produced. LiF detectors consisting of natural lithium are sensitive to slow neutrons, their response to neutrons being enhanced by ^{6}Li-enriched lithium or suppressed by using lithium consisting entirely of ^{7}Li. Pairs ^{6}LiF/^{7}LiF detectors allow distinguishing between neutron/non-neutron components of radiation field. For detection of neutrons of higher energy there is a need of moderators. Cylindrical moderators (25 cm diameter and 25 cm height) have been produced from polyethylene (PE-300) rods. All TLDs, located in the centre of cylindrical moderators, were installed at eleven positions in the JET hall and the hall labyrinth in July 2012, and exposure took place during the last two week of experimental campaign. Measurements of the gamma dose and of the neutron fluence were obtained for all positions over a range of about five orders of magnitude variation. The experimental results are compared with calculations using MCNP code. The results confirm that the TLD technology can be usefully applied to measurements of neutron streaming through JET Torus Hall ducts. New detector positions, further in the labyrinth and ducts, will be investigated in the next measurement campaign.

JW13-FT-JET (FT-5.48) Calculations of neutron streaming through JET Torus Hall ducts

Additional TL measurement locations have been preselected, with emphasizing on low neutron fluence positions. It was decided by all parties included that 16 locations with moderators and some without moderators will be used for TLD measurements. It was decided to perform TL background measurement in moderator during JET downtime before final decision will be made. BG measurement have been performed, readout and evaluated. LiF TL detectors of two types (MCP-N and MCP-7) have been manufactured at the IFJ in Krakow and annealed to be prepared for measurements. A new arrangement for the TL detectors inside moderators has been proposed to reduce the interference between them and the shadow effect. Reduction of numbers of detectors in the horizontal box and stable positioning of each of them in this box has been achieved by the new arrangement. Also, a new vertical box was proposed to be inserted in a vertical slot in the plug at a minimum distance above the screw to be able to investigate the effect of directional flux. Upgrade of moderators' plugs has been executed. Additional boxes for detectors have been produced. TLDs have been installed at JET. Due to interruption of JET experimental campaign dosemeters have been removed after 2 weeks of exposure at JET during which the total neutron production has been about 2.5E18 neutrons, a factor of two higher than in the previous campaign. Readout has been done using Harshaw 3500 TL reader. All detectors together with calibration detectors have been annealed in 100°C/10min. before readout, than readout in Nitrogen atmosphere (140l/h flow) with rate 2°C/s, MCP detectors in the temperature range 100-270C and MTS detectors in 100-370°C. Evaluation of obtained results is in progress.

JW13-FT-5.53 Activation measurements at JET in DD plasma and assessment of activation reactions for DT calibration and operation

The neutron activation method shall be used as a benchmark against numerical calculation (MCNP) and to cross-calibrate against other neutron diagnostics both during regular DT and TT JET operation and during 14 MeV neutron calibration. The main aim of the task was to assess the capabilities of the activation method for above-mentioned conditions. Proper 14 MeV neutron calibration is particularly crucial in preparation for neutron measurements during JET DTE2. The purpose of this work is the assessment of activation reactions to be used for DT calibration and operation at JET. A review of activation cross-sections to be used in KN2 JET diagnostic, for 14 MeV neutron calibration and DT, TT plasma operation has been performed. Elements with sufficient large threshold cross-sections leading to the radioactive nuclides have been selected. An activation set for neutron measurement during 14 MeV neutron calibration and DT operation has been proposed. To define the required intensity and irradiation time of the 14 MeV neutron calibration source, neutron spectra at KN2 irradiation end in DT calibration have been used. These spectra had been calculated using MCNP and a simplified model of JET. The MCNP calculations have been performed for the selected activation samples placed inside the 3U KN2 irradiation end and with the DT calibration source located 30 cm below. The results suggest that the activity of 1 g samples irradiated for 3 hours by 14 MeV neutron source with strength 10^8 neutrons per second should be suitable to record the activation products with acceptable low uncertainties. During JET Neutron Source Calibration (NSC) performed in April 2013 the activation measurements were done several times. The activity of irradiated indium samples has been determined by means of two HPGe gamma-spectrometers. The improved cross-calibration of the semiconductor gamma-detectors used during JET NSC has been performed. The activation coefficients obtained during NSC for particular indium samples allows after the measurement of the total neutron emission during regular plasma operation of JET tokamak. Review of the activation reactions for JET DT and TT operation and for 14 MeV neutron calibration was the initial phase of preparations for proper neutron measurements during the highest JET neutron budget experimental campaigns which are going to be performed in coming years. The activation method shall be used as a benchmark against numerical calculations and to cross-calibrate all other neutron diagnostics.

JW11-FT-4.21 The activation measurements in support of the JET neutron calibration

The goal of the task was to perform the activation measurements in order to calibrate the KN2 system for a number of reactions. The multi-element activation measurements were proposed and performed by IPPLM during JET Neutron Source Calibration (NSC) conducted in April 2013. Irradiation of two multi-foil sets has been performed during JET in-vessel NSC. The following samples have been irradiated in the first set: Au, In, Al, Fe, Ni, Mn, Au[Cd], In[Cd] and in the second set: Fe, Ti, Ni, Sc, Ta, W. The activities of induced radioactive products of nuclear reactions in In, Au, W, Mn, and Fe samples have been measured immediately after irradiation by means of modern, precalibrated HPGe gamma spectrometer equipped with LabSOCS software enable accurate determining the measuring efficiency for particular set-up geometry and photon energy. The activities of Co-58, Sc-46 and Ta-182 have been determined one month after irradiation in a low-background gamma-spectrometry laboratory using a low background HPGe gamma spectrometer. Based on measured activities, the rates of recorded nuclear reactions have been calculated. Obtained results will be used to check correctness and validate the MCNP model of JET structure.

Conclusions

As regards the Polish participation in JET experimental program in 2013, 9 secondees took part in C31-C32 JET Experimental Campaigns. The main tasks performed during campaigns and notification work were oriented on the upgrading of high-resolution X-ray crystal spectrometer (KX1) and first measurements of radiation emitted by Ni26+ and W46+ ions. A part of the JET activities was dedicated to calibration of the JET VUV spectroscopy diagnostics (KT1, KT2, KT7). Moreover, numerical analyses of plasma discharges in JET ITER-like Wall configuration were performed with the help of the COREDIV

code. The achievements of the IPPLM Association in the JET activities were also related to neutron activation measurements and calculations of neutron streaming through JET Torus hall ducts. The limits of the W coatings deposited on CFC tiles for the ITER-like wall at JET using FIB and SEM/TEM techniques were investigated. Sensitivity study of the Edge LIDAR systems for the LIBS application was performed.

Collaboration

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