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- Gas Electron Multiplier Detector for X-ray Crystal Spectrometry – GXS
- Assessment of the suitability of neutron and gamma detectors in the future experiment at JET for the validation of shutdown dose rate prediction
- The activation measurements in support of the JET neutron calibration
- Gamma Ray Cameras: Neutron Attenuators - GRC
- Assessment of efficiency of laser removal of fuel-inventory for mixed material samples using LIBS

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Introduction

Involvement of the Association IPPLM in the JET activities concerns the realization of the following tasks:

- Gas Electron Multiplier Detector for X-ray Crystal Spectrometry – GXS (JW10-NEP-POL-09, JW10-OEP-POL-06)

  ITER-oriented JET research program brings a new requirement for the high-resolution x-ray diagnostics (KX1) which is expected to monitor the impurity level of tungsten – the main component of a new JET ITER-like divertor. Therefore besides the upgrade of the Ni monitoring diagnostics, in order to implement the W impurity monitoring one has to design and construct a new diagnostic channel based on the same KX1 geometry. Both, Ni and W characteristic X-ray radiation at 7.8 and 2.4 keV, respectively will be recorded by new generation energy-resolved multipattern gas detectors with 1-D position reconstruction capability. Detectors will have three gas electron multiplier (T-GEM) foils in order to ensure the optimal electron amplification. Each detector will consist of the readout plane with 0.8 mm strip pitch (256 vertical strips in each detector). The aim of detector's signals processing is an estimation of energy distribution for 512 bins (at least) in histogram and 50 histograms (at least) per second. Two such processing units have been delivered and dedicated to the 'low-energy' (2.4 keV) and 'high-energy' (7.8 keV) x-ray detectors.

- Assessment of the suitability of neutron and gamma detectors in the future experiment at JET for the validation of shutdown dose rate prediction (JET JW9-NFT-POL-05)

  Process of choosing a proper method for radiation dose assessment needs some quantitative estimator that allows comparisons of a few spectrometric method. The Lowest Limit of Detection (LLD) as well as the Relative Minimum Detectable Activity (MDAr) both faces the above mentioned challenge. The aim of the mentioned studies is to show measurability of shut down dose by means of BrilLanCe380 scintillation probe and compare this method with measurements obtained by means of HPGe systems. Based upon the mentioned quantitative factors was shown that BrilLanCe380 probe has had better LLD and MDAr then HPGe detector. However for the qualitative analyse HPGe system is better due to the its higher resolution.

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

  The neutron diagnostics need to be calibrated very carefully, because they are essential to proper determine fusion power and estimate dose rate from activated structure materials. The

JET calibration has been included in EFDA Work Programme as a high priority diagnostic issue for ITER.

The fission chambers system (KN1) is used in JET as a permanent neutron yield monitor. It is cross-calibrated against the activation system (KN2) which enable to measure neutron yield due to the MCNP neutron transport calculations [1]. Therefore, the calculations need to be verified by the measurements carried out with the well-known calibration source.

- Gamma Ray Cameras: Neutron Attenuators – GRC (JET JW9-NEP-POL-06)

  The JET KN3 gamma-ray cameras diagnostics system has already provided valuable information on the fast ion evolution in JET plasmas. Gamma-ray diagnostics at JET (gamma-ray spectrometry [2] and imaging [3]) have provided some of the most interesting results in experiments such as those of the TTE campaign [4].

  The objectives consists in the design, construction and testing of neutrons attenuators for the vertical and horizontal cameras of the KN3 gamma-ray imaging diagnostics. This diagnostics upgrade should make possible gamma-ray imaging measurements in high power deuterium JET pulses, and eventually in deuterium-tritium discharges

- Assessment of efficiency of laser removal of fuel-inventory for mixed material samples using LIBS

  The works performed in the framework of this task were concerned on the accomplishment of EFDA-JET project JW10-FT- 3.58 which in details was aimed at:

  - Systematization of the results for calibrated samples with various material mix and fuel amounts,

  - Verification of the possibility of application data from experiments on calibrated samples for characterization of the removal process from real-machine samples,

  - Attempt to quantify LIBS indications for mixed material conditions.

Results

Gas Electron Multiplier Detector for X-ray Crystal Spectrometry

The structure of both final KX1 detectors is the following :

- Cascade of 3 GEM foils with the gap of *2* mm in each detector,
- Conversion gap of 15 mm,
- Readout plane with 0.8 mm strip pitch (256 strips in each detector),
- Induction gap width of 2.5 mm in each detector,
- 5 μm for 'low energy' detector (W monitoring) and 12 μm Mylar for 'high energy' detector window (Ni monitoring) thin Aluminium layer (~0.2 μm) on the inner surface.

Below we present the conclusions on the construction materials, mechanics, mechanical assembly and HV distribution obtained in the prototype phase of the project:

- DELRIN frames sustain well the discharges across the bulk and the current flow on the inner surface of the detector elements was not observed,
- The system of the detector assembly based on the bolts and o-rings assures the gas tightness and the stability of the detector structure,
- Assembly bolts should be made out of DELRIN in order to eliminate metallic parts having non-defined electrical potential,
- Technology developed for the GEM electrode construction assures the correct flatness of the electrode plane and good gas tightness,

- Materials used for the detector construction do not exhibit measurable out-gassing,
- Technology of the thin mylar window stretching and gluing to the dedicated frame assures good window flatness when operated under small overpressure due to the gas circulation. However, the window support system consisting of two slabs installed on the outer side of the window should be used in the final detector,
- Drift voltage connection to the thin aluminium layer of the mylar window by the mechanical contact installed in the thick drift-gap frame proved to be reliable and robust design,

The final detector electronics processing unit has 256 measurement channels. The aim of detector's signals processing is to estimate the energy distribution for 512 bins (at least) in histogram and 50 histograms (at least) per second. Two such processing units have been constructed and dedicated to the ‘low-energy’ (2.4 keV) and ‘high-energy’ (7.8 keV) x-ray detectors. Each final detector electronics consists of several blocks:

- Detector strip board with backplane,
- Amplifiers and differential cable drivers board - 16 Analogue Front End boards (AFE),
- 16 FMC digital boards,
- The carrier module with 16 FMC slots

The final construction has been prototyped using following equipment:

- one 16-channel Analogue Front End board,
- MD5 ribbon cable,
- one FMC board with miscellaneous ADCs. Both 8 and 10bit versions running at 100 and 130 MHz were installed and tested,
- Spartan 6 Devkit with FMC connector,
- ITX form factor PowerPC main board.

Fig. 6a The GEM detector Construction Team

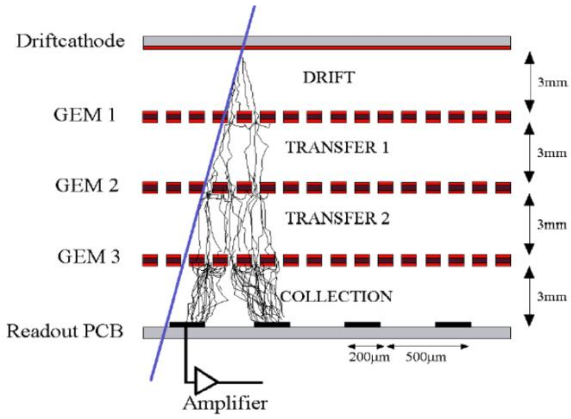

Fig. 6b Schematics of the GEM detectors

Assessment of the suitability of neutron and gamma detectors in the future experiment at JET for the validation of shutdown dose rate prediction

The two gamma spectrometry systems were used for assessment of the detection limits. The main system has been equipped with BrilLanCe380 scintillation probe and Tukan 8k MCA. The HPGe spectrometry system with I2k MCA was used for cross calibration of the previous system as well as for parallel measurements. The 51 mm diameter and 3 mm thick inconel cylindrical sample has been activated with an Am-Be neutron source of strength equal to1.5 10^7 n/s. Due to the differences in half life times of the activated radionuclides a special time sequence of the measurements has been implemented. After a few hours (2-100 h) of the inconel sample activation inside the Am-Be neutron source and tree different cooling time (1 hour, 5 days and 3 weeks) the sample has been measured with both systems. The activity of the particular nuclide was determined by the HPGe system and after that the BrilLanCe380 was cross calibrated. This allows to estimate the AFEPE (absolute full energy efficiency) for the BrilLanCe380 probe.

For all detected radionuclides the total peak area, net peak are, detection resolution, detection efficiency, activity, MDAr as well as LLD were read out from the system report files.

The activation measurements in support of the JET neutron calibration

The multi-element activation measurements will be performed during JET neutron calibration. The measurements will be carried out by means of the KN2 system utilizing purpose-prepared activation samples enable to record a number of nuclear reactions induced by the neutrons coming from calibration source. Modern, pre-calibrated HPGe gamma-spectrometer belongs to IPPLM will be used to estimate activity of irradiated samples. The experimental data collected in such way allow determination of the activation coefficients for recorded reactions. The coefficients will be then compared with the MCNP results. It allows verification of the MCNP model of inner torus and calibration of the KN2 enable to improve the accuracy of neutron calculations and measurements at JET. Calibrated KN2 system can be used to cross-calibrate the KN1 (neutron monitor), KN3 (neutron camera), etc.

Similar neutronics issues relevant to licensing process need to be performed on ITER as well. The experiences acquired during JET neutron calibration will be useful for preparing such action on ITER.

Gamma Ray Cameras: Neutron Attenuators

The experiments were performed using the prototype version of the KN3-VC-NA (Short) attenuator. The main goal of the experiments consisted in determining the attenuation factor. The experiments were performed taking into the assumption that the neutron source can be approximated with a point source: the source was estimated by IPPLM staff to have a cylinder shape (2 cm diameter, 5 cm length) and the direction from the point source is perpendicular to the detectors.

Preliminary experiments were dedicated to the characterization of neutron field specific to the PF-1000 device. During extensive experiments neutron spectra were recorded, using the detectors with different energy thresholds (BDS bubble detector spectrometer).

The experimental results revealed that even without the attenuator, the energy distribution has a strong component in the low energy range ($E < 0.1$ MeV). It was assessed that the main reason for this component are the surrounding structures. The low-energy neutron field would have a strong influence on measurements concerning the attenuation factor. Therefore further experiments were performed in order to find an optimum experimental setup and to determine the transfer function of the attenuator. A new measuring location, placed also on the axis of neutron emission was used. The location was chosen in order to minimize the influence of the neutron scattering surrounding structures. Additionally the detectors were placed inside a paraffin collimator in order to ensure additional shielding.

In order to test this configuration neutron spectra were recorded. It is worth to be mentioned that for these experiments new spectrometric detectors (BDS), with increased efficiency and energy threshold above 1 MeV were purchased and used.

Assessment of efficiency of laser removal of fuel-inventory for mixed material samples using LIBS

In order to accomplish the aims of this task, experiments with laser removal of various layers of ITER relevant material mixes (C, W and Al used as Be proxy) contaminated with hydrogen and/or deuterium were performed. As the diagnostics for the layer removal Laser Induced Breakdown Spectroscopy (LIBS) has been used. The results obtained in these experiments were compared with previous results obtained for samples from in vessel components of operating tokamaks – TEXTOR (limiter) and Asdex Upgrade (divertor).

The experiments allowed to confirm that the LIBS technique can be used for monitoring of the laser fuel-removal process from in vessel tokamak components. The detection limit which was estimated in the framework of the task assures that when the deuterium/hydrogen signal drops to immeasurable level, the whole co-deposited layer is removed and the surface of the component is reached.

The quantification of the results is still a big challenge, but the main problems are connected with difficulties of getting calibrated samples with a broad range of deuterium/hydrogen contents for the experiments.

Conclusions

JW10-NEP-POL-09, JW10-OEP-POL-06: For both, low- at 2.4 keV (W^{46+}) and high-energy at 7.8 keV photon energy (Ni^{26+}) KX1 diagnostic channels two T-GEM detectors with 206x92 mm^2 detection area and 256 strip channels each have been proposed. Two materials are considered as final detector windows, namely Mylar 5 µm + Al 0.2 µm (M5Al) and Mylar 12 µm + Al 0.2 µm (M12Al). The final detector windows should be supported by two slabs (0.8 mm in diameter) installed on the outer side of the window. As a working gas the $ArCO_2$ (70:30) gas mixture with 15 mm thickness of gas-mixture layer has been chosen. The expected detector efficiencies are 45% at 2.4 keV (W monitoring channel) and 20% at 7.8 keV (Ni monitoring channel), respectively.

Both detection systems of the KX1 diagnostics will be integrated with the Composite Time and Trigger Signal (CTTS) systems which distribute timing information and event related triggers throughout JET's Control and Data Acquisition Systems. The CTTS network should provide 1MHz clock, Start of JET Pulse Signal, End of JET Pulse Signal, Pulse in Progress Signal and others in the RS485 output standard directly to the main FPGA board. The JET datanet system will be responsible for sending (stream of data) Pre-start Module Initialization Signal and Pulse Abort Signal to the CODAS PC that can forward the signal to the main FPGA board.

For assessment of the detector gain and energy resolution fluctuations we propose to install a ^{55}Fe X-ray calibration source with 3.7 MBq activity, which emits predominantly Mn-K X-ray at 5.9 keV. The source should be installed on the rotational holder inside the vacuum pipe connecting the crystal chamber and the KX1 ending port in distance of about 2 m from surfaces of T-GEM detectors. This set-up will ensure the possibility a calibration between the following JET discharges with about 20'000 photon counts statistics.

In order to improve the total KX1 beam line sensitivity, especially for 'low energy' channel, the old 125 mm Mylar foil in the ending pipe window must be replaced by the extremely thin 12 µm Mylar foil with a support flange. This construction will slightly reduce the sensitivity for high energy channel but significantly (more than three orders of magnitude) improve the sensitivity for tungsten monitoring channel.

JET JW9-NFT-POL-05:

- MDAr for BrilLanCe380 is higher than respective values for HPGe detector due to the higher efficiency of the scintillation probe.
- LLD is smaller for for BrilLanCe380 probe. This means that it can distinguish lower concentrations of radionuclides but there will be some difficulty in identifying them because of the lower resolution of the probe in comparison to the HPGe detector resolution.
- The BrilLanCe380 probe is suitable for measurement of a shutdown dose provided that the level of the activity induced in the vacuum vessel walls is greater than 0.1 Bq.
- The measurement of the shutdown dose should be made with the probe held directly on the device wall surface because this increases the AFEPE.

The measurements should be performed three times: a few hours, a few days and a few weeks after shut down respectively.

JW11-FT-4.21: The activation materials have been selected for preparation of the calibration measurements and the activation samples have been made. The following materials have been selected for neutron activation measurements during JET calibration by means of Cf-252 source: In, Au, Mn, W, Ta, Sc, Fe, Ni, Al. The activation samples consisting of above mentioned materials have been prepared in KN2-standard size (18 mm in diameter)**.**

As a part of the preparation procedure, the testing irradiations on PF-1000 with neutron fluence similar to calibration conditions have been performed. According to the MCNP simulations the neutron energy spectrum from PF-1000 device have been shaped by moderating medium in order to be similar to the spectrum expected in JET 3U irradiation end during calibration by means of Cf-252 source. Prepared activation samples have been irradiated in the neutron field shaped in such way. The neutron fluence, however, was about 6 times less than expected during 3-hours irradiation by means of Cf-252 source in 30 cm-distance from 3U irradiation end. Besides of that, most of expected radiative capture reactions have been recorded, unlike threshold reactions, which mostly have not been recorded due to difference in fast neutrons spectrum coming from d-d reaction and Cf-252 source.

JET JW9-NEP-POL-06: The attenuation factor was determined by recording the detector response, with and without attenuator, in the energy range above 1 MeV. The detectors were exposed to multiple shots in order to ensure a good statistic. The total neutron production was 0.81 x 10^{12} for the measurements without attenuator and 1.03 x 10^{12} for the measurements with attenuator respectively. The detector responses were scaled in respect with the neutron production characteristic during their exposure and also according to their sensitivity. The detector response function was used for detector response deconvolution.

Collaboration

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