International Conference on DiagnosticsFor Fusion Reactors (ICFRD2020)

Monday, 6 September 2021 - Friday, 10 September 2021

Varenna, Villa Monastero

Book of Abstracts

With the contribution of:

Contents

2

Oral_23: The Progress of ITER Divertor Langmuir Probe design

Authors: Lin Nie[1]; Li Zhao[1]; Yali Wang[1]; Yuzhong Jin[1]; Hongxia Zhou[1]; Linfeng Wei[1]; Jiahui Sun[1]; Guangwu Zhong[1]

Co-author: Wei Zhao [1]

[1] *Southwestern Institute of Physics*

Corresponding Author: nielin@swip.ac.cn

Divertor Langmuir probe (DLP) system is one of ITER diagnosis used to measure the divertor parameter profiles such as ion saturation current, electron temperature, density, for ITER advanced control and physics research. The system consists of three components: 1) 400 Langmuir probes installed on the side of monoblock in 5 cassettes. DLPs should sustain 10MW/m2 Steady-state heat load and 20MW/m2 transient-state heat load. With the thermo-mechanical analysis, the structure design of DLP has gone through 3 main versions, and now the full tunsten design has been reviewed and accepted. The preliminary machining and welding process researches are on going. 2) the electronics system, including powersupplies, mode switching and signal conditioning components, will be used for 3 kinds of probe operational mode: Single probe voltage scanning mode, double probe voltage scanning mode and ion saturation current mode. 3) Instrumentation and control system is used to provide scan waveform output for power supply and measured data to CODAC for calculation of Te, ne and ion flux. The work of DLP system is in the preliminary design stage, and we will start our preliminary design review in a year.

3

Oral_18: Compact diagnostic systems for X-rays, gammas, and neutrons: a "swiss-knife" detectors portfolio ranging between magnetic confinement fusion, thermal and fast neutrons detection, and laser produced plasmas experiments

Author: Francesco Cordella[1]

[1] *ENEA Frascati*

Corresponding Author: francesco.cordella@enea.it

Between the various compact diagnostics systems, the hybrid CMOS-based and gas electron multiplier (GEM) detectors of multiple sizes, types, and combinations can offer a real "swiss-knife" solution for the experimental investigation of ionizing radiation. They were used, for many years, by the LabNIXT group of ENEA Frascati on many experimental setups (FTU, KSTAR, EAST, VEGA, GEKKO, etc.). In particular, the hybrid detectors based on silicon or other semiconductors are realized with a single or multiple chips bump-bonded with a semiconductor layer. Interaction of ionizing radiation in this configuration produces some characteristic tracks inside the detector. The produced charge is collected and recorded as a cluster of pixels. For each cluster, a variety of physical and morphological parameters can be defined. These detectors can be used, with different settings, to discriminate alpha, beta, gammas, hard-X, and neutrons. The hybrid detectors can be coated with one (or more) layers of converter material to observe thermal neutrons. Moreover, by combining chemical-vapor-deposited diamond and the hybrid detectors' ASIC, a fast neutron measurement is also possible in harsh environments. The triple GEM detector is an outstanding candidate for detecting plasma volumes emitting X-ray photons in the 2-30 keV energy range, thanks to its high dynamic range, sensitivity, high rate, energy resolution, and noise-free detection. The GEM camera system is a micropattern proportional gas detector that consists of an ionization gap. X-ray photon conversion occurs, three consecutive foils that act as an amplification stage, and finally, a dedicated printed circuit board that can be easily mounted outside the port of a fusion machine. A hybrid GEM detector that couples the GEM versatility and the hybrid detectors compactness (GEMPix) can be proficiently used in all the experimental situations where higher spatial resolution is required, keeping the intrinsic gain. GEMpix has been positively tested also for 2-D imaging of laser-produced plasma in VEGA (Spain) and Gekko XII (Japan) Laser Facilities

4

Oral_3_ITER_DIA: Development of the NPA based diagnostic complex in ITER

Authors: Valery Afanasyev[1]; Fedor Chernyshev[1]; Stanislav Kozlovsky[2]; Andrey Melnik[1]; Gennady Marinin[3]; Maxim Mironov[1]; Andrey Navolotsky[1]; Vladislav Nesenevich[1]; Mikhail Petrov[1]; Sergei Petrov[1]; Anton Yatsenko[4]; Alexander Shevelev[1]; Igor Chugunov[1]; Margarita Iliasova[1]; Evgeniy Khilkevitch[1]; Dmitri Doinikov[1]; Dmitry Gin[5]; Kirill Artemev[6]; Vitaly Krasilnikov[7]; Timofey Kormilitsyn[7]; Andrei Kovalev[6]

[1] *Ioffe Institute*

[2] *Peter the Great St. Petersburg Polytechnic University*

[3] *RUSSIAN TECHNOLOGIES Ltd.*

[4] *Ioffe Institute / RUSSIAN TECHNOLOGIES Ltd.*

[5] *Ioffe Institute / ITER Organization*

[6] *Institution "Project Center ITER"*

[7] *ITER Organization*

Corresponding Author: shevelev@cycla.ioffe.ru

Deuterium-tritium fuel isotope composition monitoring is essential for effective plasma burning in a tokamak-reactor. This is the primary task for the Neutral Particle Diagnostic Complex, which is now being developed for the ITER tokamak. The complex comprises several diagnostics led by two Neutral Particle Analyzers (NPA) - HENPA and LENPA. The HENPA, High Energy NPA, provides registration of fast deuterium and tritium atoms with energies from 0.1 to 2.2 MeV, while the LENPA, Low Energy NPA, operates in the thermal energy range from 10 to 200 keV.
Fast deuterium and tritium ions in the MeV energy range can emerge in fusion plasma as a result of close collisions between fuel ions and fusion-born alpha-particles (knock-on effect). The fast ion population belongs to the hot plasma region, and this fact makes possible NPA measurements of the fuel isotope composition in the plasma core. Besides, the shape of neutralized knock-on ion spectra provides information on the alpha-particle confinement properties. Another application of the HENPA is related to studying the fast ion dynamics in the ITER plasma. An example here is the sawtooth oscillations, which lead to redistribution of fast ions not only along the plasma radius but also in the phase space.
The LENPA provides information on the edge isotope composition and ion temperature and can be used in studies of the evolution of near boundary plasma during various phenomena, like for instance, penetration of fuel pellets.
The ITER NPA system is accompanied by three other diagnostic instruments - the Diamond Neutral Particle Spectrometer (DNPS), the Gamma-Ray Spectrometer (GRS), and the Neutron Spectrometer. These tools supplement the NPA measurements, at the same time providing some unique capabilities. The GRS can assess the alpha-particle density profile as well as monitor the runaway electrons, which is of high priority for machine protection. The DNPS will measure charge-exchange atom fluxes with high temporal and energy resolution (but without mass-discrimination) for plasma instabilities studies, and also will provide data for NPA cross-calibration. Besides, it can be effectively used as a DT neutron spectrometer in high-power discharges.
In the present report, the physical basis of the NPA based diagnostic complex and its measurement capabilities for the ITER plasma is considered. The design of the complex and the engineering solutions implemented to meet the requirements of the ITER tokamak-reactor are described.

5

Oral_22: Soft-X rays and neutron diagnostics in magnetic confinement and inertial fusion: the SIDE-ON GEM detector and DIAMONDPIX

Author: Gerardo Claps[1]

[1] *LNF*

Corresponding Author: gerardo.claps@lnf.infn.it

In the last years, our group developed new compact detectors not only for soft-X rays diagnostic, but also for gamma photons, charged particles, and neutrons. In the first case, 10×10 cm2 Gas Electron Multiplier (GEM) detectors have been developed and installed on Tokamaks like KSTAR (South Korea) and EAST (China). Recently, these detectors have been equipped with new readout electronics based on GEMINI chips which allow a simultaneous measure of time, charge, and position for each interacting photon. In addition, data transfer is managed through an optical link that can sustain X-rays fluxes until 500 MHz. In the second case, our work concerned solid-state detectors based on the Timepix chip. They are 2D C-MOS hybrid detectors with a 14×14 mm2 area and 256×256 pixels, each pixel having an area of 55×55 µm2. The active material is a few hundred-micron semiconductor layers, typically Si or CdTe. It has also been used for thermal neutron using appropriate converting layers based on B4C or LiF. Two new detectors will be presented and their related applications in magnetic confinement (e.g., DTT, ITER, DEMO) and inertial fusion experiments. The first is a Side-on GEM detector. It has a 10×10 cm2 active area but is equipped with a pad layout of 4 lines of 64 strip pads, each one having an area of 1.5 × 20 mm2. This GEM detector has a 1 cm drift region with two lateral windows, as well as the head-on Mylar window like the previous GEM detectors. With this configuration, this new GEM can work in head-on mode to realize 1D plasma profiles on Tokamaks and in Side-on mode for soft-X rays diagnostic on laser-plasma experiments to realize a spectral reconstruction of X-rays emission. The second novelty is represented by the "Diamondpix". The first prototype was realized through a coupling of a Timepix3 chip with a 10×10 mm2 polycrystalline diamond and used successfully for 2.5 and 14.0 MeV neutrons, the typically observed energies on Tokamaks reactors. In addition, the high time resolution (until 1.6 ns) allows Time-of-Flight (ToF) measurements, which can be used effectively for inertial fusion plasmas. In this case, it has been realized with a 10×10 mm2 single crystal diamond having a thickness of 500 µm. For the coupling to the Timepix3 chip, the innovative technique of Anisotropic Conductive Film (ACF) has been applied after the metallization of the diamond plate on both sides. In the present work, the layout and the first quality tests of this new diamond detector will be presented.

6

Short_Oral_6_REIS: Determination of Runaway Electron Distribution Parameters from Synchrotron Radiation Measurements

Authors: Giorgio Ghillardi[1]; Concetta Barcellona[2]; Chiara Monti[1]; Basilio Esposito[1]

[1] *ENEA*

[2] *UNICT*

Corresponding Author: chiara.monti@enea.it

Runaway electrons (RE) in a tokamak can deposit a significant quantity of energy onto the plasma facing components and therefore represent a threat to ITER. This paper presents the Runaway Electron Imaging Spectroscopy (REIS) diagnostic, designed to collect spectra and images produced by the RE synchrotron radiation emission. The system is composed by spectrometers covering the range from 0.4 μm up to 5 μm and a fast CCD camera. We show how the RE energy, pitch angle, radial density profile and total number can be inferred through the comparison of REIS experimental images and spectra with simulations. Results of the application of this method to the study of the RE dynamics in FTU discharges as well as prospects for ITER will be discussed.

7

Oral_1_ITER DIA: Design of the ITER Radial Neutron Camera (RNC)

Authors: Basilio Esposito[1]; Daniele Marocco[None]; Giada Gandolfo[1]; Francesco Belli[1]

[1] *ENEA*

Corresponding Author: basilio.esposito@enea.it

The paper presents an overview of the design status of the ITER Radial Neutron Camera. The main role of this system is to provide, through reconstruction techniques applied to the line-integrated neutron fluxes, the time resolved measurement of the neutron and α-source profile (i.e. Neutron Emissivity, neutrons emitted per unit time and volume) in ITER. The RNC is composed of two subsystems – In-Port-Plug (IPP) and Ex-Port-Plug (EPP) respectively dedicated to probe the outer and inner plasma cross section regions. The Preliminary Design Review of the IPP subsystem has been recently carried out successfully, which brings this subsystem to a more advanced design stage. We will focus on the description of the diagnostic and its interfaces, the performance analysis and the R&D and tests on candidate neutron detectors.

9

Short_Oral_9: Neutron diagnostic system at the Globus-M2 tokamak

Authors: Margarita Iliasova[1]; Alexander Shevelev[2]; Evgeniy Khilkevitch[1]; Nikolai Bakharev[1]; Dmitri Doinikov[1]; Dmitry Gin[3]; Vasily Gusev[1]; Vladimir Kornev[1]; Vladimir Minaev[1]; Victor Naidenov[1]; Alexander Novokhatskii[1]; Yury Petrov[1]; Igor Polunovsky[1]; Nikolay Sakharov[1]; Petr Shchegolev[1]; Olga Skrekel[1]; Anna Telnova[1]; Vladimir Varfolomeev[1]

[1] *Ioffe Institute*

[2] *Ioffe Institute, Saint Petersburg, Russia*

[3] *Ioffe Institute / ITER Organization*

Corresponding Author: margaritavadimovna@gmail.com

The spherical tokamak Globus-M was upgraded in 2018. The upgraded facility was renamed to Globus-M2 [1]. The upgrade was aimed to get the experimental conditions closer to the compact spherical tokamak-based fusion neutron source, used as a driver in a hybrid fusion-fission reactor [2]. Due to the modernization the following parameters have already been achieved: Ip = 0.4 MA, BT = 0.8 T for deuterium plasma [3]. Moreover, the second injector of a neutral beam was put into operation during the upgrade. Thus, tangential co-injection of two neutral beams can be carried out on the Globus-M2 tokamak with maximal atomic energy up to 30 keV and 50 keV, respectively, and with the total input power up to 2 MW [4].
A neutron spectrometry diagnostic system was developed at the Ioffe Institute as part of an upgrade to optimize NBI heating conditions and evaluate heating efficiency. The system contains two compact neutron spectrometers based on the liquid organic scintillator BC501-A and two gas-discharge counters based on a 10B isotope. The BC501-A spectrometers were calibrated by measuring neutron emission produced in a 9Be(α,n)12C nuclear reaction on the cyclotron facility at the Ioffe Institute. The neutron-gamma coincidence method was applied in these measurements. Response functions of the BC-501A spectrometers to monoenergetic neutron radiation were obtained and registration efficiency as a function of neutron energy was estimated. In addition, in situ calibration of the system, including the neutron spectrometers and the gas-discharge counters, was carried out using Am-Be neutron source to provide accurate measurements of the total neutron yield from the plasma of the Globus-M2 tokamak.
During the plasma experiments at the Globus-M2 tokamak, a deuterium beam was injected in the deuterium plasma that causes a yield of the DD-neutrons with ~2.45 MeV energy. The neutron spectrometry diagnostic system was used to provide neutron measurements and detect the DD-neutrons in these experiments. The neutron yield during plasma discharges was evaluated, the estimation of the DD-reaction rate and neutron confinement time were obtained, and energy distributions of neutrons in plasma during discharge were reconstructed from the measured neutron spectra.
The work was performed on the Unique Scientific Facility "Spherical tokamak Globus-M", which is incorporated in the Federal Joint Research Center "Material science and characterization in advanced technology", and was supported by the Russian Science Foundation grant № 21-72-20007.
[1] Minaev, VB et al, « Spherical tokamak Globus-M2: design, integration, construction», Nucl. Fusion 57 (2017) #066047
[2] Bakharev,NN et al, «First Globus-M2 Results», 2020, Plasma Phys. Rep., v.46, 7, pp. 675-682
[3] Yu.V. Petrov et al, Overview of Globus-M2 spherical tokamak results at the enhanced values of magnetic field and plasma current. 28th IAEA Fusion Energy Conference (FEC 2020),10–15 May 2021, EX-OV/4, virtual event
[4] Minaev, VB et al, «Progress in the experiment on the neutral beam injection on the spherical tokamak Globus-M2», 46TH EUROPEAN PHYSICAL SOCIETY CONFERENCE ON PLASMA PHYSICS, EPS 2019, 2019, P4.1084/

10

Short_Oral_10: Advances in the DTT poloidal interferometer/polarimeter design

Author: D. Fiorucci[1]

Co-authors: A. Fassina [2]; F. Filippi [3]; C. Mazzotta [4]; G. Rocchi [4]; R. Rossi [5]; David Terranova [2]; O. Tudisco [4]; P. Andreoli [4]; M. Cipriani [4]; F. Consoli [4]; P. Gaudio [5]; M. Gelfusa [5]; L. Giudicotti [6]; P. Innocente [2]; G. Mauro [7]; D. Mascali [7]; E. Naselli [7]; F.P. Orsitto [4]; G. Torrisi [7]

[1] *Consorzio RFX-CNR*

[2] *CNR, Corso stati uniti 4, 35127 Padova, Italia*

[3] *ENEA. Centro Ricerche Casaccia, 00123, Roma, Italia*

[4] *ENEA. Centro Ricerche Frascati, 00044, Roma, Italia*

[5] *Università Roma Tor Vergata, Via Cracovia, 50, 00133 Roma, Italia*

[6] *Università degli studi di Padova, dipartimento di fisica e Astronomia, Via Marzolo 8, 35131 Padova, Italia*

[7] *INFN Sezione di Catania. Via Santa Sofia,64 - 95123 Catania, Italia*

Corresponding Author: fiorucci@igi.cnr.it

A multi-channels poloidal interferometer/polarimeter is under development for the Divertor Tokamak Test (DTT) facility, a new tokamak device whose construction is starting in Italy [1]. The aim of the diagnostics is the simultaneous measurement of the line integrated electron density, Faraday rotation and Cotton Mouton effect. The measurement of two polarimetric signals together with the interferometric one would allow for a robust electron density estimate, for the internal magnetic field measurement as well as for the magnetic equilibrium reconstruction.
In this work, we present the advances in the diagnostics design whose characteristics are constrained by both scientific requirements as well as the DTT structural aspects. In this regards, we have analyzed the possibility of accommodating up to 16 lines of sight in the available space and the contribution of different chords positions in the magnetic equilibrium reconstruction.
In particular, we have used the VMEC and V3FIT codes to evaluate the expected interferometric/polarimetric signals and their contribution in the reconstruction of the q profile. These results were used to optimize the chords positions. Eventually, we present a realistic CAD-driven design of the diagnostics, with details of the most critical components (e.g. the corner cube retroreflectors in the high field side), which would allow for the selected chords configurations implementation.

References

[1] R. Martone, R Albanese, F. Crisanti, P. Martin and A. Pizzuto, DTT-Divertor Tokamak Test Facility, Interim Design Report (ENEA, 2019),
https://www.dtt-project.enea.it/downloads/DTT_IDR_2019_WEB.pdf

11

Short_Oral_11: Preliminary design of a LIDAR Thomson scattering diagnostic for DTT

Authors: Leonardo Giudicotti[1]; Roberto Pasqualotto[2]; francesco paolo orsitto[3]; Alessandro Fassina[2]

[1] *Padova University Departmento of Physics and Astronomy*

[2] *Consorzio RFX*

[3] *CREATE Consortium and ENEA Department FSN Frascati Italy*

Corresponding Author: leonardo.giudicotti@unipd.it

A LIDAR Thomson scattering diagnostic is under development for the measurement of the spatial profiles of electron temperature Te and density ne of the core plasma in the DTT experiment [1]. After the first implementation in JET, a LIDAR TS diagnostic has never been replicated because its capabilities in terms of spatial resolution and repetition rate were soon surpassed by the conventional (non LIDAR) TS technique. In present days however, tanks to the improvements in laser and detectors technology, the performances of LIDAR TS may be made comparable to those of a conventional multipoint imaging TS system. In an experiment of the size of DTT, the LIDAR approach has some important advantages over a conventional TS system, in term of reduced impact on the machine structure, complexity of the apparatus, and possibly cost. In this paper we present the general layout of the diagnostic under design for DTT and a preliminary analysis of the expected performances.

[1] R. Martone, R. Albanese, F. Crisanti, A. Pizzuto, P. Martin Eds., "DTT Divertor Tokamak Test facility Interim Design Report", ENEA (ISBN 978-88-8286-378-4), April 2019 ("Green Book")
https://www.dtt-dms.enea.it/share/s/avvglhVQT2aSkSgV9vuEtw.

12

Short_Oral_12: Bayesian inference applied to electron temperature data: computational performances and diagnostics integration.

Authors: Domenico Abate[1]; Alessandro Fassina[2]; Paolo Franz[3]

[1] *Consorzio RFX*

[2] *ISTP-CNR*

[3] *Consorzio RFX-CNR*

Corresponding Author: fassina_alessandro@libero.it

Bayesian inference proves to be a robust tool for the fitting of parametric models on experimental datasets. In the case of electron kinetics, it can help the identification of non-thermal components in electron population and their relation with plasma parameters and dynamics.
We present here a tool for electron distribution reconstruction based on MCMC (Monte Carlo Markov Chain) based Bayesian inference on Thomson Scattering data, discussing the computational performances of different algorithms and information metrics. Along, a possible integration between Soft X-ray spectroscopy and Thomson Scattering is presented, focusing on the parametric optimization of diagnostics spectral channels in different plasma regimes.

13

Short_Oral_13: Final design of the Fiber-Optic Current Sensor bundle in the ITER buildings

Authors: Alessandro Danisi[1]; Jose Luis Barbero Soto[2]; Andres Gomez[3]; David Gray[3]; Iraitz Zubiaga[3]; George Vayakis[1]; Michael Walsh[1]

[1] *ITER Organization*

[2] *Arkadia Technology, Aix-En-Provence, France*

[3] *Added Value Solutions (AVS), Elgoibar, Spain*

Corresponding Author: alessandro.danisi@iter.org

The Fiber-Optic Current Sensor (FOCS) will be used in ITER to measure the total plasma current using Faraday effect. Sensing spun fibers will be placed around the Vacuum Vessel (VV) on a poloidal loop in two different VV sectors. To link the loop fibers with the reading instruments, placed several tens of meters away in electrical cabinets, a fiber bundle link is needed. This fiber bundle would start from the Tokamak Building port-cell, cross several rooms and end in the ITER Diagnostics building. The design of such bundle needs to fulfil the unique requirements of ITER buildings, some of them related to safety, such as non-propagation of smoke and fire, as well as maximum allowable leak rate, between two separate rooms. To this regard, the FOCS fiber bundle is classified as a Safety-Relevant (SR) component. To fulfil these requirements, and at the same time achieve a good design using as many Commercial Off The Shelf (COTS) components as possible, the fiber bundle design entailed a complete qualification procedure, aimed at benchmarking the use of the selected components against the required constraints. This paper presents the final design and qualification of the FOCS fiber bundle, from the applicable requirements to the final technical solution, benchmarked through careful qualification tests. Being the first work addressing qualification of Safety-Relevant fiber bundles in ITER buildings, this work is also considered to be relevant for current and future diagnostics in ITER using similar components.

14

Short_Oral_14: Guidelines for optimal design of Radio-Frequency in-vacuum coaxial transmission line for mirror cleaning service in ITER diagnostics

Authors: Alessandro Danisi[1]; George Vayakis[1]; Michael Walsh[1]

[1] *ITER Organization*

Corresponding Author: alessandro.danisi@iter.org

Several optical diagnostics in the ITER fusion reactor make use of big mirrors which are placed within the ITER vacuum vessel (VV), and therefore cannot have high accessibility. Deposition of dust on these mirrors may hinder the reflectivity of the mirror themselves, requiring a remote cleaning operation. The radio-frequency (RF) discharge mirror cleaning service operates a plasma discharge in the vicinity of the mirror, eroding the dust layer and therefore cleaning the mirror remotely. In order to achieve this, RF power needs to be sent from outside the VV to the mirror, using a transmission line. Very stringent design requirements are applicable to the design of this RF line, such as vacuum compatibility, high power handling, low losses, matching, no cable over-heating, etc. This paper analytically addresses the design optimization of the RF mirror cleaning transmission line, taking into account ITER requirements, in order to give robust guidelines for the possible ad-hoc cable design adaptation that is to be undertaken case-by-case. The design guidelines are based on underlying transmission line theory, from which a set of design equations are drawn. The optimal design is achieved using design optimization considerations in the available design space. These guidelines are considered to be a useful design tool for optical diagnostics requiring mirror cleaning operation, and are aimed at harmonising the transmission line design procedures across the different cases.

15

Oral_12: ITER Toroidal Interferometer and Polarimeter (TIP) Development and Testing

Authors: Michael Van Zeeland[1]; Tsuyoshi Akiyama[1]; Thomas Carlstrom[1]; Daniel Finkenthal[2]; Michael LeSher[1]; Rejean Boivin[1]; Anthony Gattuso[1]; Fenton Glass[1]; Christopher Muscatello[1]; Raymond O'Neill[1]; David Brower[3]; Jie Chen[3]; David Johnson[4]; Christopher Watts[5]

[1] *General Atomics*

[2] *Palomar Scientific Instruments*

[3] *UCLA*

[4] *Princeton Plasma Physics Laboratory*

[5] *ITER*

Corresponding Author: vanzeeland@fusion.gat.com

ITER will be equipped with a five channel combined toroidal interferometer and polarimeter (TIP) system to provide line-integrated density for feedback control and density profile reconstruction as well measurements of instability-induced core density fluctuations. In the current design, two-color vibration compensated interferometry is carried out at 10.59 μm and 4.6 μm using a CO2 and Quantum Cascade Laser (QCL) respectively while a separate polarimetry measurement of the plasma-induced Faraday effect is made at 10.59 μm. Because polarimeter phase shifts are expected to be less than 180 Deg., the inclusion of polarimetry allows the two-color system to recover unambiguously from fringe skips at all densities, up to and beyond the Greenwald limit as well as the potential to use the polarimeter itself for feedback density control. The system features five independent first mirrors and a common first wall hole to minimize penetration sizes and to reduce risks associated with deposition, erosion and neutron streaming. Alignment on the ~100 m beam paths will be maintained using an active feedback alignment system.

In support of the TIP design efforts, a full-scale prototype has been constructed and tested both in the laboratory and on the DIII-D tokamak. High-resolution TIP phase information is obtained using an FPGA based phase demodulator and precision clock source. Feedback alignment is accomplished using a dual mirror piezo tip/tilt stage active feedback alignment system which minimizes noise and maintains diagnostic alignment indefinitely through both simulated bake cycles on the laboratory prototype as well as through pulsed tokamak discharges on DIII-D. During DIII-D discharges, the measured phase resolution for the polarimeter and interferometer is 0.05 Deg. (100 Hz bandwidth) and 1.9 Deg. (1 kHz bandwidth), respectively. The corresponding line-integrated density resolution for the vibration-compensated interferometer is *nL* = 1.5x10¹⁸ m⁻², and the magnetic field-weighted line-integrated density from the polarimeter is *nBL* = 1.5x10¹⁹ Tm⁻². Both interferometer and polarimeter measurements during DIII-D discharges compare well with the expectations, are capable of meeting ITER measurement requirements and largely validate the approach for application to ITER. Remaining issues to be resolved were also identified throughout the course of testing including atmospheric interaction and dispersion which, in long discharges like those expected in ITER, can cause significant uncompensated interferometric phase shifts.

Work supported by the U.S. DOE under Contracts DE-FC02-04ER54698 and No. DE-AC02-09CH11466 with Princeton University. All U.S. activities are managed by the U.S. ITER Project Office, hosted by Oak Ridge National Laboratory with partner labs Princeton Plasma Physics Laboratory and Savannah River National Laboratory. The project is being accomplished through a collaboration of DOE Laboratories,

16

Short_Oral_16: Study for a tangential dispersion interferometer/polarimeter for DTT

Author: Francesco Filippi[1]

Co-authors: Donatella Fiorucci [2]; A. Fassina [3]; C. Mazzotta [4]; G. Rocchi [4]; R. Rossi [5]; Onofrio Tudisco [1]; P. Andreoli [4]; Mattia Cipriani [6]; Fabrizio Consoli [7]; P. Gaudio [5]; M. Gelfusa [5]; L. Giudicotti [8]; P. Innocente [3]; G. Mauro [9]; D. Mascali [9]; E. Naselli [9]; francesco paolo orsitto [10]; G. Torrisi [9]

[1] *ENEA*

[2] *Consorzio RFX-CNR*

[3] *CNR, Corso stati uniti 4, 35127 Padova, Italia*

[4] *ENEA. Centro Ricerche Frascati, 00044, Roma, Italia*

[5] *Università Roma Tor Vergata, Via Cracovia, 50, 00133 Roma, Italia*

[6] *ENEA - CR Frascati*

[7] *ENEA - Centro Ricerche Frascati*

[8] *Università degli studi di Padova, dipartimento di fisica e Astronomia, Via Marzolo 8, 35131 Padova, Italia*

[9] *INFN Sezione di Catania. Via Santa Sofia,64 - 95123 Catania, Italia*

[10] *CREATE Consortium and ENEA Department FSN Frascati Italy*

Corresponding Author: francesco.filippi@enea.it

The Divertor Tokamak Test (DTT) facility [1], whose construction is starting in Frascati, will require robust and reliable diagnostics for the correct operation of the machine and the characterization of the plasma discharge.

For this purpose, we are studying a common-path dispersion interferometer/polarimeter for the detection of plasma electron density and magnetic field in 2 different tangential chords in the equatorial plane. The physical principle is based on the generation of a second harmonic which crosses the plasma collinearly with the beam at its fundamental. Being the plasma a dispersive medium, the two beams are subject to different dephasing from which it is possible to retrieve the plasma free electron density. Besides, the unconverted part of the fundamental can be used for polarimetric measurement.

Two different implementations of the interferometer have been considered, one with a CO_2 laser (λ = 10.6/5.3 μm) and another one with Nd:YAG (λ = 1.064/0.536 μm). The former is more sensitive to lower plasma densities and to Faraday rotation, while the latter is more robust to fringe jumps.
We have studied the key advantages and disadvantages of both for the experimental conditions expected in DTT. In particular, we analysed the optical propagation of the beams at the different wavelengths, considering the effects of the plasma and the criticality of the main components. The comparison between these solutions, as well as a tentative draft of the final layout for DTT, will be presented.

[1] R. Martone, R. Albanese, F. Crisanti, A. Pizzuto, P. Martin. Eds "DTT Divertor Tokamak Test facility Interim Design Report, ENEA (ISBN 978-88-8286-378-4), April 2019 ("Green Book")"
https://www.dtt-dms.enea.it/share/s/avvglhVQT2aSkSgV9vuEtw.

17

Short_Oral_17: Characterization of Vacuum HV Micro discharges at the HVPTF Facility Through X-ray Bremsstrahlung Spectroscopy

Author: Matteo Hakeem Kushoro[1]

Co-authors: Andrea Muraro [2]; Antonio De Lorenzi [3]; C. Fontana [4]; E. Martines [3]; E. Spada [3]; F. Pino [4]; G. Pesavento [4]; Gabriele Croci [5]; Giovanni Grosso [6]; Isabella Mario [7]; L. Lotto [4]; M. Fincato [3]; M. Zuin [3]; Nicola Pilan [3]; Oisin McCormack [8]; Oscar Putignano [9]; R. Gobbo [4]; Roberto Pasqualotto [10]; S. Spagnolo [3]; Silvia Maria Deambrosis [11]; T. Patton [3]

[1] *Università degli Studi Milano Bicocca*

[2] *IFP-CNR*

[3] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete)*

[4] *Università di Padova*

[5] *ISTP*

[6] *Consiglio Nazionale delle Ricerche, Istituto per la Scienza e Tecnologia dei Plasmi, Milano*

[7] *INFN – Sezione di Milano-Bicocca*

[8] *Università di Milano-Bicocca*

[9] *Istituto Nazionale di Fisica Nucleare*

[10] *Consorzio RFX*

[11] *CNR-ICMATE Padova*

Corresponding Author: m.kushoro@campus.unimib.it

The development of MITICA, the prototype for a neutral beam injector for ITER, drives the interest in investigating HV insulation in vacuum. The High Voltage Padova Test Facility (HVPTF) is an experimental device which has the double aim of studying the physical phenomena underlying the voltage holding in vacuum and testing technical solutions to increase the breakdown threshold. HVPTF features a vacuum chamber containing two stainless steel electrodes separated by an adjustable gap of few centimeters. Electrodes are available in different shapes and can achieve an HV difference up to 800 kV. Both the current and the voltage of the electrodes are sampled at a 100 Hz rate along with the vacuum pressure and the gas composition. Two scintillating crystals, a LYSO and a LaBr3, are installed to detect the hard X-ray bremsstrahlung radiation produced by the interaction of the free charges accelerated by the HV difference on the electrode surfaces. Both scintillators are coupled to photomultipliers and have small active volumes and fast electronics, resulting in very fast signals (40-100 ns); this minimizes the pile-up effect and enhances time resolution, allowing for the measurement of X-ray emission spectra to up to 500 keV with a time-width of few hundreds of μs.
The electrodes are subject to a conditioning process through which the breakdown voltage is gradually increased until the system reaches a saturation value. Between major breakdown discharges a series of current micro-discharges are observed, during which the number of bremsstrahlung photons drops almost to zero. A global increase in gas emission is measured in correspondence of such events, likely due to degassing induced by the discharges.
The aim of this contribution is to expand the knowledge around the micro-discharge dynamics focusing on the bremsstrahlung spectra obtained through the scintillators. Different micro-discharge types will be characterized and put in relation with the different electrodes and the conditioning phase.

18

Short_Oral_18: First measurement of neutrons produced by deuterium fusion reactions in SPIDER

Author: Oisin McCormack[1]

Co-authors: Andrea Muraro [2]; Davide Rigamonti [3]; Enrico Perelli Cippo [4]; Gabriele Croci [5]; Giovanni Grosso [6]; Giuseppe Gorini [7]; Isabella Mario [8]; Luca Giacomelli [9]; Luigi Cordaro [10]; Marco Tardocchi [5]; Marica Rebai [5]; Matteo Zuin [10]; Roberto Pasqualotto [11]

[1] *Università di Milano-Bicocca*

[2] *IFP-CNR*

[3] *ISTP CNR*

[4] *Istituto per la Scienza e Tecnologia dei Plasmi - CNR*

[5] *MIB*

[6] *Consiglio Nazionale delle Ricerche, Istituto per la Scienza e Tecnologia dei Plasmi, Milano*

[7] *Universita' degli Studi di Milano-Bicocca*

[8] *INFN – Sezione di Milano-Bicocca*

[9] *Milano-Bicocca University*

[10] *CNR RFX*

[11] *Consorzio RFX*

Corresponding Author: oisin.mccormack@igi.cnr.it

The inaugural Deuterium acceleration campaign in the SPIDER negative ion source facility in Padua has recently taken place. The first neutrons generated by Deuterium-Deuterium fusion reactions (2.5 MeV) have been recorded, occurring from the collision of accelerated Deuterium with Deuterium absorbed by the beam dump of SPIDER. A neutron detector based on a novel EJ276 plastic scintillator has been employed to successfully measure the neutron flux, which shows strong agreement with the extracted current of the acceleration grid. We have performed a neutron-gamma pulse shape discrimination characterization of the EJ276 detector at the ISIS Neutron source (241AmBe up to 10 MeV), as well as direct spectroscopic comparisons of the D-D neutrons with data from the Frascati Neutron Generator (241AmB quasi-monoenergetic 2.5 MeV). Despite the low statistics produced in this first campaign, both pulse shape discrimination and spectral analysis of the fusion neutrons was viable. The success of these first measurements has led to the installation of an array of 6 new scintillators to be used for further physical studies in future campaigns.

20

Short_Oral_20: On preliminary considerations towards development of radiated power and SXR diagnostics for DEMO

Authors: Maryna Chernyshova[1]; Karol Malinowski[1]; Slawomir Jablonski[1]; Tomasz Fornal[2]; Katarzyna Mikszuta-Michalik[2]; Tomasz Czarski[1]; Krzysztof Tomaszewski[2]

[1] *Institute of Plasma Physics and Laser Microfusion*

[2] *IPPLM*

Corresponding Author: maryna.chernyshova@ipplm.pl

On preliminary considerations towards development of radiated power and SXR diagnostics for DEMO

M. Chernyshova, K. Malinowski, S. Jabłoński, T. Fornal, K. Mikszuta-Michalik, T. Czarski, K. Tomaszewski

Institute of Plasma Physics and Laser Microfusion, Hery 23, 01-497 Warsaw, Poland

maryna.chernyshova@ipplm.pl

Currently, a new X-ray detection technology is required for tokamaks such as ITER or DEMO, since conventional X-ray detectors that are being used nowadays in existing equipment may rapidly degrade due to harsh fusion reactor environment. Processes that occur during the interaction of radiation with matter in fusion facilities obligate for materials that are used in such facilities to have an excellent radiative stability. That obligation is imposed not only on the wall materials but on other materials that are constituents of, e.g., detectors, and it constantly cultivates the search for new technologies in the field of plasma diagnostics.
This work addresses such a particular task as creation of a new diagnostics for radiated power and soft X-ray core intensity measurements that will be useful for future thermonuclear reactors and will be able to provide reliable plasma control (monitoring the power loss across the separatrix) in accordance with the DEMO control requirements. It could be also supportive in studying heavy impurity profiles, MHD modes and localization, plasma positioning and shape.
Gas Electron Multiplier (GEM) technology is chosen to be the base for such a new SXR detection system. This technology's main advantages include compactness of GEM detector, good temporal and spatial resolution, availability of energy discrimination of the incident photons, better neutron resilience than the existing systems. All of these make it potentially a good candidate for SXR measurement in ITER and DEMO.
This contribution will present the results of the preliminary work on the conceptual design of the DEMO Prad/SXR diagnostics based on EU-DEMO Physics Baseline 2018 parameters [M. Siccinio et al., Fus. Eng. Design 156 (2020) 111603]. The overall activity is targeted at the detailed diagnostics design, engineering and integration studies, including investigation of the feasibility, performance of diagnostics and its components. The details on the preliminary considerations on the above will be provided.

21

Short_Oral_21: Neutron spectrometer for studies of deuteron burn and triton burn-up states in D plasmas

Authors: Massimo Nocente[1]; Jan Kaellne[2]; Giuseppe Gorini[3]; Marco Tardocchi[4]

[1] *Dipartimento di Fisica - Università di Milano-Bicocca*

[2] *Department of Electrical Engineering, Uppsala University, Uppsala, Sweden*

[3] *Universita' degli Studi di Milano-Bicocca*

[4] *Istituto per la Scienza e Tecnologia dei Plasmi, CNR*

Corresponding Author: massimo.nocente@mib.infn.it

A new neutron time-of-flight spectrometer (TOF-X) is proposed for simultaneous measurement of the 2.5 and 14-MeV neutron emission groups such as due to the d+d->τ+n reaction and triton burn-up reaction tdd+d->α+n. The aim of the instrument is to provide data for the study of the slowing-down and confinement of 1-MeV tritons in D plasmas that can serve as proxy for the same information on 3.5-MeV α-particles. Of special interest is the use of TOF-X spectrometer as a new diagnostics of plasmas which have demonstrated high fusion power capabilities in D operation but whose fast ion confinement capabilities need to be explored and determined. Suitable plasmas are those produced in long pulse discharges, such as in present and planned super conducting tokamaks and stellarators, or other future plasma configuration. The performance of TOF-X as a fast ion diagnostic depends on the 14-MeV neutron energy resolution and (flux) detection efficiency; these parameters were assed using parameterized analytical expressions. The performance limit is set by the 14-MeV count rate which, in turn, is ultimately set by the collimated flux and the neutron yield rate of the plasma for the time integration times that can be utilized. The presentation is focused on TOF-X as a an instrument to study fast-ion confinement with illustrations of diagnostic capabilities and the plasmas that it can be used to study.

22

Tutorial_9: Introduction to Integrated Data Analysis and Validation

Author: Rainer Fischer[1]

[1] *Max-Planck-Institute for Plasma Physics, Garching, Germany*

Corresponding Author: rainer.fischer@ipp.mpg.de

A major challenge in nuclear fusion research is the coherent combination of data from heterogeneous diagnostics and modelling codes. Measured data from different diagnostics often provide information about the same subset of physical parameters. Additionally, information provided by some diagnostics might be needed for the analysis of other diagnostics. A joint analysis of complementary and redundant data allows, e.g., to improve the reliability of parameter estimation, to increase the spatial and temporal resolution of profiles, to obtain synergistic effects, to consider diagnostics interdependencies and to find and resolve data inconsistencies. Modelling codes may provide additional physical information allowing for an improved treatment of ill-posed inversion problems. A coherent combination of all kind of available information within a probabilistic framework allows for improved data analysis results.

The concept of Integrated Data Analysis (IDA) in the framework of Bayesian probability theory will be introduced and contrasted with conventional data analysis. Applications from nuclear fusion research will highlight various aspects of IDA and the respective benefits.

23

Short_Oral_23: Performance of neutral pressure gauges using LaB6-emitters in deuterium plasmas

Author: Victoria Haak[None]

Co-authors: Uwe Wenzel [1]; Gen Motojima [2]

[1] *Max Planck Institute for Plasma Physics*

[2] *National Institute for Fusion Science*

Corresponding Author: victoria.haak@ipp.mpg.de

Neutral pressure gauges of the ASDEX type [1] have been adapted for stable and reliable operation in magnetic fusion experiments. Neutral pressure gauges using an electron emitting LaB6-crystal aligned with the magnetic field do not experience damage due to the j × B force as observed in neutral pressure gauges with filaments of thoriated tungsten. They were successfully operated in hydrogen in Wendelstein 7-X (W7-X) during OP1.2b in a magnetic field of 1.6-2.2 T at a low heating current of 2.25-2.5 A [2]. Neutral pressure gauges using a crystal emitter present a promising concept for measurements of the neutral gas pressure in a future fusion reactor.

However, there are concerns about its use in the reactor due to the boron. Two LaB6-neutral pressure gauges were installed and tested in the Large Helical Device (LHD). In the campaign 2020/2021, the influence of neutrons on the electron emission properties of LaB6 was studied during two months of deuterium operation yielding 2×10^18 neutrons in total.
The pressure gauges were installed in different positions, one in the subdivertor region (8I-div) featuring high neutral gas pressures and one near the midplane (9O-mid) in a magnetic field of 2.8T.

Confirming the results from W7-X, both crystals showed stable electron emission during operation in hydrogen and helium and were operated at a low heating current of 1.7 A, allowing for reliable and precise neutral pressure measurements. However, the crystal in position 8I-div experienced a sudden increase of the heating current from 1.7 to 4 A within few plasma discharges during deuterium operation, while the crystal in position 9O-mid remained unaffected. As stability of the emission properties under the influence of neutrons is essential for the use of LaB6-neutral pressure gauges in fusion devices, the degradation of the emission properties in deuterium plasmas is studied in this contribution.

[1] Haas G and Bosch H S 1998 Vacuum 51 39-46
[2] U. Wenzel et al, Rev. Sci. Instrum., 90, 123507 (2019).

24

Short_Oral_24: Assessment of long-term stability of the plasma current measurement at JET using fibre optics current sensor

Author: Andrei Gusarov[1]

Co-authors: Prasad Dandu [2]; Alex Boboc [3]; David Croft [3]; Nicolas Berkis [4]; Paola Batistoni [5]; Willem Leysen [1]; Perry Beaumont [3]; Marc Wuilpart [2]

[1] *SCK CEN*

[2] *UMons*

[3] *UK AEA*

[4] *EuroFusion*

[5] *ENEA*

Corresponding Author: andrei.goussarov@sckcen.be

The Fibre Optic Current Sensor (FOCS) is a system that will perform plasma current measurements at ITER during long plasma discharges under intense nuclear radiation. Plasma current measurements are important for safe machine operation. The FOCS must perform measurements is harsh tokamak environment, which include strong magnetic fields, high temperatures, and also significant levels of neurons and high energy photons. JET is a unique machine where the impact of such conditions on the sensor performance can be investigated experimentally. In particular, DT operation is fully ITER-representative in terms of 14 MeV neutron fluxes.
Considering assessment of the FOCS performance in a tokamak environment, polarisation detection based FOCS systems were installed at JET and performed measurements in various machine operating scenarios at currents up to 3.5 MA. The FOCS 1 system installed in 2015 uses the Fibrecore Ge-doped core spun fibre SLB 1250 with a 10 mm spun period, and the FOCS 2 operational since 2018 is based on the Crystal Techno pure silica core LB1300 from with a 5 mm spun.
FOCS at ITER is a unique diagnostics, which consider the possibility of the sensing head replacement. However, it is preferable to use this possibility for the system upgrade and not as a maintenance procedure. The sensing optical fibre must remian mechanically stable and preserve optical properties during several years in service. The JET vacuum vessel temperatures during operation and backing are 200℃ and 300-320℃, which is higher than the corresponding temperatures in ITER, 100℃ and 200-220℃, respectively. Therefore operation at JET means that FOCS will sustain the ITER temperature conditions.
To address the radiation effect on the FOCS operating in a tokamak environment operating with hydrogen, which is relevant for the ITER first phase operation, analysis of the performance of FOCSs during DD and H operation provides necessary information. Analysis of data accumulated during more than five years of operation is presented. Rogowski system, which measures the same current as FOCS is used as a reference to assess the performance and the stability. The neutron radiation dose is estimated based on the KN1 absolute calibration system. Possible transient effect have been observed, but on a long term the performance variation are within measurement uncertainties.

25

Short_Oral_25: Conceptual design of a Cherenkov based gamma-ray diagnostic for measurement of 17 MeV gamma rays from T(D, γ)5He in magnetic confinement fusion plasmas

Authors: Oscar Putignano[1]; Gabriele Croci[None]; Andrea Muraro[2]; Stephanie Cancelli[3]; Luca Giacomelli[4]; Giuseppe Gorini[5]; Giovanni Grosso[6]; Matteo Hakeem Kushoro[7]; Marcer Giulia[8]; Massimo Nocente[9]; Enrico Perelli Cippo[10]; Marica Rebai[11]; Marco Tardocchi[12]; Marco Tardocchi[12]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *IFP-CNR*

[3] *Unimib*

[4] *ISTP-CNR*

[5] *Universita' degli Studi di Milano-Bicocca*

[6] *Consiglio Nazionale delle Ricerche, Istituto per la Scienza e Tecnologia dei Plasmi, Milano*

[7] *Università degli Studi Milano Bicocca*

[8] *UNIMIB*

[9] *Dipartimento di Fisica - Università di Milano-Bicocca*

[10] *Istituto per la Scienza e Tecnologia dei Plasmi - CNR*

[11] *MIB*

[12] *Istituto di Fisica del Plasma "Piero Caldirola",CNR*

Corresponding Author: oscar.putignano@mib.infn.it

At present, the only method for assessing the fusion power throughput of a reactor relies on the absolute measurement of 14 MeV neutrons produced in the D-T nuclear reaction. [1]
For ITER and DEMO, however, at least another independent measurement of the fusion power is required.
The 5He*nucleus produced in the D-T fusion reaction has two de-excitation channels. The most likely is its disintegration in a particle and a neutron, D+T⟶5He*⟶α+n, by means of the nuclear force. There is however also an electromagnetic channel, with a branching ratio ~10-5, which leads to the emission of a 17 MeV gamma-ray, i.e. D+T⟶5He*⟶ 5He+γ. [2] The detection of this gamma-ray emission could serve as an independent method to determine the fusion power.
In order to enable 17 MeV gamma-ray measurements, there is need for a detector with some coarse energy discrimination and, most importantly, capable to work in a neutron rich environment.
Conventional inorganic scintillators, such as LaBr3(Ce), have comparable efficiencies to neutrons and gamma rays and they cannot be used for 17 MeV gamma-ray measurements without significant neutron shielding.
In order to overcome this limitation, we here propose the conceptual design of a gamma ray counter with a variable energy threshold based on the Cherenkov effect and designed to operate in intense neutron fields.
The detector geometry has been optimized using Geant4 so to achieve a gamma-ray to neutron efficiency ratio better than 105. The design is based on a gas Cherenkov detector and uses a CsI coated scintillating GEM (Gas Electron Multiplier) as photon pre-amplifier, together with a wavelength shifter to minimize the sensitivity to neutrons.
Photons produced in the GEM are collected by an optical window and a bundle of optical fibers, which guides them towards an array of silicon photomultipliers (SiPMs) located further away from the plasma, in a region at low nuclear radiation.

References

[1] L. Bertalot et al., "Fusion Power Measurement at ITER," in IEEE Transactions on Nuclear Science, vol. 63, no. 3, pp. 1682-1687, June 2016, doi: 10.1109/TNS.2016.2553125.
[2] F. E. Cecil et al, "Measurement and application of DDγ, DTγ and D3Heγ reactions at low energy." Netherlands: N. p., 1985. Web.
[3] S. Agostinelli er al. "Geant4—a simulation toolkit", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,V 506, Issue 3, 2003, 250-303.

26

Oral_17: Overview and Recent Progress of KSTAR Diagnostics

Author: Sang Gon Lee[1]

[1] *Korea Institute of Fusion Energy*

Corresponding Author: sglee@kfe.re.kr

Diagnostic systems are essential to perform machine operation and physics understanding for magnetic fusion experiments. The 14th experimental campaign from Korea Superconducting Tokamak Advanced Research (KSTAR) device has passed since the first experimental campaign was carried out successfully in 2008. The basic diagnostic systems such as magnetic diagnostics, interferometer, inspection illuminator, visible spectrometer, ECE radiometer and so on have been used for the first plasma experiment in KSTAR. Currently more than 50 diagnostics have been continuously installed including the basic diagnostic systems and advanced imaging diagnostics in KSTAR. In addition, diagnostic systems for burning plasma environments like ITER and DEMO are under development from KSTAR. Overview and progress of diagnostic systems, and activities for new diagnostic system developments for KSTAR will be discussed.

27

Oral_13: Diagnostics on the stellarator TJ-II

Author: Kieran Joseph McCarthy[1]

[1] *Ciemat*

Corresponding Author: kieran.mccarthy@ciemat.es

The TJ-II is a heliac-type stellarator device with major radius of 1.5 m and averaged minor radius ≤0.22 m that has been operated at Ciemat, Madrid since 1998.1 Its magnetic field (B ≤1 T at plasma axis) is generated by a system of poloidal, toroidal and vertical field coils. Plasmas created with hydrogen, deuterium or helium, tpulse ≤300 ms, are heated using two gyrotrons operated at 53.2 GHz, the 2nd harmonic of the electron cyclotron resonance frequency (Pech ≤600 kW). With this set-up, central ne and Te up to 1.7x1019 m-3 and 2 keV, respectively, are achieved. Additional heating is undertaken by injecting accelerated neutral hydrogen atoms (≤31 kV) using 2 tangential neutral beam injectors. These provide up to 1 MW for ≤120 ms so that a central ne up to 5�1019 m-3 is attained. Moreover, TJ-II possesses a complicated vacuum-vessel layout, a bean-shaped plasma cross-section and a fully 3-dimensional plasma structure. Nonetheless, it has excellent diagnostic access (96 portholes).
During its initial operational phase, TJ-II was equipped with a limited set of essential diagnostics.2 These included passive systems such as H� monitors, spectrometers, an Electron Cyclotron Emission radiometer, X-ray monitors, neutral particle analysers as well as magnetic diagnostics such as Rogowski coils, diamagnetic loops and Mirnov coils. In addition, some active systems, e.g., a single pulse per discharge Thomson Scattering system, were operational. Thereafter, over the following years, a larger set of diagnostics was installed some of which are dual, or double, systems that are unique to this device. These include a dual fast-reciprocating Langmuir probe system, impurity injection using both the laser ablation and Tracer Encapsulated Solid Pellet (TESPEL) techniques,3 a helium gas puff based system to study edge turbulence using a fast-frame imaging camera equipped with a triple bundle fitted and transmission filters, a compact neutral beam injector with a fibre optic based light collection system (to measure impurity ion temperature and velocity profiles plus radial electric fields using Charge Exchange Recombination Spectroscopy or magnetic field components using the Motional Stark effect),4 a dual Heavy Ion Beam probe system that has allowed obtaining 2-dimensional distribution plots of plasma potential and density,5 a pulsed helium beam (to obtain ne, Te and Ti at the plasma edge by the Line Ratio method), and a 2 channel Doppler reflectometer to study plasma fluctuations and radial electric fields.6 Of particular note is the TESPEL system which shares its injection line and diagnostic systems with a cryogenic pellet injector.7 This unique combination has provided information for pellet ablation and deposition comparisons and on the impact of pellets on plasma parameters. The experience and knowhow gained from the development, installation and operation of these systems has provided valuable input for TJ-II Team participation in diagnostics for new and future fusion devices, i.e., dual Doppler reflectometer and TESPEL systems for W7-X,8,9 the Wide Angle Viewing and Collective Thomson systems for ITER, and UV, visible and IR diagnostic systems for DEMO.

28

Short_Oral_28: Characterization of Cs-free negative ion production in the ion source SPIDER by Cavity Ring-Down Spectroscopy

Author: Marco Barbisan[1]

Co-authors: Riccardo Agnello [2]; Ginevra Casati [3]; Roberto Pasqualotto [1]; Gianluigi Serianni [1]

[1] *Consorzio RFX*

[2] *Ecole Polytechnique Fédérale de Lausanne (EPFL)*

[3] *Imperial College London*

Corresponding Author: marco.barbisan@igi.cnr.it

The Neutral beam Injectors of the ITER experiment will be based on negative ion sources for the generation of beams composed by 1 MeV H/D particles. The prototype of these sources is currently under testing in the SPIDER experiment, part of the Neutral Beam Test Facility of Consorzio RFX, Padua. In SPIDER, the negative ions are extracted and accelerated from the source by means of a three grids acceleration system. Among the targets of the experimentation in SPIDER, it is of foremost importance to maximize the extracted beam current density, while minimizing the fraction of electrons co-extracted from the source. This requires to adjust several source parameters, as the gas pressure, the input radiofrequency power sustaining the plasma, and the magnetic and electric fields generated in proximity of the grid facing the source plasma to reduce the amount of co-extracted electrons and the electron-ion stripping reactions. This study was performed thanks to a Cavity Ringdown Spectroscopy diagnostic, which is able to give line-integrated measurements of negative ion density in proximity of the acceleration system apertures. The study, which is here presented, was performed operating SPIDER in hydrogen and deuterium; in this first phase of experimentation, negative ions are mostly produced by reactions in the plasma volume since the source operates in Cs-free conditions.

29

Short_Oral_29 Preliminary parametric analysis of the first neutrons measured with a scintillator array at SPIDER

Author: Isabella Mario[1]

Co-authors: Oisin McCormack [2]; M. Zuin [3]; Gabriele Croci [4]; Andrea Muraro [5]; Luca Giacomelli [6]; Luigi Cordaro [7]; Giuseppe Gorini [8]; Enrico Perelli Cippo [9]; Giovanni Grosso [10]; Davide Rigamonti [11]; Marica Rebai [12]; Roberto Pasqualotto [13]; Marco Tardocchi [14]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *Università di Milano-Bicocca*

[3] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete)*

[4] *ISTP*

[5] *IFP-CNR*

[6] *Milano-Bicocca University*

[7] *CNR RFX*

[8] *Universita' degli Studi di Milano-Bicocca*

[9] *Istituto per la Scienza e Tecnologia dei Plasmi - CNR*

[10] *Consiglio Nazionale delle Ricerche, Istituto per la Scienza e Tecnologia dei Plasmi, Milano*

[11] *ISTP CNR*

[12] *MIB*

[13] *Consorzio RFX*

[14] *Istituto di Fisica del Plasma "Piero Caldirola",CNR*

Corresponding Author: isabella.mario25@gmail.com

SPIDER, the full size ITER NBI ion source, aims to prove the ITER requirements in terms of the ion source performance, a beam uniformity better than 90% and a low beam divergence. The SPIDER experiment can operate in deuterium, thus producing beam-target D-D fusion neutron emissions. These emissions can be used to evaluate the beam uniformity as well as machine parameter dependence, since the neutron flux is proportional to the beam power.
To this end, a new neutron diagnostic array, consisting of a mix of seven crystal, plastic, and liquid scintillators, has been installed externally on the beam dump side of the vessel. Six of them are capable of neutron/gamma discrimination and are positioned to study the beam uniformity and allow parametric comparisons. An NaI scintillator-based gamma detector allows for the energy spectra reconstruction of incident gamma rays without neutron interference. In this work, the scintillator array's capability and arrangement, together with first results achieved during the deuterium campaigns performed in SPIDER, are presented and discussed.

30

Short_Oral_30: An ultrahigh-bandwidth Phase Contrast Imaging system to detect electron scale turbulence and gigahertz radio-frequency waves

Author: Alessandro Marinoni[1]

Co-authors: John Chris Rost [1]; Miklos Porkolab [1]; Raymond Seraydarian [1]

[1] *Massachusetts Institute of Technology*

Corresponding Author: marinoni@mit.edu

The Phase Contrast Imaging (PCI) diagnostic is an absolutely calibrated internal reference interferometer that creates an image of line-integrated electron density fluctuations [H.Weisen, Rev. Sci. Instrum. 59 1544 (1988)]. Detector arrays with appropriate frequency bandwidth are used to extract the spatial structure of the plasma imaged by the diagnostic.
A novel PCI system has been developed to measure the internal structure of waves and turbulence in fusion grade magnetically confined plasmas across an unprecedented range in frequency and wavelength. This is accomplished by changing the wavelength of the probing laser beam from the Mid InfraRed ($10.59\ \mu m$) to the Near InfraRed region ($1.55\ \mu m$). The shortening of the probing laser wavelength delivers two key advantages. Firstly, perturbations of a given wave-number scatter off the probing laser beam at an angle that is reduced by a factor of 7 which, for a given maximum scattering angle permitted by in- and ex-vessel apertures along the laser beam path, gives access to higher wave-numbers approaching actual electron scale fluctuations at $k\rho_e \simeq 1$. Alternatively, any given fluctuation wave-number can be collected by 7 times smaller optics or by the same size optics located 7 times further away from the plasma. Secondly, the system capitalizes on the considerable progress in the NIR region made by research and development programs in the telecommunication and military sectors. More specifically, low noise room temperature detector arrays are readily available with GHz frequency bandwidth, i.e. almost three orders of magnitude larger than that of existing systems. This allows to directly digitize data without using complex heterodyning detection schemes. Examples of such phenomena include fast particle modes, such as Ion Cyclotron Emission, and waves used for current drive in large scale devices, such as Helicon. Additionally, high quality lasers, optical components and imaging tools suitable for remote alignment tasks are available off-the-shelf and at a much lower price; maintenance overhead is also reduced as detectors are not cryogenically cooled.
Phase plates, custom mirrors with engraved grooves that are at the heart of the PCI technique, were successfully developed for light at $1.55\ \mu m$ with two methods at a competitive price: masked coating and a micro-technology lift-off process. The latter technique provided grooves of exceptional quality with a few nano-meter accuracy.
Bench-top tests using a PCI prototype and calibration sound waves demonstrated excellent wavelength measurements with the expected response. The observed signal-to-noise ratio is of the order of the theoretical minimum expected from specifications of the various components used.
The increased wavenumber-frequency bandwidth, the easier accessibility to components and remote alignment tools, along with lower maintenance overhead, makes this system relevant to future large devices where access to the optical system will be restricted and optical paths will be much longer than in present day machines.

Work supported under US-DOE award DE-SC0018095

31

Short_Oral_31: A new hard X-ray spectrometer for runaway electron measurements in tokamaks

Author: Andrea Dal Molin[None]

Co-authors: Massimo Nocente [1]; Enrico Panontin ; Davide Rigamonti [2]; Alexander Shevelev [3]; Evgeniy Khilkevitch [4]; Margarita Iliasova ; Luca Giacomelli [5]; Giuseppe Gorini [6]; Enrico Perelli Cippo [7]; Federico D'Isa ; Gabriella Pautasso ; Gergely Papp ; Giovanni Tardini ; Eva Macusova ; Jaroslav Cerovsky ; Ondrej Ficker ; Marco Tardocchi [8]

[1] *Dipartimento di Fisica - Università di Milano-Bicocca*

[2] *ISTP CNR*

[3] *Ioffe Institute, Saint Petersburg, Russia*

[4] *Ioffe Institute*

[5] *Milano-Bicocca University*

[6] *Universita' degli Studi di Milano-Bicocca*

[7] *Istituto per la Scienza e Tecnologia dei Plasmi - CNR*

[8] *Istituto di Fisica del Plasma "Piero Caldirola",CNR*

Corresponding Author: andrea.dalmolin@istp.cnr.it

Runaway electron generation remains one of the major challenges to the success of high-current tokamaks. Investigation of runaway electron physics is a crucial step towards developing effective prediction, avoidance, and mitigation strategies to reduce the impact of these dangerous events. Valuable information on the runaway electron distribution function can be obtained performing spectral analysis of the bremsstrahlung radiation emitted in the interaction between the runaway beam and the post-disruption plasma. Measurement of this radiation is challenging and requires dedicated instruments.

This work presents REGARDS, a novel portable hard X-ray spectrometer optimised for bremsstrahlung radiation measurement from runaway electrons in fusion plasmas. The detector is based on a 1"x1" LaBr3:Ce scintillator crystal coupled with a photomultiplier tube. The system has an energy range exceeding 20 MeV with an energy resolution of 3% at 661.7 keV. The detector gain is stable even under severe HXR flux (gain shift below 3% with a HXR counting rate in excess of 1 MCps). The high performance of the system enables unprecedented studies of the time-dependent runaway electron energy distribution function. Examples from recent runaway electron physics experiments performed at the ASDEX Upgrade and COMPASS tokamaks are shown.

32

Short_Oral_32: Status of the ITER CXRS diagnostic system modeling

Authors: Stanislav Serov[1]; Maarten De Bock[2]; Manfred von Hellermann[3]; Sergei Tugarinov[1]

[1] *Institution "Project Center ITER", RF*

[2] *ITER Organization*

[3] *FOM Rijnhuizen*

Corresponding Author: s.serov@iterrf.ru

Charge Exchange Recombination Spectroscopy (CXRS) is a powerful diagnostic tool for fusion plasma in tokamaks [1, 2]. The ITER CXRS system will provide spatially resolved measurements of the ion temperature, low-Z impurity density and rotation velocity. These plasma parameters are extracted from the active charge-exchange (CX) spectral line, emitted during high-energy neutral beam injection into plasma. The measurements could become complicated because of the low signal-to-noise ratio (SNR) and the presence of the other spectral lines due to CX reactions with the edge neutrals (passive CX line) and due to the electron impact excitation (edge lines). Therefore, modeling is an important part of the diagnostic.

This report describes the status of the ITER CXRS diagnostic system modeling. Modeling was carried out for the latest system design using Simulation of Spectra code [3]. Statistical errors for ion temperature, density, and rotation velocity were calculated. Minimal concentrations, allowing measurements with the required accuracy, were obtained. Halo effect influence on the measurements was assessed. Alternative modeling using ray-tracing CHERAB [4] framework was also carried out. This allowed among other things to estimate the contribution of the reflected light from the metallic first wall. The comparison of two principally different models confirmed the reliability of the obtained results.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

33

Short_Oral_33: Verification of Ni ion dielectronic satellite structure in JET plasma diagnostic for low and high plasma rotation

Authors: Karol Kozioł[1]; Jacek Rzadkiewicz[1]; Ashwin Patel[2]

[1] *National Centre for Nuclear Research*

[2] *Culham Centre for Fusion Energy*

Corresponding Authors: karol.koziol@ncbj.gov.pl, jacek.rzadkiewicz@ncbj.gov.pl

Measurement of the x-ray spectra of the He-like Ni ions (Ni^{26+}) and their dielectronic satellites (Ni^{25+}, Ni^{24+}, and Ni^{23+}) plays a crucial role in determination of electronic and ionic temperature of plasma in the JET device. Because $n \geq 3$ satellites of Ni^{25+} overlap with resonance 'w' line of Ni^{26+}, it is important to reconstruct the structure of these satellites reliably. It is especially important in the cases when plasma rotation is high what results in additional shift of $n \geq 3$ satellites of Ni^{25+} in respect to resonance 'w' line.

Collisional-Radiative Modelling (CRM) by using the FAC code has been used for modeling the spectral emission from Ni^{26+} + dielectronic satellite ions from plasmas for various electronic temperatures. Multi-Configurational Dirac-Hartree-Fock + Configuration Interaction (MCDHF-CI) calculations by using the GRASP code has been used to examining electron correlation effect on wavelengths and transition rates for $L \rightarrow K$ transitions occurs in He- and Li-like Ni ions. Basing on ab initio calculations we were searching for optimal approach to fit the $n \geq 3$ satellites of Ni^{25+} in experimental JET spectra.

34

Oral_9: JET Diagnostic Capability in Preparation of Tokamak Nuclear Age

Author: Andrea Murari[1]

[1] *Consorzio RFX*

Corresponding Author: andrea.murari@istp.cnr.it

JET next campaigns foresee various scans in the fuel mixture, full T operation and a 50-50 D-T campaign called DTE2 scheduled at the beginning of next decade. The main scientific objectives include the assessment of the isotopic effects on various plasma aspects: mainly on confinement, on the threshold to access the H mode and on ELM behaviour. Another very important subject of investigation will be the physics of the alpha particles. From a technical point of view, the total yield available for the entire D-T phase is expected to be 1.7 1021 n, about a factor of 6 higher than the previous main D-T campaign on JET, DTE1. Therefore the radiation field will be quite relevant for next step devices, since the neutron flux at the first wall (~ 1013 n/s•cm2), for example, will be comparable to the one in ITER behind the blanket. These experiments will therefore be a unique opportunity to prepare Tokamak diagnostics and related technologies for the full nuclear age, which will be inaugurated by ITER and consolidated by DEMO.

From the point of view of diagnostics developments, for many years JET diagnostics have been upgraded in order to provide adequate support for the scientific exploitation of JET programme. The main efforts have concentrated on improving four main aspects of JET measuring capability: 1) the quality of the measurements of the electrons and ions 2) the diagnostic for the fusion products 3) interpretation codes 4) specific technologies for ITER.

In terms of general diagnostic capability, compared to the previous DTE1, JET diagnostics have a much better spatial and temporal resolution of the electrons (about one order of magnitude improvement for each parameter). The accuracy and consistency of the various independent measurements of the same parameter have also increased significantly; the three independent measurements of the electron temperature, for example, agree now well within 10%. On the other hand, various improvements of the active charge exchange are being pursued to overcome the significant difficulties encountered in measuring the temperature and rotation velocity of the ions in ITER relevant scenarios. Moreover, solutions have been found to operate some cameras, both visible and IR, even during the full D-T phase to provide imaging of the plasma and the first wall. Specific new and upgraded diagnostics have been explicitly developed to investigate disruptions, in particular the physics of the runaway electrons, in support to the Shutter Pellet upgrade.

With regard to the fusion products, JET now can deploy a consistent set of techniques to measure the neutron yield and neutron spectra and to diagnose the fast particles. A full calibration of the neutron diagnostics with a 14 MeV source has been successfully completed, complementing the previous calibration for the 2.45 MeV neutrons and validating ITER procedures. Vertical and horizontal lines of sight are foreseen for neutron spectrometry, in order to separate the RF component from the other contributions. Various gamma ray spectrometers are being developed to cover all the various operational scenarios and to discriminate the trapped and passing components of the alphas. The redistribution of the alphas will be measured with the gamma ray cameras, recently upgraded with full digital electronics; new detectors (LaBr3) have been tested to bring the time resolution of the system in the ten of ms range. The lost alphas will also be diagnosed with improved spatial and temporal resolution, using Faraday cups and a scintillator probe, while an upgraded system to detect the TAE modes, and their interactions with the fast ions, has been proved for the first time to work also in divertor configurations.

For most major diagnostics, and in particular for practically all the enhancements, a very significant effort has been exerted to improve JET interpretative capability via the development of specific synthetic diagnostics. From the measurements of the fusion product to the instabilities and tomographies, a series of advanced codes can be now deployed to better link the diagnostic outputs with the physics of the plasma configurations. Interesting developments are also taking place in the fields of data mining, for the efficient retrieval of the information, and in the exploitation of many measurements for real time control.

From a technological perspective, the full T and D-T campaigns will provide a unique opportunity to test ITER relevant technologies. From radiation hard detectors, for example Hall probes and diamond sensors, to neutron absorbers and to shielding concepts, the potential of various solutions in real radiation fields will be assessed. The effects of neutrons and gamma on ancillary technologies and systems, such as fibre optics and electronics circuits, are also expected to be sufficiently high to derive useful information about the competitive advantage of various potential solutions

35

Oral_3.1: Fusion alpha-particles diagnostics: from JET to ITER and DEMO

Author: Vasily Kiptily[1]

[1] *United Kingdom Atomic Energy Authority*

Corresponding Author: vasili.kiptily@ukaea.uk

The nuclear fusion reaction between deuterium and tritium, D(T,n)4He is the main source of energy in future thermonuclear reactors. Charged fusion products of this reaction, α-particles (4He-ions), are born with an average energy of 3.5 MeV. They transfer energy to the thermal plasma during their slowing down, providing the self-sustained deuterium-tritium plasma burn. Adequate confinement of α-particles is essential to provide efficient heating of the bulk plasma and steady burning of a reactor plasma. Investigation of fusion-born α-particles behaviour will be a priority task for the planned DT experiments on Joint European Tokamak (JET) [1] and International Thermonuclear Experimental Reactor (ITER) in order to understand the main mechanisms of their slowing down, redistribution and losses and to develop optimal plasma scenarios.
Today's JET machine has ITER-like wall (beryllium wall and tungsten divertor) and enhanced auxiliary heating systems, including NBI with power up to 34 MW and ICRF power up to 7 MW. Therefore, forthcoming DT experiments on JET are aiming to produce 10 – 16 MW fusion power during a 5-second stationary state plasma. It is expected to produce significant population of α-particles to provide a step-ladder approach for extrapolating to ITER, so the experiments will give great opportunities to study fusion alphas.
The first full scale DT experiment on JET in 1997 (DTE1) has shown that direct measurements of alphas are very difficult. Alpha-particle studies require a significant development of dedicated diagnostics. What do we want to measure in the next deuterium-tritium experiments on JET? The principal priorities are the DT fusion reaction rate and the spatial α-particle birth profile. Measurement of the slowing down, diffusion, redistribution and loss of fast α-particles is another high priority requirement for optimisation of the plasma scenarios and assessment of MHD effects on the DT plasma performance. In order to make such measurements, JET, as a testbed for ITER, has now been equipped with an excellent set of fast α-particle diagnostics for operation at the high neutron and γ-ray fluxes expected in forthcoming DT experiments: γ-ray spectrometers for measuring energy distribution; 2D neutron/γ-ray camera for tomographic reconstruction of the α-particle source and the temporal evolution of its spatial profile; a fast ion loss detector with energy and pitch-angle resolution and a set of the lost α-particle collectors with poloidal, radial and energy resolution.
The confinement of fast α-particles produced in fusion reactions is of crucial importance for ITER. Indeed, it is planned to reach burning plasma at the fusion gain factor Q=10 (the ratio of fusion power to the external heating power). In burning plasmas, fundamentally new α-particle physics is anticipated. α-particles could affect the magnetohydrodynamic (MHD) stability and turbulence in plasma discharges with 10>Q>5; at Q>10, a strong non-linear coupling between alphas and a pressure driven plasma current is predicted. In future fusion reactors like DEMO with Q⟶∞ ignition transient phenomena will be the main issue. Some plasma instabilities may lead to significant α-particle losses and the loss of plasma heating that is not acceptable for the efficient fusion plant as it can cause problems with ignition and damage to the first wall. To keep fusion α-particles under control, a range of specific diagnostics is needed for monitoring the α-particle population in real-time.
A goal of the DEMO fusion power plant is to demonstrate that the major scientific and technological obstacles on the way to the commercial power plant have been overcome, and one of the real challenges is development of a highly robust and reliable diagnostic system. A harsh DEMO environment with a very high level of neutron and γ-ray fluxes will make some conventional ITER diagnostics unfeasible [2]. Among the restricted set of instruments, which are available for the machine protection and plasma control in DEMO, neutrons and γ-ray measurements will be useful as detectors can be placed far away from the plasma and they do not require a direct access to the vessel. Some neutron and γ-ray diagnostics developed and tested on JET and used in ITER will be the main work horses in DEMO for monitoring fusion power, the core fuel ratio and α-particle loss control.

This work was funded partly by the RCUK Energy Programme [grant number EP/T012250/1]. It was also carried out partly within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[1] Joffrin E. et al 2019 Nucl. Fusion 59 112021
[2] Donné A.J.H., Costley A.E. and Morris A.W. "Diagnostics for plasma control on DEMO: challenges of implementation" Nuclear Fusion 52 (2012) 074015
* See the author list of 'Overview of JET results for optimising ITER operation' by J. Mailloux et al to be published in Nuclear Fusion Special issue: Overview and Summary Papers from the 28th Fusion Energy Conference (Nice, France, 10-15 May 2021).

36

Short_Oral_36: Runaway electron velocity-space observation regions of bremsstrahlung hard X-ray spectroscopy

Authors: Enrico Panontin[None]; Massimo Nocente[1]; Andrea Dal Molin[None]; Jacob Eriksson[2]; Giuseppe Gorini[3]; Enrico Perelli Cippo[4]; Davide Rigamonti[5]; Mirko Salewski[6]; Marco Tardocchi[7]

[1] *Dipartimento di Fisica - Università di Milano-Bicocca*

[2] *Department of Physics and Astronomy, Uppsala University, Sweden*

[3] *Universita' degli Studi di Milano-Bicocca*

[4] *Istituto per la Scienza e Tecnologia dei Plasmi - CNR*

[5] *ISTP CNR*

[6] *Technical University of Denmark*

[7] *Istituto per la Scienza e Tecnologia dei Plasmi*

Corresponding Author: e.panontin@campus.unimib.it

The reconstruction of the distribution function of runaway electrons (RE) in magnetically confined fusion plasmas can give insights on the runaway electron beam dynamics during plasma disruptions and it may help at understanding the effect of disruption mitigation techniques on the RE velocity space. When RE are assumed to be purely co-passing, i.e. to have a pitch=1, a one dimensional inversion technique can be used to infer their energy distribution function from the bremsstrahlung spectrum. However, this holds only as an approximation, as the bremsstrahlung cross section depends also on the pitch of the electrons, besides energy, and this may deviate from unity. In view of enabling a two-dimensional, energy-pitch reconstruction of the RE velocity space, in this work we present a calculation of the weight functions for the bremsstrahlung emission by the RE. The weight functions allow bridging the bremssstrahlung spectrum with the RE velocity space, as they tell the region of the velocity space that contributes to a particular spectral measurement. The results are applied to investigate the RE velocity-space sensitivity of the hard X-ray diagnostic installed at the Joint European Torus.

37

Short_Oral_37: Inverse scattering based plasma density profilometry retrieval in front of ICRF Antennas

Authors: David Mascali[1]; Eugenia Naselli[1]; Giuseppe Torrisi[1]; Loreto Di Donato[2]; Santi Pavone[2]; Gino Sorbello[2]; Silvio Ceccuzzi[3]

[1] *INFN-LNS*

[2] *Università degli Studi di Catania - Dipartimento di Ingegneria Elettrica, Elettronica e Informatica (DIEEI)*

[3] *ENEA, DTT S.C.a.r.l., Frascati, Italy*

Corresponding Author: peppetorrisi@lns.infn.it

A new profilometry diagnostic method is investigated in this work to measure the plasma electron density profile in front of the Ion Cyclotron Range of Frequencies (ICRF) antennas. As a reference scenario for our numerical study, the Divertor Tokamak Test (DTT [1]) ICRF antennas and plasma will be considered. Specifically, the profilometry needs to solve an inverse scattering problem, which is non-linear and ill-posed. In some recent papers [2-4], we performed plasma imaging profilometry in compact plasma reactors, such as the electron cyclotron ion sources (ECRIS), by means of electromagnetic inverse scattering techniques requiring only measurements of the reflection coefficient. In this paper, we would like to extend this method also to large-size (scale-length) fusion reactors by addressing the profilometry of DTT-like plasma, assuming a very high-frequency probing regime (~ 0.5 THz) for the accessibility of both O and X-modes in the DTT plasma (electron density up to 10^20 m−3 and magnetic field up to 9 T). To this aim, we adopt a ray-tracing technique for describing wave propagation and to determine the probing antenna configuration, with a proper formulation which allows to reconstruct the non-homogeneous plasma, approximated as an isotropic medium, due to the high probing frequency.

[1] R. Martone, R. Albanese, F. Crisanti, A. Pizzuto, P. Martin, "DTT Divertor Tokamak Test facility Interim Design Report, ENEA, April 2019 ("Green Book")" https://www.dtt-dms.enea.it/share/s/avvgl-hVQT2aSkSgV9vuEtw

[2] L. Di Donato, A. F. Morabito, G. Torrisi, T. Isernia and G. Sorbello, "Electromagnetic Inverse Profiling for Plasma Diagnostics via Sparse Recovery Approaches," in IEEE Transactions on Plasma Science, vol. 47, no. 4, pp. 1781-1787, April 2019, doi: 10.1109/TPS.2019.2902469.

[3] G. Torrisi et al " Electromagnetic inverse profiling for plasma diagnostics in compact microwave-based ion sources Journal of Instrumentation", Volume 14, September 201931 3rd European Conference on Plasma Diagnostics (ECPD2019)

[4] Di Donato, L.; Mascali, D.; Morabito, A.F.; Sorbello, G. "A Finite-Difference Approach for Plasma Microwave Imaging Profilometry". J. Imaging 2019, 5, 70. https://doi.org/10.3390/jimaging5080070

40

Tutorial_0_T: European Fusion Roadmap

Author: Tony Donné[1]

[1] *EUROfusion*

Corresponding Author: tony.donne@euro-fusion.org

The European Roadmap to the realisation of fusion energy presents a long-term perspective on fusion. The roadmap covers three periods: The short term which is roughly until 2030, the medium term until 2040 and the long term.

ITER is the key facility of the roadmap as it is expected to achieve most of the important milestones on the path to fusion power. Thus, the vast majority of resources proposed in the short term are dedicated to ITER and its accompanying experiments. The medium term is focussed on taking ITER into operation and bringing it to full power, as well as on preparing the construction of a demonstration power plant DEMO, which will for the first time supply fusion electricity to the grid. Building and operating DEMO is the subject of the last roadmap phase: the long term. It might be clear that the Fusion Roadmap is tightly connected to the ITER schedule. A number of key milestones are the first operation of ITER (presently foreseen in 2025), the start of the DT operation foreseen in 2035 and reaching the full performance at which the thermal fusion power is 10 times the power put in to the plasma.

DEMO will provide first electricity to the grid. The Engineering Design Activity will start a few years after the first ITER plasma, while the start of the construction phase will be a few years after ITER reaches full performance. In this way ITER can give viable input to the design and development of DEMO. Because the neutron fluence in DEMO will be much higher than in ITER (atoms in the plasma facing components of DEMO will undergo 50-100 displacements during the full operation life time, compared to only 1 displacement in ITER), it is important to develop and validate materials that can handle these very high neutron loads. For the testing of the materials a dedicated 14 MeV neutron source is needed. This DEMO Oriented Neutron Source (DONES) is therefore an important facility to support the fusion roadmap.

The presentation will focus on the strategy behind the fusion roadmap and will describe the major challenges that need to be tackled on the road towards fusion electricity. Encouraging recent results will be given to demonstrate the progress of the focused approach in European fusion research.

41

Oral_28: Overview of the T-15MD tokamak diagnostics

Author: Alexey Sushkov[1]

[1] *National Research Center "Kurchatov Institute"*

Corresponding Author: alexey-sushkov@yandex.ru

The preparation of the T-15MD tokamak for the first experiments has been almost completed now. The main parameters of T-15MD are: R = 1.48 m, a = 0.67 m, B = 2.0 T, Ipl = 2.0 MA. Scientific objectives of the T-15MD are: investigation of the particle and energy transport in the ITER-like plasma configuration; disruption mitigation system development; plasma turbulence investigations; plasma edge physics; divertor optimization and first wall materials investigations under reactor-like power load on the divertor plates; steady-state operation; investigations of the advanced tokamak regimes with the real time MHD activity and current density profile control. To meet this challenge, the tokamak should be equipped with state-of-art diagnostics, real time plasma control, auxiliary heating and current drive systems. Therefore, in the vacuum vessel design, a special attention was focused to the convenient placement of the diagnostics and heating systems.

42

Tutorial_2: Nuclear measurements of fusion products in magnetic confinement reactors

Author: Massimo Nocente[1]

[1] *Dipartimento di Fisica - Università di Milano-Bicocca*

Corresponding Author: massimo.nocente@mib.infn.it

Fusion reactions in magnetic confinement systems generate MeV range particles, both charged and uncharged, which are key to qualify the fusion process. 14 MeV neutrons from the d+t ⟶ alpha + n fusion reaction in deuterium-tritium plasmas carry information on the fusion power and its profile, as well as on the kinematic properties of the fuel ions. 3.5 MeV alpha particles are responsible for the self-sustainment of the fusion burn, but their detailed physics is still partially unknown, as the fusion community awaits the production of a burning plasma at the ITER tokamak by the mid-2030s.
While the nuclear measurement of both type of fusion products is recognized as being key for the development of a fusion reactor, this is also – perhaps - one of the most difficult tasks for fusion diagnostics. As neutrons escape the confining magnetic fields, they can be measured directly. Through a careful and lengthy calibration procedure, fission chambers and activation foils allow determining the neutron yield up to a demonstrated accuracy of about 10%. Systems made of solid state or liquid detectors, deployed at the end of several collimated lines of sight, determine the spatial profile of the emission. A range of spectrometers with different design analyze the relatively narrow distribution of neutron energies around their peak at 14 MeV, which tells the kinematic properties of the fuel ions that generate the emission.
Charged fusion products, such as alpha particles from d+t, are more elusive. Faraday cups and scintillator probes can measure ions that are lost to the machine first wall, but their deployment is increasingly challenging as the fusion performance approaches reactor conditions, and possibly unfeasible in a reactor at full scale. On the other hand, confined fusion products are indirectly observed by the gamma-ray emission they induce. As in the case of neutrons, gamma-rays escape the confining magnetic field and travel along dedicated lines of sight, where spectrometers sufficiently away from the vacuum vessel can detect them.
In this tutorial presentation, the most established techniques for the nuclear detection of fusion products will be introduced, with examples taken predominantly from experience at the Joint European Torus. A discussion of the challenges the systems face as full scale reactor parameters are approached will also be presented, including the need for further research and development.

43

Oral_25: Plasma equilibrium reconstruction in a Tokamak

Author: Jacques Blum[1]

Co-authors: Blaise Faugeras [2]; Cedric Boulbe [2]

[1] *Laboratoire LJAD, Université Côte d'Azur*

[2] *Université Côte d'Azur*

Corresponding Author: jblum@unice.fr

The problem of the equilibrium of a plasma in a Tokamak is a free boundary problem, the plasma boundary being defined either by its contact with a limiter or as being a magnetic separatrix (hyperbolic line with an X-point).
The equilibrium equation inside the plasma, in an axisymmetric configuration, is a semi-linear elliptic partial differential equation, called Grad-Shafranov equation. The right-hand side of this equation is a non-linear source, which represents the toroidal component of the plasma current density.
The aim of this work is to perform the identification of this non-linearity from experimental data, such as magnetic measurements, polarimetric measurements (integrals of the magnetic field over several chords), kinetic pressure measurements or MSE (Motional Stark Effect) measurements.
Discrete magnetic measurements are interpolated thanks to toroidal harmonics in order to provide Cauchy boundary conditions on a closed fixed contour surrounding the plasma [ACL.B.Faugeras.14.2].
Polarimetry measurements can be modelized using the classical linear approximation or using the Stokes model [ACL.B.Faugeras.17.2, ACL.B.Faugeras.18.2].
A C++ software, called NICE/EQUINOX [ACL.B.Faugeras.12.1, ACL.B.Faugeras.18.2, ACL.B.Faugeras.20.2] has been developed in collaboration with the IRFM (Institute of Research on Magnetic Fusion) at CEA-Cadarache, and has been tested for WEST (the CEA-EURATOM Tokamak at Cadarache), JET (Joint European Torus), TCV, AUG and JT-60 SA in particular through the ITER-IMAS infrastructure.
It is possible to simulate ITER configurations.
Only a few number of degrees of freedom can be identified from the magnetic measurements (Dirichlet and Neumann boundary conditions) on the vacuum vessel.
A better identification of the current profile is performed by using other measurements such as polarimetric measurements.
This considerably improves the identification of the non-linearities and hence of the toroidal plasma current density.
An important problem is to achieve this within a few ms, so as to be able to control
in real time the current profile.
With all these techniques, it is possible to follow the quasi-static evolution of the plasma equilibrium in existing tokamaks.

[ACL.B.Faugeras.14.2]
B. Faugeras, J. Blum, C. Boulbe, P. Moreau, and E. Nardon.
Interpolation and extrapolation of discrete magnetic measurements with toroidal harmonics for equilibrium reconstruction in a Tokamak.
Plasma Phys. Control Fusion, 56:114010, 2014.

[ACL.B.Faugeras.17.2]
B. Faugeras, J. Blum, H. Heumann, and C. Boulbe.
Optimal control of a coupled partial and ordinary differential equations system for the assimilation of polarimetry stokes vector measurements in tokamak free-boundary equilibrium reconstruction with application to iter. Comput. Phys. Comm., 217(Supplement C):43 – 57, 2017.

[ACL.B.Faugeras.18.2]
B. Faugeras, F. Orsitto, and JET Contributors.
Equilibrium reconstruction at {JET} using {S}tokes model for polarimetry.
Nuclear Fusion, 58(10):106032, 2018.

[ACL.B.Faugeras.12.1]
J. Blum, C. Boulbe, and B. Faugeras.
Reconstruction of the equilibrium of the plasma in a tokamak and identification of the current density

profile in real time.
J. Computational Physics}, 231:960–980, 2012.

[ACL.B.Faugeras.20.2]
B. Faugeras.
An overview of the numerical methods for tokamak plasma equilibrium computation implemented in the NICE code.
Fusion Eng. Design, 160:112020, 2020.

44

Oral_21: Feedback control using divertor multi-spectral imaging diagnostics

Author: J.T.W. Koenders[1]

Co-authors: A. Perek [1]; M. van Berkel [1]; C. Galperti [2]; B.P. Duval [2]; O. Février [2]; B. Kool [1]; T. Ravensbergen [3]; C. Theiler [2]; M.R. de Baar [1]

[1] *DIFFER - Dutch Institute for Fundamental Energy Research, Eindhoven, the Netherlands*

[2] *Ecole Polytechnique Fédérale de Lausanne (EPFL), Swiss Plasma Center (SPC), Lausanne, Switzerland*

[3] *ITER Organization, St. Paul Lez Durance Cedex, France*

Corresponding Author: j.t.w.koenders@differ.nl

The heat and particle exhaust in tokamaks is guided to a dedicated region called the divertor. Unmitigated, the expected power fluxes impacting the divertor targets during reactor relevant operation exceed present-day engineering limits [1]. Real-time feedback control of plasma detachment, a regime characterized by a large reduction in plasma temperature and pressure at the divertor target, is required to maintain a sufficient reduction of these fluxes [2, 3]. During plasma detachment a temperature gradient along the divertor leg is established. This gradient gives rise to a sharp optical emission fall-off, frequently referred to as a front. These fronts are indicative of a local electron temperature, and their location can be used as a measure of detachment strength. A real-time algorithm for detection of these radiation fronts using multi-spectral imaging was recently developed [4], and experimentally demonstrated [5] on the Tokamak à Configuration Variable (TCV) [6] utilizing the multi-spectral imaging diagnostic MANTIS [7].

In this talk, we will show the state-of-the art and further development of using MANTIS for feedback control of the divertor plasma. Including: 1) feedback-control of the C-III emission front using deuterium fueling and the N-II emission front using nitrogen seeding, and 2) the use of system identification techniques to obtain control-oriented models for offline controller design. We conclude with our view towards multi-input, multi-output (MIMO) control of the divertor plasma using MANTIS, fully exploiting its 10 available cameras. Specifically, combining multiple spectrally filtered images to obtain real-time information on the loss processes driving detachment.

References

[1] R. Pitts et al., Nucl. Mat. Ener. 20, 100696 (2019)
[2] B. Lipschultz et al., Nuclear Fusion 56, 056007 (2016)
[3] A. Leonard, Plasma Phys. Control. Fusion 60, 044001 (2018)
[4] T. Ravensbergen et al., Nucl. Fusion 60, 066017 (2020)
[5] T. Ravensbergen et al., Nat. Commun. 12, 1105 (2021)
[6] S. Coda et al., Nucl. Fusion 59, 112023 (2019)
[7] A. Perek et al., Rev. Sci. Instrum. 90, 123514 (2019)

45

Tutorial_3: A systems and control perspective on fusion plasmas

Authors: Marco de Baar[1]; Matthijs van Berkel[1]

[1] *NWO institute DIFFER*

Corresponding Author: m.r.debaar@differ.nl

A short historical overview of modern systems and control theory is given. Basic systems and control concepts are introduced, with special emphasis on their relevance for Nuclear Fusion research.
Control parameters and associated processes for present-day fusion experiments are identified and classified. The state-of-the-art fusion plasma control for these categories will be presented. The gap to burn control will be identified and it will be shown that a model based control approach is essential for the development of control of fusion reactors.
Models are required to synthesize controllers and test their performance, to interpret data of multiple sensors in real-time, and to anticipate and avoid limits in the plasma. We will discuss how such models can be built from first principles or can be extracted from experimental data. Finally, we will discuss the (need for the) development of supervisory controllers, essential to deal with discrete events in the plasma that necessitate a change in the controller functionality.

46

Oral_26: Multi-Channel Synchronized Data Acquisition Techniques for Plasma Diagnostics

Author: Jan-Erik Eklund[1]

[1] *Teledyne SP Devices*

Corresponding Authors: kacper.matuszynski@teledyne.com, jan-erik.eklund@teledyne.com

High-performance data acquisition is an essential part of plasma fusion diagnostics instruments. Typically, the measurement is conducted using a pulsed laser that generates repeated pulses that are shone into the plasma. Some of the laser light is scattered of free electrons in the plasma resulting in spectral expansion. Digitizers enable measurements of the scattered photons in a time domain by sampling at the speed of 10^9 Sa/s. Synchronizing (even) hundreds of channels is a challenge for modern digitizers to distribute the trigger signal and capture the data simultaneously in reference to the laser. The most common solution is to use passive impedance matched splitters to fan out a trigger signal in a star pattern. However, this solution does not scale with the number of digitizers in the system—eventually, the trigger signal is attenuated, and the trigger edge is distorted, which results in a precision loss. To address these issues a special daisy-chain triggering system was developed. The trigger signal is passed from one device to the next using the SYNC IN/OUT connectors. However, a common time frame is needed to keep track of the trigger point across all devices. A system consisting of several chassis must use an external source provided to each chassis through cables of equal length. The first device in the daisy chain is designated as the master device and the other as consecutive slave devices. The trigger signals in consecutive digitizers are delayed precisely by the 10MHz reference period. In turn, this means that each slave device will have to record data before its perceived trigger point to capture data around the true trigger point. When the data is retrieved, following a successful acquisition, the trigger information from the slave devices is adjusted with the trigger information from the master device. This technology was tested in the Joint European Torus (JET).

Disclaimer: the technology was developed by Teledyne Signal Processing Devices Sweden AB and the related products and materials belong to the company.

47

Short_Oral_47: Application of FDTD algorithm to the analysis of polarization state evolution in tokamak plasma

Author: Bohdan Bieg[1]

[1] *Maritime University of Szczecin*

Equations of Stokes vector formalism or the technique of angular variables are usually used to analyze the evolution of the electromagnetic wave polarization state in a tokamak plasma. Both approaches assume that plasma is a weakly anisotropic and smoothly inhomogeneous media. The description of polarization changes for the plasma that does not meet these assumptions (e.g. in the region of turbulent plasma) requires a numerical solution of Maxwell's equations. In such a case the finite-difference time-domain (FDTD) method can be used. This paper presents a computational algorithm based on the FDTD method. To test the software, a linear polarized wave propagation through the magnetized tokamak plasma has been simulated and compared to the solution based on the angular variables technique in selected plasma conditions.

48

Short_Oral_48: CVD diamond detectors for VUV and SX-ray fusion plasma diagnostics

Authors: Silvia Cesaroni[None]; Maurizio Angelone[1]; Gerarda Apruzzese[1]; Francesca Bombarda[1]; Lori Gabellieri[1]; Marco Marinelli[2]; Enrico Milani[2]; Silvia Palomba[2]; Gianluca Pucella[1]; Afra Romano[1]; Claudio Verona[2]; Gianluca Verona-Rinati[2]; Cristina Centioli[1]; Andrea Grosso[1]; Valerio Piergotti[1]; Giuliano Rocchi[1]; Alessandro Sibio[1]; Benedetto Tilia[1]

[1] *ENEA, Fusion and nuclear safety department, Frascati (Rome), Italy*

[2] *"Tor Vergata" University of Rome, Industrial Engineering Department, Rome, Italy*

Corresponding Author: silvia.cesaroni@uniroma2.it

Diamond is a semiconducting material widely used in technological applications where extreme operating conditions are required: its outstanding physical and electrical properties (high band-gap, high thermal conductivity, high radiation hardness, high charge carrier mobility, visible-band radiation blindness) make feasible the realization of fast, low noise and well performing radiation detectors suited to withstand environments characterised by high temperatures and high radiation fluxes like those found in thermonuclear fusion experiments. In view of the above, diamond detectors appear to be especially promising for VUV and Soft X-ray (SX) radiation detection and two of them were successfully installed on JET since 2007 [1].

We report on the performances of two Chemical Vapor Deposition (CVD) single crystal diamond-based detectors installed in one of the equatorial ports of the FTU tokamak during the last two experimental campaigns of the machine. The devices were developed by University of Rome "Tor Vergata" and they are Schottky photodiodes with a metal/intrinsic/p-type diamond layered structure; their responsivity curves (A/W vs incident photon energy) were calculated from tabulated atomic scattering factors [2]. The diamond detectors were placed in the machine high vacuum and they were operated in current mode using low-noise preamplifiers.

Several examples of plasma events have been collected, confirming the fast response capabilities of diamond detectors. The so-called Anomalous Doppler Instabilities were observed and there are interesting results related to the pellet ablation during a SPI. Diamond detectors often but not always followed the MHD activity, depending on its localization relative to the emitting region. Core temperature oscillations following ECH modulation were also observed. The comparison of the diamond signals was extended to selected channels of the FTU bolometry system [3] with similar line-of-sight and the encouraging results have launched an R&D program for the development of diamond-based bolometers.

[1] M. Angelone et al., Nucl. Instrum. and Methods A 623, 726 (2010)
[2] B. L. Henke, E. M. Gullikson and J.C. Davis, Atomic data and nuclear data tables 54(2), 181 (1993)
[3] L. Di Matteo, Technical Report RT_2009-38-ENEA, 2009

49

Oral_20: Overview on the development of the plasma diagnostic and control system for the European DEMO reactor concept

Authors: Wolfgang Biel[1]; Marco Ariola[2]

[1] *Institute of Energy- and Climate Research, Forschungszentrum Jülich GmbH, Jülich, Germany*

[2] *Universita' di Napoli "Parthenope", Consorzio CREATE, Italy*

Corresponding Author: w.biel@fz-juelich.de

Within the European development of the concept for a future tokamak demonstration fusion power plant (DEMO) [1] the studies on the plasma diagnostic and control (D&C) system are progressing to prepare the basis for reliable plasma operation at high overall performance [2]. A variety of plasma diagnostics will be employed on DEMO in order to provide an accurate knowledge of the actual plasma state, which is needed to achieve controlled plasma operation within the allowed physical and technical limits. In addition, model based control techniques will be employed to provide early predictions of critical evolutions of the plasma state and to allow for timely reactions by the control system.

The integration of diagnostic front-end components on DEMO has to cope with strong adverse effects arising from neutron and gamma irradiation, heat loads, impinging particles and forces. In this environment, the quality of measurements can only be ensured for longer periods by using robust diagnostic components, mounting them in sufficiently protected (retracted) locations, and any maintenance can only be performed via remote handling. Major open issues are the durability of magnetic measurements in the presence of irradiation induced effects and the feasibility of detachment control under DEMO conditions. In parallel to diagnostic developments, the details of the main control issues are being formulated and investigated by quantitative plasma control simulations. In order to obtain the envisaged desired power output, DEMO operates close to some physics limits where even small disturbances, if not properly controlled, can trigger major variations of the plasma parameters. Equilibrium control requires high control power and can drive the poloidal field coil system to its operational limits. Within this paper, we will provide an overview on the current status of the ongoing D&C developments for the European DEMO concept.

References:

[1] G. Federici et al., Fus. Engin. Des. 109-111 (2016) 1464-1474

[2] W. Biel et al., Fus. Engin. Des. 146 (2019) 465-472

50

Tutorial_5: Introduction to Stellarator Diagnostics

Authors: Robert Wolf[1]; Wendelstein 7-X Team[None]

[1] *MPI for Plasma Physics*

Corresponding Author: robert.wolf@ipp.mpg.de

Stellarators have fundamental advantages, providing steady-state magnetic confinement of fusion plasmas without large toroidal currents and without the associated instabilities and operational limits. In order to fully exploit these advantages, the design of stellarators has to undergo elaborate optimization procedures. Optimization criteria range from reduced neoclassical transport and high-β stability, to acceptable fast ion confinement and reduced or tailored intrinsic plasma currents. However, generating a rotational transform by external coils means that stellarators cannot be toroidally symmetric. As a consequence, the plasma equilibrium and the divertor configuration have to follow the predefined 3D-geometry.
Based on these design criteria, stellarator experiments such as Wendelstein 7-X have operational requirements deviating from comparable tokamaks. Aiming at 30 minutes high performance plasmas, long-pulse plasma operation puts specific demands on diagnostics, data acquisition and plasma control: Long-term effects, continuous provision of data and the protection and cooling from steady energy and particle fluxed need to be considered. An example is the dispersion interferometer, which has to provide accurate density measurements without detrimental drifts or fringe jumps. A magnetic island divertor, following the helicity of the edge magnetic field, requires full 3-dimensional coverage by infra-red systems to monitor and assess heat exhaust including the symmetry of the heat distribution. Recent measurements using coherent imaging spectroscopy made the complicated flow patterns in the plasma boundary layer visible. An additional feature of stellarators is that achieving optimum confinement requires high plasma densities (up to $2{\times}10^{20}$ m^{-3}), which is actually advantageous for achieving optimal fusion parameters. For this reason in Wendelstein 7-X, the conditions for the use of the 3^{rd} harmonic X-mode ECE as an electron temperature measurement above the X2 cut-off density were investigated. Moreover, the validation of the optimisation criteria generates a whole range of very specific diagnostic requirements. Very complex tasks are, for instance, the assessment of fast ion confinement, which in Wendelstein 7-X improves with plasma-β, or the measurement of the small deviations from the rotational transform caused by residual plasma currents or by local current drive. With the reduction of neoclassical transport, turbulent transport becomes increasingly important for the characterization of plasma confinement. However, the 3-dimensional geometry means that the turbulent modes may be toroidally and poloidally localized (e.g., through "bands" of unfavourable curvature drive), which makes them more difficult and costly to observe.
Using Wendelstein 7-X as an example, the presentation will address the specific diagnostic requirements going along with the special properties of (optimized) stellarators. Driven by scientific goals, Wendelstein 7-X enters into a new era of long-pulse-capable instruments. The special features of the diagnostics will be illustrated by selected highlights.

51

Tutorial_3: Microwave Diagnostics for Fusion Reactors

Authors: Neville Luhmann, Jr.[1]; Yilun Zhu[1]; Benjamin Tobias[2]; Jo-Han Yu[1]; Q. Jane Gu[1]; Ying Chen[1]; Anh-Vu Pham[1]; Ahmed Diallo[3]; Y. Ren[3]; William Tang[3]; G. Dong[3]; D Gamzina[4]; Srabanti Chowdhury[5]; J.R. Sirigiri[6]

[1] *University of California, Davis*

[2] *LANL*

[3] *PPPL*

[4] *Elvespeed, Inc.*

[5] *Stanford University*

[6] *Bridge12 Technologies*

Corresponding Author: ncluhmann@ucdavis.edu

Microwave diagnostics are particularly important in that they do not, in general, perturb the plasma being measured, have relatively modest access requirements, and excellent spatial and temporal resolution. Fundamental measurements include: electron temperature (ECE radiometry), electron density (interferometry, polarimetry, and reflectometry), thermal, energetic, fuel, ash, and impurity ion distributions (ion cyclotron emission and collective Thomson scattering), fluctuations and flows (ECE-Imaging and microwave imaging reflectometry(MIR); Doppler, high-k, and cross-polarization scattering). In this tutorial, we describe the basic principles of a number of microwave diagnostics. Although the basic principles may be understood through reference to the cold plasma permittivity, the case of burning plasmas requires a treatment that encompasses thermal plasmas, non-thermal distributions, and relativistic effects.
In implementing microwave diagnostics on reactor plasmas, there is a slight increase in required operating frequencies mandating some technology developments1. However, there are considerably more serious issues raised by the harsh radiation environment. ITER is the first magnetic confinement fusion machine to be able to produce net fusion power and will generate radiation levels, i.e., neutrons and gamma rays, that are orders of magnitude higher than present-day experimental machines. There is thus a need to develop electronics with higher performance and capability, as well as the robustness to survive the hostile burning plasma environment. Major improvements can be realized by employing wide-bandgap materials, such as gallium nitride (GaN), which has a bandgap of 3.39 eV versus 1.43 and 1.11 for GaAs and Si, respectively. GaN semiconductor devices have been shown to handle high power, exhibit high breakdown voltages and low noise beyond 200 GHz. In addition, we describe recent activity in the development of ultra-miniature vacuum devices fabricated using solid-state technology which are also well suited to the harsh, reactor environment and which can provide the required power for active microwave probing diagnostics.
Another recent advance is the so-called "System-on-Chip" millimeter wave integrated circuit technology, where complete receivers and transmitters are fabricated on an advanced substrate integrated with high-reliability circuit protection and packaging. This allows one to optimize custom solutions that can be fabricated in bulk quantities at a fraction of today's cost. The small size of the resultant components greatly simplifies the shielding. Advanced optical designs reduce the port access requirements and are key to

52

Short_Oral_52: Development of a compact multivariable sensor probe for two-phase detection in high-temperature PbLi-Ar columns

Author: ABHISHEK SARASWAT[1]

Co-authors: Ashokkumar Prajapati [2]; Rajendraprasad Bhattacharyay [2]; Paritosh Chaudhuri [2]; Sateesh Gedupudi [3]

[1] *INSTITUTE FOR PLASMA RESEARCH*

[2] *Institute for Plasma Research*

[3] *Indian Institute of Technology Madras*

Corresponding Author: asaraswat@ipr.res.in

Nuclear fusion Breeding-Blanket (BB) concepts employ attractive solid and liquid breeder materials in the form of lithium/lithium-containing compounds like Li, Pb-16Li, Li2O, LiAlO2, Li4SiO4, Li2SiO3, Li2TiO3 and Li2ZrO3. Out of these candidate materials, eutectic lead-lithium (Pb-16Li; hereafter referred to as PbLi) has gained immense focus owing to its various advantages including a high tritium breeding ratio (TBR) without an additional neutron-multiplier, circulation ability facilitating tritium-extraction outside fusion blanket, inherent immunity towards radiation damage and thermal stresses, high thermal-conductivity and reduced chemical-activity compared to pure Li. Success of a breeder concept is primarily governed by TBR and heat-extraction performance, which can be well achieved using PbLi in a self-cooled concept. However, interaction of Li with fusion neutrons to breed tritium leads to generation of helium gas as a by-product, which has a low-solubility in PbLi and could precipitate in the form of bubbles affecting system design and safety. Gas-phase generation and entrapment within a breeder/coolant liquid-metal circuit may lead to reduction in fuel-generation due to reduction in TBR, safety consideration caused by improper nuclear shielding and jeopardized structural integrity due to formation of local hot-spots. Recent simulation studies have reported significant gas generation for PbLi flow-rates upto 1000 kg/s, which further suggests various breeding blanket (BB) concepts like HCLL (Helium-Cooled Lithium Lead), WCLL (Water-Cooled Lithium Lead), DCLL (Dual Coolant Lithium Lead) and LLCB (Lead-Lithium Ceramic Breeder), therefore, would invariably be prone to such a phenomenon. An in-box Test Blanket Module (TBM) Loss of Coolant Accident (LOCA) will further lead to ingress of a high-pressure gas-phase (helium/steam) inside PbLi circuit, resulting in a liquid metal-gas two-phase flow with unconventionally high density-ratio between the two-phases, unlike the case of generally studies water-air flows. Preliminary experimental studies at Institute for Plasma Research (IPR) with water as a surrogate test-fluid corroborated presence of trapped gas-pockets at 90° bends and entrained gas-bubbles in recirculation zones inside TBM-like complex geometry. A two-phase regime and trapped gas-pockets are also expected in lab-scale R&D facilities due to standard practices of charging liquid-metal in presence of an inert cover gas to avoid oxidation. To model such occurrences of relevance towards design and operational safety of ancillary breeder/coolant circuits towards applications in future fusion reactors, extensive experimental database needs to be generated, mandating development of proper diagnostic tools compatible with high-temperature and corrosive PbLi environment. Numerous experimental studies for room temperature and low-melting LMs have been conducted worldwide utilizing commercial and specialized techniques like particle image velocimetry, laser, γ-ray, X-ray, neutron radiography, ultrasound doppler velocimetry, etc. Although such techniques inherently benefit from their non-intrusive nature of detection, the required resources, licensing requirements, opaque nature of fluid coupled with extreme operating environments, installation constraints, requirements of localized detections and high-attenuation characteristics exhibited by liquid-metals towards radiation methods render most of the techniques challenging towards a practical implementation in a PbLi circuit. As a preliminary attempt to study two-phase flow regimes, electrical-impedance based techniques offer a better route considering ease of installation, feasibility of adaptation and better-response owing to large difference in electrical-conductivities of liquid-metal and gas. However, adaptation of such a technique towards PbLi scenario puts severe demands on electrical-insulation compatibility towards corrosive media and operational temperature upto 400℃. Considering above-mentioned limitations and unavailability of experimental data, researchers have recently initiated studies utilizing numerical tools to predict two-phase flow regimes in PbLi/He environment. To the best knowledge of authors, no reported experimental data exists for two-phase flow detection in PbLi environments.

This work primarily aims to bridge the existing gap with development and preliminary validation of a compact sensor probe as a measurement tool to study two-phase regimes in PbLi environment.

In this study, a multivariable probe employing electrical-conductivity based detection with simultaneous temperature measurement scheme is fabricated using an electrical-insulation coating of high-purity alumina (Al2O3). Fabricated probe is then validated towards detection on Argon bubbles rising in a high-temperature PbLi-Ar two-phase vertical column with bulk PbLi temperature upto 400℃. Two-phase generation in liquid-metal environment is achieved using an 8-legged spider-configuration gas sparger. Probe is functionally validated for time-averaged void-fraction varying from 0 to 0.95 covering flow regimes from dispersed bubbly flow upto in-box Loss of Coolant Accident (LOCA) characterized by a very large gas flow inside bulk PbLi. Developed probe provides high reliability with excellent temporal-resolution towards individual bubble detection using electrical-conductivity based principle while coherent two-phase bulk temperature trends provide qualitative insights about the presence of two-phase regime. Present paper provides details about sensor probe fabrication and calibration methods, PbLi-Ar two-phase test-facility, time-averaged void-fraction estimations using threshold method, bubble-frequency and bubble residence-time estimations along-with critical observations from the preliminary experimental investigations.

57

Oral_15: Development of Nuclear Detectors for Tokamak Harsh Environments

Author: Maurizio Angelone[1]

[1] *ENEA*

Corresponding Author: maurizio.angelone@enea.it

Fusion and hybrid fusion-fission reactors (HFFR) are characterized by having intense neutron and gamma fluxes and high working temperature. This is particularly relevant for the breeding blanket region (BB) whose environment results very hostile to nuclear detectors to be used to monitor/measure fundamental nuclear parameters like e.g. neutron/gamma fluxes and spectra, tritium production, etc. furthermore, these experimental quantities need to be compared with the prediction from the calculation tools used for the BB design so providing information about the affordability of the tools.
Presently no detectors are ready for being hosted in the harsh environment of the BB and R&D activity is needed to develop and test the detectors. Some important lessons about the detectors can be learned from past activities carried out in the EU, devoted to studying and realizing nuclear detector prototypes for the European Test Blanket Modules (TBM) of ITER. Amongst the other, these studies pointed out the need for intense neutron source, appropriate calibration facilities closely reproducing the expected working environments for testing the prototypes and accurate simulation of the proposed detectors. Simulation allows to mimic and thus foresee the response and performances of the detectors under the expected working conditions as well as to compare the prediction to the experimental tests in the calibration facilities.
To mention that the experience gained so far for ITER-TBMs can be helpful also to study and develop nuclear detectors for hybrid fusion-fission reactors (HFFR). Indeed, despite the difference, TBMs/BB of fusion devices and the breeding blanket of HFFR reactors experience a number of similarities in terms of radiation level, temperature and nuclear quantities to be measured, so the lesson learned for ITER-TBM can be very helpful to study and develop nuclear detectors to be used in hybrid reactors.
In this paper the results so far achieved at ENEA Frascati in developing nuclear detectors for the ITER-TBM as well as the many issues not yet solved are highlighted and the possible follow up to HFFR instrumentation discussed.

58

Oral_19: Diagnostic integration concepts for DEMO – The reflectometry example

Author: Artur Malaquias[1]

Co-authors: Raul Luis [2]; António Silva [2]; Yohanes Nietiadi [2]; Jorge Belo [2]; Alberto Vale [2]; Diogo Rechena [2]; Jorge Santos [2]; Filipe Silva [2]; Emanuel Ricardo [2]; Wolfgang Biel [3]

[1] *Instituto Superior Técnico*

[2] *Instituto de Plasma e Fusão Nuclear, Instituto Superior Tecnico, Universidade de Lisboa*

[3] *Institute of Energy- and Climate Research, Forschungszentrum Jülich GmbH, Jülich, Germany*

Corresponding Author: artur.malaquias@ipfn.tecnico.ulisboa.pt

Integration studies of diagnostics in fusion grade devices (e.g. ITER, DEMO) aim to provide concepts and technical solutions for installation of diagnostic components that can perform the required measurements in a nuclear harsh environment while providing an optimized interface with the baseline tokamak systems and services and offering high levels of reliability and lifetime.
The challenges to overcome are relatively large in view of the unavoidable intrusion into otherwise optimised tokamak systems (blanket, divertor, vessel, etc.). For instance, the simple notion of apertures for plasma access (e.g. spectroscopy or reflectometry diagnostics) would imply reduction of the final Tritium breading ratio. Or the installation of in-vessel diagnostic components would require traversing safety and vacuum boundaries. Finding solutions for integrating diagnostics poses more stringent requirements on components performance to not become a weak point in the system and imposing higher maintenance rates. Assessment of risks, failure modes and criticality analysis, and remote handling compatibility are examples of constraints that emerge from fusion power plant requirements that need to be included on the diagnostic design. Open options on machine baseline systems also strongly affects the diagnostic design. In particular, the selection of one or other blanket type has implications on shielding effectiveness, immediately translated in different diagnostic cooling requirements, which influences not only mechanically but functionally the choice of diagnostic designs.
In this presentation we discuss the status of the reflectometry diagnostic illustrating the steps on the measurement optimization and integration concept in DEMO. Studying concepts that minimise the disturbance to the plant systems requires an early parallel development of the interfaces between diagnostic and the baseline systems and services in order to elaborate a more realistic analysis (mechanical, thermal, functional, etc.) and deliver a robust diagnostic system.

59

Oral_28: ITER Diagnostics Progress in China

Author: Tongzhen Fang[1]

[1] *Chinese domestic agency*

Corresponding Author: fangtz@iterchina.cn

Four ITER diagnostics are being developed in China, namely Neutron Flux Monitors (NFM), Radial X-Ray Camera (RXC), Equatorial Port 12 (EP#12) Integration, and Divertor Langmuir Probes (DLP). Based on functional specifications, China Domestic Agency (CNDA) performs the design of the diagnostic system besides delivering the diagnostic components. NFMs, located in equatorial port 1, 7, 8, 17, measure the total neutron flux and emissivity from the plasma, providing information of the fusion power. RXC, providing measurement of the X-ray emission over the full poloidal profile, will be integrated within EP#12, together with 6 other tenant systems. DLP, with 400 probes installed along five divertor cassettes, measures the plasma parameters at the divertor target plates. As one of the most advancing ports, EP#12 design has been completed and steps into manufacturing phase, targeting ITER first plasma in 2025. RXC system has completed the design of camera structure, electronics, and instrumentation and control (I&C) components. NFM in EP#07 has passed the preliminary design review (PDR), a gate before proceeding to final design phase, while the remaining NFMs in other ports are in PDR phase. Moreover, NFM#07 sub-system "support frame", a captive component, became the first diagnostic component installed in the tokamak pit. Regarding the DLP system, the probe sensors need to survive the high thermal and nuclear radiation in the ITER divertor, which leads to a full-tungsten design. The probe manufacturing had been studied and samples are being tested for structure and performance assessment. With strong support from Southwestern Institute of Physics (SWIP) and Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), CNDA is working closely with ITER Organization and other interfacing DAs, increasing pace as ITER construction accelerates.

60

Oral_24: Progress in ITER ECE Diagnostic Design and Integration

Authors: Victor Udintsev[1]; Yong Liu[2]

Co-authors: G. Paraiso [3]; Gary Taylor [3]; S. Danani [4]

[1] *ITER Organisation*

[2] *ITER Organization*

[3] *Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ 08543, USA*

[4] *ITER-India, Institute for Plasma Research, Bhat Gandhinagar-382 428, India*

Corresponding Author: yong.liu@iter.org

Abstract. The ITER Electron Cyclotron Emission (ECE) diagnostic has primary roles in providing measurements of the core electron temperature profile and the electron temperature fluctuation associated with the Neoclassical Tearing Modes (NTM). Indian domestic agency (IN-DA) and US-DA share the responsibility to supply this diagnostic. The IN-DA scope has passed its Preliminary Design Review (PDR) and is progressing towards the Final Design Review (FDR). In parallel, the diagnostic integration in the Equatorial Port is ongoing. Several so-called captive components for transmission lines have passed FDR and will be manufactured for installation in the tokamak building soon. The ITER ECE system includes radial and oblique lines-of-sight. Four 45-meter long low-loss transmission lines are designed to transmit mm-wave power in the frequency range of 70- 1000 GHz in both X- and O-mode polarization from the port plug to the ECE instrumentation room in the diagnostic building. Prototype transmission lines are being tested. A prototype polarizing Martin-Puplett type Fourier Transform Spectrometer (FTS), operating in the frequency range 70-1000 GHz, features an in-vacuo fast scanning mechanism and a cryo-cooled dual-channel THz detector system. Its performance has been assessed in detail against ITER requirements. Assessment of the instrumentation and control requirements, functional and non-functional requirements, operation procedures, plant automation are ongoing. The current status of the diagnostic, together with integration activities, is presented.

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

62

Oral_11: ITER Beam Aided Diagnostics

Author: Fred Levinton[1]

[1] *Nova Photonics, Inc.*

Corresponding Author: flevinton@novaphotonics.com

The plan for ITER is to have a comprehensive suite of diagnostics for machine protection, basic machine control, advanced plasma control, and physics studies. This includes measurements typically seen on present day fusion devices, however ITER is unlike any device presently operating. In particular the high fusion production rate and large plasma size combined with the high density and long pulse make diagnostic designs extremely challenging. The high fluency of neutron and gamma radiation from DT operation result in design issues affecting thermal loading, activation, and darkening of optics. This leads to complex optical design paths utilizing mirrors in a labyrinth to reduce activation and mitigate neutron streaming. The difficulty of access and long pulse makes maintenance of the plasma facing optical component, usually a mirror, a challenging problem. Coating from plasma deposition is expected to significantly degrade the reflectivity of the plasma facing mirror surface over time. A cleaning system that is based on a plasma source in close proximity to the mirror will be integrated into the design to remove deposited impurities by sputtering and restore the mirror reflectivity to an acceptable level for the diagnostic measurement. The large high density plasma means the heating neutral beam (HNB) energy is 1 MeV to penetrate the plasma, which has consequences for both the motional Stark effect (MSE) and the charge exchange recombination spectroscopy (CXRS) diagnostics. In the case of MSE it is an advantage. The larger beam energy results in a larger Lorentz ($v \times B$) electric field and spectral splitting. We can take advantage of this and use a new approach for MSE measurements utilizing the spectral splitting. However, for CXRS it is problematic. Above about 100 keV/amu the charge exchange cross sections drop precipitously, so much so that a dedicated diagnostic beam (DNB), operating at 100 keV, will be used for all the CXRS measurements. Numerous constraints on the optical design require multiple viewing systems to obtain a profile to cover the minor radius for both MSE and CXRS.

63

Oral_14.1 Introduction to LHD diagnostics

Author: Tokihiko Tokuzawa[1]

[1] *National Institute for Fusion Science*

Corresponding Author: tokuzawa@nifs.ac.jp

The LHD is the world's largest (30 m ⁻³) helical plasma confinement device, with a major radius of 3.9m and an average small radius of 0.65m. In order to make the best use of the characteristics of the three-dimensional magnetic coordination, a number of diagnostics have been developed and applied. For profile measurements, electron temperature and density by Thomson scattering, electron density by FIR and CO2 laser interferometer, ion temperature by CXS, rotational transform by MSE, impurity measurement by multichannel spectrometer, etc. For turbulence physics research, PCI with spatial resolution using the pitch angle of the magnetic field, DBS with multi frequency channel, BS specialized for electron-scale measurement, and HIBP with potential and density information are utilized. Imaging measurements to promote intuitive understanding of complex plasma structure are also being developed, and IR bolometers, tangential SX cameras, BES, GPI, and ECEI are being applied. We are also trying to develop advanced measurements for the era of nuclear burning experiments, such as velocity and phase space measurements of high-energy particles using CTS, FIXS, CXS, etc. We have also developed and are using the LABCOM system, which is a sophisticated system for collecting data for each instrument and linking it with a data server, as well as the AutoANA system for automatic data analysis and MyView2, a dedicated viewer. These assets can be applied to other devices in the future, so please consider them.

This work was partially supported in part by KAKENHI (Nos. 19H01880 and 21H04973), by a budgetary Grant-in-Aid from the NIFS LHD project under the auspices of the NIFS Collaboration Research Program.

64

Oral_14.2: Energetic-particle physics studies with an integrated set of neutron and energetic-particle diagnostics in LHD deuterium discharges

Author: Mitsutaka Isobe[1]

Co-authors: Kunihiro Ogawa [1]; Siriyaporn Sangaroon [1]; Shuji Kamio [1]; Yutaka Fujiwara [1]; Makoto Kobayashi [1]; Ryosuke Seki [1]; Hideo Nuga [1]; Sadayoshi Murakami [2]; Yutaka Matsumoto [3]; Takafumi Homma [3]; Masaki Osakabe [1]

[1] *National Institute for Fusion Science*

[2] *Kyoto University*

[3] *Hokkaido University*

Corresponding Author: isobe.mitsutaka@nifs.ac.jp

The Large Helical Device (LHD) has been operated with deuterium gas since March 2017 [1]. One of primary objectives of the LHD deuterium operation is to demonstrate energetic-particle (EP) confinement in a toroidal magnetic field with three dimensionality, and to contribute to comprehensive understanding of EPs in toroidal magnetic confinement system. Because beam-driven DD neutron and secondary DT neutron resulting from burnup of DD-born 1 MeV triton become available in LHD as a new measurement object, LHD has been equipped with an integrated set of neutron diagnostics, e.g. in situ calibrated neutron flux monitor, neutron activation system, vertical neutron cameras etc. [2], and has been steadily extended year by year[3]. The maximum total neutron emission rate has reached 4.1×10^15 (n/s) in LHD. By using this system, change of DD neutron emission profile before and after EP-driven MHD instabilities, presence of beam ion trapped in a helical ripple well has been clearly observed. Confinement of DD-born 1 MeV tritons has been also demonstrated for the first time in heliotron/stellarator plasmas. Lately we have initiated neutron spectrometry to obtain further understanding of beam ions' kinematics [4]. In parallel to the upgrade of neutron diagnostic system, EP diagnostics, e.g. CVD diamond detector as a neutral-particle analyzer [5], Fast-ion D-alpha diagnostics often called FIDA [6] has been largely enhanced. Recent advances of neutron and EP diagnostics, and representative results from EP physics experiments in LHD will be presented.

[1] M. Osakabe et al., IEEE Trans. Plasma Sci. 46 (2018) 2324.
[2] M. Isobe et al., IEEE Trans. Plasma Sci. 46 (2018) 2050.
[3] K. Ogawa et al., Plasma Fus. Res. 16 (2021) 1102023.
[4] S. Sangaroon et al., European Conference on Plasma Diagnostics (ECPD)2021, 7th-11th June, 2021, Virtual conference., room 14 in poster session 02.
[5] S. Kamio et al., JINST 14 (2019) C08002.
[6] Y. Fujiwara et al., Nucl. Fusion 60 (2020) 112014.

65

Short_Oral_65: Design considerations of the european DEMO's IR-interferometer/polarimeter based on TRAVIS simulations

Authors: Kai Jakob Brunner[1]; Wolfgang Biel[2]

Co-authors: Massimiliano Mattei [3]; Francesco Palermo [4]; Emiliano Fable [5]; Nikolai Marushchenko [6]; Matthias Hirsch [6]; Robert Wolf [7]

[1] *Max-Planck-Institute for Plasma Physics, Greifswald, Division E3*

[2] *Institute of Energy- and Climate Research, Forschungszentrum Jülich GmbH, Jülich, Germany*

[3] *Università della Campania "Luigi Vanvitelli"*

[4] *UK Atomic Energy Authority*

[5] *Max-Planck-Insitute for Plasma Physics*

[6] *Max-Planck-Institute for Plasma Physics*

[7] *MPI for Plasma Physics*

Corresponding Author: k.j.brunner@ipp.mpg.de

Interferometry has to this day been an essential diagnostic on any medium to large scale fusion experiment, primarily due to its resilience and "simplicity". These properties are quintessential for the diagnostic principle's success and establish it as the primary density control diagnostic on most fusion machines so far. Polarimetry is a natural extension to the interferometer concept, which can often be added to the interferometer optics with minor additional effort. It is often used as an additional information source to correct measurement errors.
Going towards the reactor scale, these diagnostics face significant challenges, which include mirror protection, fringe jump resilience, drift mitigation and relativistic corrections. Despite the increasing challenges, IR-interferometry/polarimetry still plays an important role in the current design concept of the European DEMO. Notably, the IR-
interferometer/polarimeter is envisaged to contribute to density (profile) control, vertical position control and MHD activity detection[1].
In this work we present design considerations for the IR interferometer/polarimeter design, which have been conducted using the TRAVIS code[2]. Equilibria based on the current "orange case" scenario, which optimizes ramp-rates in separatrix power and Greenwald fraction, have been used[3, 4]. The presented simulations approximate a synthetic diagnostic and investigate effects such as refraction, relativistic errors and sensitivity during the ramp-up and flat-top phase of a DEMO discharge. The current design based on the simulation results are discussed.
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 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

---

[1] W. Biel, R. Albanese, R. Ambrosino, M. Ariola, M. Berkel, I. Bolshakova, K. Brunner, R. Cavazzana, M. Cecconello, S. Conroy, et al., Fusion Engineering and Design 146, 465 (2019), URL https:// www.sciencedirect.com/ science/
article/ pii/ S0920379618308585.
[2] N. Marushchenko, Y. Turkin, and H. Maassberg, Computer Physics Communications 185, 165 (2014), URL http:// www.sciencedirect.com/ science/ article/ pii/ S0010465513003032.
[3] F. Palermo and E. Fable, Final report on deliverable(s) pmi-5.2.1-t052-d001 (2020), URL https:// idm.euro-fusion.org/?uid=2NJ85C .
[4] M. Mattei, R. Albanese, G. Ambrosino, R. Ambrosino, M. Ariola, L. E. di Grazia, R. Iervolino, and A. Pironti, Final report on deliverable(s) pmi-5.2.1-t036-d001 (2019), URL https:// idm.euro-fusion.org/ ?uid=2LFUHJ .

67

Oral_29: Overview of ITER Diagnostics from JAPAN

Authors: Ryota Imazawa[1]; Masao Ishikawa[1]; Yatsuka Eiichi[1]; Tomohiko Ushiki[1]; Kunpei Nojiri[1]; Takahiko Shimada[1]; Takaki Hatae[1]

[1] *National Institutes for Quantum and Radiological Science and Technology*

Corresponding Author: imazawa.ryota@qst.go.jp

ITER Japan domestic agency (JADA) procures five diagnostics for the ITER project; micro fission chamber (MFC), edge Thomson scattering diagnostics (ETS), poloidal polarimeter (PoPola), divertor impurity monitor (DIM) and divertor infrared thermography (IRTh). JADA has designed each individual diagnostic system taking into account the following: (1) high radiation heat (<1 MW/m2) and high nuclear heat (<10 MW/m3) from the plasma, (2) high acceleration load due to plasma disruptions, (3) effects of neutron and gamma irradiation on optical and electronic devices, (4) minimization of shutdown dose rate (ALARA (as low as reasonably achievable) principle to minimize exposure to humans), (5) containment of activated pressurized cooling water (application of nuclear pressure vessel regulations), (6) ensuring tritium confinement boundaries are maintained in case of accidents such as earthquakes or fires (e.g., vacuum windows and vacuum electrical feedthroughs), (7) structural designs that are based on nuclear safety standards, (8) position alignment, calibration, and maintenance methods that can be implemented in a radiation environment. This overview reports part of solutions and technologies that JADA developed for solving the issues.
ETS injects high power laser (>5 J) into the plasma with repetition rate of 100 Hz. The injected laser is absorbed by a beam dump that is installed into a first wall panel. The number of pulses on the beam dump will be on the order of 109. The beam dump is made of molybdenum alloy and is designed to withstand high heat loads. To reduce the risk of laser damage, the special internal structure called as Chevron has been developed for the beam dump [1]. It has been experimentally shown that a laser-induced damage threshold of this structure is higher than that of a conventional beam dump [2], and the manufacturability has been also demonstrated [3].
PoPola injects far-infrared laser beams to plasma. Since a vacuum window is the first confinement barrier, the size needs to be as small as reasonably possible. It means that the clear aperture size is not large enough comparing to the laser beam size and the laser beam needs to pass through the center of the vacuum window to avoid laser power loss. JADA developed a new laser beam alignment method that can be automated in the radiation environment [4]. The positions of the vacuum windows are identified by using visible laser beam and multiple small retroreflectors that are attached around the vacuum windows. In addition, by using the retroreflectors around the vacuum windows, the automated alignment system learns a special mirror control that can change the laser beam angle without any change of beam position at the vacuum window. Results of the prototyping test show that the beam position displacement at the vacuum window was 2.0 mm or less when the laser beam was tilted within ± 1 mrad for the sake of searching the target inside the vacuum vessel. The alignment error above leads to the laser power loss of 4 % owing to shading at the VW and is acceptable.
IRTh identifies temperature distribution of tungsten divertor surface. One of measurement requirements is the wide temperature range of 200 oC to 3,600 oC with 10 % accuracy. Conventional two-colour thermography identifies temperature from the ratio of the two spectral radiance, and the choice of the two wavelength (λ) has impact on the measurement accuracy. When applying the conventional method to IRTh, two wavelengths are not enough to cover all the required temperature range with 10 % accuracy. To resolve this issue, JADA developed dual two colour method [5], which uses both one single bandpass filter (λ=4.5 μm) and one dual bandpass filter (λ=1.5 and 3 μm). This new method can achieve temperature measurement with higher accuracy than conventional method.
Further solutions and technologies developed for ITER will be presented in this talk.

[1] E. Yatsuka et al., Rev. Sci. Instrum. 84, 103503 (2013)
[2] E. Yatsuka et al., Fusion Engineering and Design 100 (2015) 461–467
[3] E. Yatsuka et al., Fusion Engineering and Design 136 (2018) 1068–1072
[4] R. Imazawa et al., in the proceedings of 27th Fusion Energy Conference, FIP/P1-14, India (2018)
[5] T. Ushiki et al., in the proc. of 37th annual meeting of JSPF, 2P83 (2020). To be submitted to RSI.

68

Short_Oral_68: Characterisation of an aluminium triple-GEM detector coupled with GEMINI chip for soft X-rays detection in Tokamaks

Authors: Stephanie Cancelli[1]; Andrea Muraro[2]; Enrico Perelli Cippo[3]; Andrea Abba[4]; Gerardo Claps[5]; Giovanni Corradi[6]; Giovanni Grosso[7]; Giuseppe Gorini[8]; Matteo Hakeem Kushoro[9]; Fabrizio Murtas[6]; Oscar Putignano[1]; Jimmy Scionti[10]; Diego Tagnani[11]; Marco Tardocchi[12]; Gabriele Croci[12]

[1] *Istituto Nazionale di Fisica Nucleare*

[2] *IFP-CNR*

[3] *Istituto per la Scienza e Tecnologia dei Plasmi - CNR*

[4] *Nuclear Instrument SRL*

[5] *ENEA*

[6] *LNF*

[7] *Consiglio Nazionale delle Ricerche, Istituto per la Scienza e Tecnologia dei Plasmi, Milano*

[8] *Universita' degli Studi di Milano-Bicocca*

[9] *Università degli Studi Milano Bicocca*

[10] *Istituto Scienza e Tecnologia del Plasma-CNR*

[11] *ROMA3*

[12] *MIB*

Corresponding Author: stephanie.cancelli@mib.infn.it

Among other effects of interest for the optimisation of fusion plasma machines, plasma-wall interaction is one of the most investigated. Through plasma-wall interaction, the first wall material may be eroded and impurities enter into the plasma, where they can produce soft X-rays (SXR) from 5 to 20 keV. To study the rate and energy of such SXR emission it is necessary to develop adequate SRX diagnostic devices. One of the best choices is represented by gas detector based on Gas Electron Multiplier (GEM) technology. GEM detectors are very promising thanks to their possibility to cover large areas, good detection efficiency, good spatial resolution (in the order of 5 mm), and capability to sustain high counting rates ($>$MHz/mm^2). The latter feature, in particular, is possible thanks to the use of a custom electronic readout called GEMINI, an ASIC in 180 nm CMOS. This paper shows the characterisation of a triple GEM detector equipped with GEMINI readout and optimised for SXR detection with Aluminium GEM foils, instead of the standard copper GEM foils. Copper in fact has a prominent 8.04 keV K-alpha line which is in the same energy region of the interesting SXR emission, thus forbidding its use as part of an optimised diagnostic for this application; Aluminium, on the other hand, only emits X-rays at 1.5 keV.

GEMINI ASIC is made of a charge preamplifier (providing an analog signal proportional to the charge deposited into the detector) and a discriminator providing a digital Time-over-Threshold (ToT) signal. Operating in ToT, this digital electronics can sustain rates in the order of MHz per channel. In this paper, a careful study and comparison of digital ToT and analog signals is performed with pulses obtained in realistic conditions (with different X-rays sources). Spectral distribution of the sources (in particular, of Molybdenum and Titanium) have been obtained from both kind of signals; because no significant differences have been found, the two implemented procedures are demonstrated to be equivalent.

In conclusion, we demonstrate that the GEMINI-based electronic readout chosen for GEM detectors is adequate to sustain the high SXR rate from the plasma.

69

Oral_2: Steady state magnetic diagnostics for ITER and some new approaches to magnetic diagnostics of future fusion reactors

Authors: Ivan Duran[None]; Slavomir Entler[1]; Karel Kovarik[1]; Andre Torres[1]; Pavel Turjanica[2]; Jan Reboun[2]; Ladislav Viererbl[3]; Martin Kocan[4]; George Vayakis[4]; Karel Vyborny[5]; Soban Zbynek[5]; Vincent Mortet[5]; Andrew Taylor[5]

[1] *Institute of Plasma Physics of the CAS*

[2] *Faculty of Electrical Engineering, University of West Bohemia*

[3] *Research Centre Rez*

[4] *ITER Organization*

[5] *Institute of Physics of the CAS*

Corresponding Author: duran@ipp.cas.cz

The measurement of the magnetic field in future tokamaks such as ITER and DEMO will be challenging due to the long pulse duration, high neutron fluxes and elevated temperatures. This contribution will review the design of outer vessel steady state magnetic sensors for ITER. The diagnostic consists of a poloidal array of sixty sensors, mounted on the vacuum vessel outer shell, and will contribute to the measurement of the plasma current, plasma-wall clearance, and local perturbations of the magnetic flux surfaces near the wall. Each sensor accommodates a pair of bismuth Hall sensors. Key lessons learned from the process of development, manufacturing, and calibration of this ITER diagnostic will be outlined. Outlook for possible options for DEMO steady state magnetic sensors based on Hall effect will be reviewed. Novel type of inductive sensors manufactured using Thick Printed Copper technology will be introduced.

70

Oral_8: Diagnostics for DTT: opportunities of progress towards systems for fusion reactors

Author: Marco Valisa[1]

Co-author: Lori Gabellieri [2]

[1] *Consorzio RFX and ISTP-CNR*

[2] *DTT Scarl and ENEA*

Corresponding Authors: lori.gabellieri@enea.it, valisa@igi.cnr.it

Specifically designed to test power exhaust solutions, DTT will represent in the near future the closest approximation to ITER and DEMO, with its magnetic field (6T), plasma current (5.5 MA), high power density (45 MW, R= 2.19, m a= 0.7 m, k=1.7), actively cooled first wall components and superconducting coils. A series of diagnostics, system is being designed to cover all the important functional requirements of the diagnostics in a fusion device. Besides ordinary machine protection and basic feedback control functions (density, plasma current, equilibrium etc.), diagnostics are necessary to boost the comprehension of the complex physics phenomena that occur in fusion plasmas by providing accurate input to sophisticated physics models. State of the art diagnostic system are therefore being considered to be integrated on DTT to properly cover core, edge, SOL and divertor areas. They will allow full physics characterization of the plasma as well as the possibility to safely test DEMO relevant control methods based on physics and engineering models

71

Oral_16: Diagnostic Needs for Fusion DEMO and Power Plants - A Panel Discussion

Author: Rejean Boivin[1]

[1] *General Atomics*

Corresponding Author: boivin@fusion.gat.com

Diagnostics have been a key element in fusion research development, and often served as an essential component in understanding the underlying science of fusion-grade plasmas. However, as the performance of fusion devices approaches and reaches ignition, new challenges arise from environmental conditions such as radiation (e.g. neutrons, gammas), long term exposures to front-end components (e.g. mirrors, actuators) and tight requirements for stability (e.g. calibration). These have generated intense R&D and engineering work in ITER diagnostics for example. As the design of fusion DEMO and Power Plants is now progressing, additional challenges arise from long pulse operations and difficult maintenance (e.g. reliability), limited access (ports), high temperature operation and complex control and protection schemes. This panel discussion aims at sharing these challenges, how they can be met, and what developments should be undertaken to ensure success of these devices. Views from the panel members and attending conference participants are expected to be an important part of this discussion.
This material is based upon work supported by the U.S. Department of Energy, under Awards DE-FC02-04ER54698.

72

Short_Tutorial: Introduction to DIAGNOSTICS AND CONTROL OF FUSION-FISSION HYBRID TOKAMAK BASED REACTORS

Author: francesco paolo orsitto[1]

[1] *ENEA*

Corresponding Author: francesco.orsitto@enea.it

A fusion-fission hybrid (FFH) reactor is a complex machine, which includes a tokamak fusion neutron source and two blankets: the tritium regeneration and the actinide burner zones. These three systems need their own diagnostics and controls. Problems associated with the implementation and integration of control systems call for a simplified technology. In this paper, a short overview of the tokamak model devices used as neutron sources for the FFH reactors is presented taking into account the physics and engineering constraints typical of a FFH: fusion gain factor Qfus=2-3 , fusion power 80-100MW , long pulses of few hours, figures compatible with a low power DEMO-like reactor. The criteria determining the diagnostics needs of FFH reactors are then reviewed bearing in mind the requirement that the measurements systems should be simple and robust, and their number be limited, considering the space occupied by the blankets. The diagnostics for the tokamak neutron source, including the machine protection and burn control are among the basic equipment. As the fusion and fission blankets can be integrated in a single subsystem their diagnostics must be conceived as an integrated package that includes the means for measuring isotope content, neutron multiplication and effective reactivity of the fission blanket, as well as tritium regeneration in the breeding blanket. In the context of fission blankets it's important to take into account the possibility of uranium and thorium fuel cycles, with appropriate diagnostic needs. A pilot model FFH experiment presently under study for the conceptual study if the FFH reactor will be presented where the diagnostics systems will be analyzed and characterized and the most recent technological developments in the field of neutron spectroscopy for fusion and fission blankets are presented.

73

Oral_73: Nuclear diagnostics for assessing the performance of the DT burning plasma experiment SPARC

Authors: Marco Tardocchi[1]; Andrea Dal Molin[2]; Stefanie Cancelli[3]; Gabriele Croci[3]; Giovanni Grosso[None]; Matteo Hakeem Kushoro[4]; Giulia Marcer[3]; Andrea Muraro[5]; Massimo Nocente[6]; Enrico Panontin[None]; Enrico Perelli Cippo[7]; Marica Rebai[8]; Davide Rigamonti[9]; Jimmy Scionti[10]; De Marchi Elena [11]; Miriam Parisi[12]; Antonio Trotta[12]; Daniela Farina[13]; Giuseppe Gorini[14]

[1] *stituto per la Scienza e Tecnologia dei Plasmi, Consiglio Nazionale delle Ricerche, Milan, Italy*

[2] *CNR-ISTP*

[3] *Università degli Studi di Milano-Bicocca, Milan, Italy*

[4] *Università degli Studi Milano Bicocca*

[5] *IFP-CNR*

[6] *Dipartimento di Fisica - Università di Milano-Bicocca*

[7] *Istituto per la Scienza e Tecnologia dei Plasmi - CNR*

[8] *MIB*

[9] *ISTP CNR*

[10] *Istituto Scienza e Tecnologia del Plasma-CNR*

[11] *Magnetic Fusion Energy DE – R&D/MAFE, ENI, Venezia, Italy*

[12] *3Magnetic Fusion Energy DE – R&D/MAFE, ENI, Venezia, Italy*

[13] *Istituto per la Scienza e Tecnologia dei Plasmi, Consiglio Nazionale delle Ricerche, Milan, Italy*

[14] *Universita' degli Studi di Milano-Bicocca*

Corresponding Author: marco.tardocchi@istp.cnr.it

Various private investors have recently shown their interest into nuclear fusion as a source of clean energy. One of the most challenging project is SPARC, a DT tokamak under development by Commonwealth Fusion Systems in collaboration with the Massachusetts Institute of Technology and contribution from investors among which the Italian ENI. The SPARC [1] tokamak is at present under design and has the main features of being superconducting, of compact size (major radius ~1.9 m, minor radius ~0.6 m) with very high magnetic field (toroidal field>12 T). External heating to achieve these plasma conditions will be provided by ICRH. Despite being of compact size, SPARC aims to reach the conditions of a burning plasma with a fusion gain Q~2 and Pfus~55 MW in the most conservative extrapolations, and Q>10, Pfus~140 MW in the most favorable one, with high power density (Pfusion/Vplasma~7 MWm-3) relevant for fusion power plants. This will open up the possibility to study the alpha particle physics and their of interactions with high-frequency MHD modes.
In this work, starting from the last two decade experience on JET, we will present a preliminary study of the nuclear (neutron and gamma ray) diagnostics that could be installed on SPARC. Focus will be given to the alpha particle diagnostic capabilities offered by gamma ray diagnostic and to the assessment of the effectiveness of ICRH heating scheme with high resolution neutron and gamma ray spectroscopy.

74

Oral_10: Advances in ITER Thomson scattering diagnostic systems

Authors: Michele Bassan[1]; Benoit Brichard[2]; Mark Kempenaars[3]; Gleb Kurskiev[4]; Eugene Mukhin[4]; Jordi Puig[5]; George Vayakis[6]; Ulrich Walach[2]; Eiichi Yatsuka[7]; Michael WALSH[8]

[1] *ITRE srl*

[2] *Fusion for Energy*

[3] *ITER*

[4] *Ioffe Physical Technical Institute - Russian Federation*

[5] *Latesys Iberia*

[6] *ITER Organization*

[7] *National Institute for Quantum and Radiological Science and Technology - Japan*

[8] *ITER ORGANIZATION*

Corresponding Author: michele@bassan.org

Thomson scattering (TS) is a proven diagnostic technique that will be implemented in ITER in three independent systems. The Edge TS will measure electron temperature Te and electron density ne profiles at high resolution in the region with r/a>0.8 (with "a" the minor radius). The Core TS will cover the region r/a<0.85 and shall be able to measure electron temperatures up to 40 keV. The Divertor TS will observe a segment of the divertor plasma more than 700 mm long and is designed to detect Te as low as 0.3 eV.
The three systems are at different design stages and subject to different constraints, however they can share a number of innovative technical solutions. Results of R&D conducted for one system are often useful for another one.
The outcomes of several recent developments are presented, namely design and testing of laser sources, laser beam dump, shutters, plasma facing mirrors with mirror cleaning systems and spectrometers, optimization of injection optics, collection optics and calibration techniques. Ongoing R&D activities including neutron and gamma irradiation tests on optical components, together with the challenges still remaining, are summarized.

75

Short_Oral_75: A Thermal Helium Beam Diagnostic for the ASDEX Upgrade Divertor

Authors: Marco Cavedon[1]; R. Dux[2]; M. Griener[2]; A. Kappatou[2]; H. Köhnlein[2]; K. Schmid[2]; D. Wendler[2]; M. Wischmeier[2]; W. Zeidner[2]

[1] *Università degli Studi di Milano-Bicocca, Dip. di Fisica 'G. Occhialini', Milan, Italy*

[2] *Max-Planck-Institute for Plasma Physics, Boltzmannstr. 2, D-85748 Garching, Germany*

Corresponding Author: marco.cavedon@ipp.mpg.de

The power exhaust problem is one of the most critical challenges for realizing a commercial fusion power plant. High dissipative divertor and SOL condition, up to 90% of radiation, are now routinely obtained in several tokamaks providing a possible solution to protect the plasma facing components. However, a complete understanding of tokamak SOL and divertor physics is key to extrapolate with high confidence to a fusion power plant. To this extend, accurate knowledge of the electron density and temperature within the divertor volume is a crucial requirement.

The intrinsic two-dimensional geometry and the extreme plasma parameter gradients pose a great challenge when designing a diagnostic for diverted plasmas. Building upon the experience with the ASDEX Upgrade (AUG) mid-plane system [1], a new thermal helium beam diagnostic for the AUG divertor has been designed and it is going to be operational during the upcoming experimental campaign. The new diagnostic will offer an unprecedented insight into the divertor physics by providing 2D measurements of the electron temperature and density on 32 channels. The system will be coupled to a high-throughput polychromator with a 900 kHz sampling rate [2]. Such temporal resolution is a breakthrough in order to understand turbulence and filamentary transport within the divertor volume, an almost experimentally unexplored field of the divertor physics.

In this contribution the design of the divertor helium beam will be presented. The optical view has been optimised to provide the best spatial resolution while allowing the installation within the closed AUG divertor. To this extend, a dedicated synthetic diagnostic has been implemented within SOLPS to determine the absolute emission of the neutral helium lines of interest. Furthermore, the impact of recycling helium neutrals and of the reduced helium pumping efficiency on the measurements has been analysed by dedicated simulations. Even when assuming an 100% rate of He-recycling, the background ("passive") emission should not interfere with the measurements.

[1] M Griener et al 2018 Plasma Phys. Control. Fusion 60 025008
[2] M Griener et al 2018 Rev. Sci. Instrum. 89 10D102

76

Tutorial_10: First principles modeling of fast electron physics

Authors: Yves Peysson[1]; Didier Mazon[2]; Jean françois Artaud[1]; Annika Ekedahl[1]; Julien Hillairet[1]; Axel Jardin[3]; K KROL[4]; Jakub Bielecki[4]; Dominik Dworack[4]; Marek Scholz[4]

[1] *CEA*

[2] *CEA Cadarache*

[3] *IJJ PAN*

[4] *IFJ PAN*

Corresponding Author: yves.peysson@cea.fr

Abstract: Quantitative modeling of the fast electron physics from first principles has always been a challenging but crucial task in order to understand observations from microscopic processes in the plasma. Synthetic diagnostics play a central role in the data analysis, allowing to make direct comparisons between modeling and measurements, thus reducing the uncertainties on the physical mechanisms at play, making the tools not only interpretative but also potentially predictive. This approach is based on a chain of numerical codes which are linked together with consistent physical and numerical assumptions. The framework in which these tools are implemented is a fundamental step to address many physical problems, not only for a single shot analysis as done usually, but also to perform massive calculations (multi-machine, -shot or -time), thus allowing detailed statistical analysis which may be valuable for estimating parametric dependencies and sensibility to the multiple parameters. The scripting methodology is presented, and its implementation for fast electron physics studies, in particular interaction with W ions, during Lower Hybrid current drive regimes is shown with applications to Tore Supra or WEST discharges using the ALOHA/METIS/C3PO/LUKE/R5-X2 chain of codes [1,2,3,4].

Acknowledgements. This work has been partially funded by National Science Centre, Poland (NCN) grant HARMONIA 10 no. 2018/30/M/ST2/00799. We thank the PLGrid project for computational resources on the Prometheus cluster.

[1] J. Hillairet, et al., Nucl. Fusion 50(12), 125010 (2010)
[2] J.F. Artaud et al., Nuc. Fusion 58, 105001 (2018)
[3] Y. Peysson, et al., Plasma Phys. Control. Fusion 54, 045003 (2012)
[4] Y. Peysson and J. Decker, Fusion Sci. Technol. 65, 22–42 (2014)
[5] Y. Peysson and J. Decker, Phys. Plasmas 15(9), 092509 (2008)

77

Oral_3.2: Fast-Ion Loss Detectors in Magnetically Confined Fusion Devices

Author: Manuel Garcia-Munoz[1]

[1] *University of Seville*

Corresponding Author: mgm@us.es

In magnetically confined fusion reactors, energetic ions must be kept well confined until they slow down to the plasma bulk through Coulomb collisions. Energetic ions are, however, subject to a wide variety of cross-field transport due to their large velocities, long mean free path and slowing down times. Indeed, a broad spectrum of magnetohydrodynamic (MHD) fluctuations have been observed to cause a significant fast-ion transport / loss degrading their heating and current drive efficiency as well as the machine integrity. In general, in the presence of MHD fluctuations, the fast-ion cross-field transport depends on the properties of the MHD wave and particle orbits, and more specifically, on the perturbation´s phase at the particle´s position at any time. To characterize, and better understand, the MHD induced fast-ion transport, and loss, the community has developed a broad set of fast-ion loss diagnostics with the goal of covering the largest particle phase-space volume with Álfvenic time resolution. As expected, however, the ideal fast-ion loss diagnostic does not exist, and a combination of diagnostics is normally used in present devices to measure fast-ion losses. In this talk, the most advanced techniques will be briefly introduced and their capabilities and prospects for present and future devices discussed.

81

Short_Oral_81: Present status of the conceptual study of the DEMO gamma-ray diagnostic

Authors: Enrico Perelli Cippo[1]; Luca Giacomelli[1]

[1] *ISTP-CNR*

Corresponding Author: enrico.perelli@unimib.it

The future DEMO tokamak will be equipped with a multi-line of sight diagnostics which will operate as sensors to monitor and control the position and operation parameters of the DT plasma. Among the suite of sensors, an integrated neutron and gamma-ray diagnostic system is also studied to verify its capability and performance in detecting possible DEMO plasma position variations and contribute to the feedback system in maintaining DEMO DT plasma in stable conditions.
Specifically, this work describes the present status of the conceptual study of the gamma-ray diagnostic (Gamma-Ray Spectroscopic Instrument, GRSI) for DEMO reactor at the end of the first Work-Package contract 2015-2020.
The gamma-ray reaction of interest for DEMO DT plasma consists of D+T ⊠ 5He + ⊠ (16.63 MeV). Being the gamma-ray emission so energetic, it can be clearly detected above the neutron induced background. Depending on the geometry of the integrated neutron and gamma-ray diagnostic system, the GRSI can contribute to the neutron information on DEMO DT plasma position and assess independently and alternatively the DT fusion power with respect to the neutron emission. The characteristics of the GRSI to measure the16.63 MeV gamma-ray emission are reported in this presentation, along with the results of optimization studies conducted with GENESIS and MCNP simulation codes.
In particular, the following arguments will be addressed: i) the cross section of the named reaction and how it compares with other gamma-ray reactions in DEMO plasma; ii) the assessment of dimensions and characteristics of the detector of choice for the present application, i.e., Cerium-doped Lanthanum Bromide scintillating crystals; iii) the assessment of the neutron-induced gamma-ray background and use of suitable (neutron) attenuators like lithium hydride and instrument shielding; iv) the assessment of the integration of the gamma-rays and neutron detectors along multiple lines-of-sight both vertical and horizontal according to different geometry to match the DEMO position monitoring and control requirements.
The further phases of the neutron and GRSI design and integration are also discussed.

84

Tutorial_1: Diagnostics Design for Fusion Reactors prepared

Author: Michael WALSH[1]

[1] *ITER ORGANIZATION*

Diagnostics Design for Fusion Reactors

M. Walsh and ITER Team
ITER Organization, CS 90 046, F-13067 Saint Paul Lez Durance Cedex, France

Understanding of the operation of fusion reactor systems is of crucial importance for the development of economical fusion power. Currently, ITER is the world's largest magnetic fusion device. It will operate with a plasma current of 15MA and produce 500MW of fusion power. The device will have a plasma volume of approximately 800m3.
ITER is now well in to its construction in France and it will have a set of diagnostics chosen to meet the needs of the ITER Research Plan. While some systems have been specifically developed for ITER, many of these diagnostic systems have been adapted from current tokamaks with key developments to make sure they can work in the new challenging environment. These so called key-developments are also crucial for the next step Fusion Machine Development. While key measurements cannot be ignored, simplification and ruggedization of the systems is crucial. This is an important development point. Also, the area of global Tokamak Systems monitoring is also a key topic going forward to ensure that all the infrastructures are well monitored and the integrity of the devices are maintained. The presentation will outline the current state of the developments and the strategy going forward.
*Presenting author: michael.walsh@iter.org
The views and opinions expressed herein do not necessarily reflect those of the ITER Organization