CONSORZIO RFX
Ricerca Formazione Innovazione

Activity Report

2015

INDEX

1. Introduction

The 2015 Activity Programme of Consorzio RFX was presented and evaluated at the 33rd meeting of the Scientific-Technical Committee on November 5 2014 and approved late 2015 (September 22 2015) in the Consorzio RFX Partner meeting. The delay in the approval was due to difficulties in confirming the necessary resources for the program. Nonrtheless, the initial program was maintained and the main goals achieved.

A substantial step forward in the set-up of the Neutral Beam Test Facility was obtained with the completion of the building devoted to host the two test beds – SPIDER and MITICA – and with the start of many equipment and plant installations together with the completion of the remaining design activities. A long term relevant arrangement for "Research Collaboration on Neutral Beam Injection for the Improvement of Plasma Performarce" was signed between Consorzio RFX and Japan Atomic Energy Agency in order to prepare and develop researches in NBTF and JAEA.

Such advancements, described in 2.1, attain the results that all SPIDER plants and systems are under installation with only the beam source still in manufacturing phase and that MITICA component design is completed and the tender technical specifications ready; very important event of 2015 is the delivery from JAEA of the first lot of components for the 1 MV power supplies, currently under installation. The major concern is related to the procurement of SPIDER beam source, the critical line before to start experiments with the source, because of difficulties between Fusion for Energy and the supplier.

An accompanying program on Neutral Beam physics is described in 2.2, which is focused on the operation of the ion source NIO1 and the activities within EUROfusion framework. New concepts for high efficiency neutralization and for energy recovery, the key issues for developing DEMO injectors, have been analyzed.

Another important result of 2015 is the supply completion to JT-60SA of the 13 Quench Protection Circuits of the superconducting coils of the machine, for which Consorzio RFX is in charge on behalf of Italy. The procurement was concluded in time (first EU procurement completed) and within the initial budget. Description of this activity is in 4.

Promising results, in contributing to the issues relevant for fusion science, have been obtained in the 2015 RFX-mod experimental campaigns, before the stop due to a long shut-down started at the end of the year for extraordinary maintenance. They are related to the advancement in understanding the helical RFP configurations also with non-resonant modes, the isotope effect, the role of turbulence in RFP transport both in the core and edge. Improved tokamak operation was obtained at low plasma current with the aim to study the active control of this configuration (disruption, ELMs, etc.). All these aspects are reported in 3.1. The proposed modifications of RFX-mod were finalized during the year with dedicated experiments and feasibility design of the proposed solutions in order to be ready, hopefully, to implement them during the shut-down of the machine for maintenance, started November this year.

Specific contribution to the ITER physics was carried out by the participation to the experiments in JET and Medium Size Tokamaks through EUROfusion consortium. From RFX group comes the current MST1 Project Leader and researchers were involved in scientific coordination of several experiments. Other contributions are related to JT-60SA, W7-X and other international machines (DIII-D and LHD); the details on the activities and results are reported from 3.2 to 3.6.

Studies have been performed in order to contribute to the Power Plant Physics and Technologies, within EUROfusion, as reported in 3.7. and 3.8, in the fields of power supplies, system integration, plasma heating with neutral beam systems, vacuum and socio-economics.

In the year 2015, the scientific and technological activity has produced 74 papers on national and international journals (83 in 2014), 92 publications in conference proceedings (109 in 2014) and 28 communications in national and international conferences or workshops (29 in 2014).

2. ITER Construction

2.1. *Activity for the development of Neutral Beam Injectors for ITER*

2.1.1. Introduction

This section reports the status of the activities of the Neutral Beam Test Facility (NBTF) Team, including third parties, as foreseen by the existing agreement among ITER, Fusion for Energy and Consorzio RFX to realize the PRIMA Test facility at Padova[1].

The main areas of activity performed by NBTF Team and third parties were:

- Completion of PRIMA buildings and auxiliaries and delivery of areas for the installation of SPIDER and MITICA plant systems.
- Completion of design of MITICA components, diagnostics, protection and safety systems up to the preparation of the documentation for the procurement activities.
- Completion of R&D on prototypes of components to confirm the design, assess the reliability of the chosen technologies and identify correct manufacturing processes.
- Technical follow up of procurements from Call for Tender issued by F4E up to the installation phase, including factory acceptance tests of some plant systems.
- Interface management between buildings-plant and systems-components to guarantee the coherence of the overall design.
- Support to Japan and India Domestic Agencies (JADA and INDA) in the integration of their procurements with different NB components and buildings to ensure overall performance of test beds.
- Management and coordination of the installation activities on site.
- Management of the plant integration activities between experimental plants and PRIMA buildings inclusive of development of a 3D integrated CAD model.
- Host Site actions during construction, supervision and coordination of the activities.

During 2015 there was a considerable commitment of resources to finalize the design of the MITICA Beam Source (BS) and Beam Line Components, to follow-up procurements, to support JADA procurement and installation, and to perform to Host

[1] V. Toigo, et al. "Progress in the realization of the PRIMA neutral beam test facility" Nucl Fusion, 55, 083025, (2015)

Site Activities and plant integrations.

Within the Framework Contract for the realization of CODAS, Interlock and Safety systems signed in 2014, the first specific contract to start the procurement of the SPIDER CODAS and Interlock system was signed in July 2014. Activities for the realization of the SPIDER control and protection systems were also carried out in 2015. Installations of the plant control started, but the conclusion of these activities, originally foreseen in September 2015 was postponed to March 2016 to synchronize the CODAS activities with the installation and commissioning of the systems that are interfaced with CODAS itself.

Within the Framework Contract for the Diagnostics procurement signed in December 2014, the first specific contract for the procurement of the SPIDER diagnostics in June 2015. After that, activities for the procurement of SPIDER diagnostics, not included in other procurement contracts, started and the procurement contracts were launched. Development activities for STRIKE and the Neutron diagnostics for SPIDER, not included in the first specific contract, continued under the Work Programme.

The SPIDER BS and Vacuum Vessel procurement (F4E-OPE-081) met difficulties at management level due to claims for additional costs and time by the supply Consortium (Thales, Zanon, Cecom, Galvano-T). On July 8 an extraordinary Program Committee meeting was called by F4E in order to update the PC members about the status of the negotiation. The negotiation at top management level between F4E and the Consortium is still ongoing. An agreement, close to be finalized, foresees the delivery of the Beam Source by Thales and the on-site installation and tests by Consorzio RFX. As a result of the negotiation also an updated schedule will be prepared by the Consortium. Even if the final outcome of the negotiations has not yet been released, it is probable that the Beam Source could not be delivered before of October 2016 and hence the start of the SPIDER operation could not be before the beginning of 2017.

Significant progress in the procurement of all SPIDER plant systems was achieved with the contribution of the NBTF Team. In particular:

- the HV Deck has been completed, installed and accepted;
- the Ion Source and Extraction Grid Power Supply, completed and factory tested during 2014, was installed in the HVD and Site acceptance tests are ongoing;
- the manufacturing of the Transmission Line was completed and the installation scheduled to start in January 2016;

- the SPIDER Vessel (without electric and hydraulic flanges) was delivered on Site in February 2015, submitted to acceptance tests and installed in the final position;
- the electric and hydraulic flanges of the SPIDER BS were delivered and are now under installation on the Vessel;
- the SPIDER Vacuum and Gas Injection system was installed and the commissioning will be completed with acceptance tests by January 2016;
- the installation of the Cooling plant system, started in November 2014, continued during 2015 despite significant slowdowns due to pending deviation requests.

In conclusion, all SPIDER systems and components are under installation except for the beams source. Relative to the SPIDER planning of one year ago there is an overall delay due to a general difficulty to start the on-site activities with the suppliers, taking into account the complexity of the rules imposed by the Italian law. Nonetheless, the critical line is represented by the delivery on site and installation of the beam source.

As for the MITICA experiment, the design of the injector mechanical components was completed, the calls for tender for the procurement of almost all systems have been launched and many procurement contracts have been signed;. in particular, contracts for the procurement of the MITICA Vessel, High Voltage Deck (HVD) and the bushing for the connection of the transmission line with the HVD were signed at the end of 2014 and for procurement of AGPS-CS and GRPS were signed in 2015; only a couple of calls for tenders (Beam Line Components and cryo-pumps) will be launched during 2016. Also those for beam source, cryo-plant and SF6 system will be signed in 2016. All the activities were performed directly by or with the support of the NBTF Team.

In 2015 three important on-site work organizations became fully operational and well integrated each other: Health and Safety, Coordination of the Direction of the Works, Plant integration. Since the beginning of 2015 weekly meetings for the coordination of installations and integrations activities are held on a regular basis and the integrated plan for installations is regularly updated. Training of personnel and test on diagnostic prototypes continued in different laboratories mainly at IPP.

Finally, R&D activities were performed on vacuum High Voltage (HV) using the High Voltage Padova Test Facility and on Radio Frequency (RF) with the aim of supporting the BS design and of training the NBTF staff. In particular HV tests of MITICA post insulator prototypes, were carried out and results reported in 2.2.3. The status of the project and the main achievements in the year are described in the following sections.

2.1.2. PRIMA

2.1.2.1. Buildings

The NBTF building construction started in September 2012. During 2013 foundations and basement were realized and the erection of the buildings started, including installation of cranes and some auxiliaries. During 2014 the activities continued with the completion of buildings for SPIDER power supplies, cooling system and the SPIDER pit-biosheld, other activities were the start of the construction of pit and tranches hosting MITICA transmission line and other HV components, concrete slabs and other external structures to host gas storage tanks and the the construction of all auxiliary conventional systems.

Fig. 2.1.1 PRIMA Site: external view of PRIMA buildings

In 2015 all the activities entailed in the building construction contract were completed; in particular the following structures were realized:

- pit and fixed structural parts of MITICA bio-shield
- pit and tranches to host MITICA transmission line and high voltage deck;

Fig. 2.1.2: front and rear view of building 12 hosting SPIDER/ MITICA control rooms

- the basement to support insulating transformer and relevant HV bushing;
- the oil basin to store leak oil in case of transformer tank rupture;
- pits hosting step-up transformers and other concrete structures supporting DC Filter, Testing Power Supply and HV connecting pipes.

Fig. 2.1.3: PRIMA Site: view of the SPIDER bio-shield inside building 1 complete of removable concrete beams

The commissioning of the PRIMA Medium Voltage / Low Voltage (MV / LV) distribution grid and other auxiliary systems has initiated and completed at the beginning of 2016.

The contract for feeding the 20kV PRIMA auxiliary grid has been signed allowing to supply power to the construction site and to perform commissioning activities.

The procurement of the MV experiment Distribution Boards has been launched and the components will be released on site in first quarter of 2016.

Finally, a new contract was signed for building completion: i.e. the MITICA bio-shield concrete beams, concrete slab supporting TL2 core snubber and TL3, and other minor components. The realization of these structures started in December and will be completed in first part of 2016. Some buildings are ready for the installation of the first systems and components. In particular:

- Building 2 for the installation of the Cooling Plant system;

Fig. 2.1.4: PRIMA Site: view of the fixed parts of the MITICA bio-shield inside building

Fig. 2.1.5: area hosting MITICA PS. right: 1MV insulating transformer pit; left: DCG pits

Fig. 2.1.6: PRIMA Site: view of the pit crossing building 8 and hosting part of the MITICA TL. Note the still beams to be used to anchor the TL post-insulators

- Building 6 for the installation of the SPIDER power supply system;
- Building 1 and SPIDER bio-shield for the installation of the Vessel, cooling plant and Gas and Vacuum injection System;

Other buildings and areas are involved in the installation of power supplies and of control system. In particular:

- Building 8 and external area for the installation of the JADA components;
- Building 12 and Building 6 first floor for the CODAS and Interlock systems;
- Building 3 and 4 to use as storage areas for the JADA components.

Fig. 2.1.7: Storage area, Area B, used to store components from JADA

Finally, an external area of about 2000m^2, named Area B, was arranged to store big components shipped by JADA and awaiting to be installed. This area will be used also to store components coming from F4E deliveries (Fig. 2.1.7).

Fig. 2.1.8: Pumps (Garbarino) and Heat Exchangers (Sondex) for primary and secondary circuits during factory tests

Fig. 2.1.9: Unloading and installation of pumps of tertiary and secondary circuits in Building 2 at level -4.0 m


Fig. 2.1.10: Cooling pipes installation inside Building 2 at level -2.0 m; the floor at ground level is ready for next installation of pumps and heat exchangers

2.1.2.2. Cooling Plant for SPIDER and MITICA

The procurement for PRIMA Cooling Plant advanced regularly during 2015 under F4E contract OPE-351.

Apart the activities related to the pending deviation requestes. RFX performed the foreseen follow up activities verifying the documents produced by the Supplier (Delta-Ti Impianti) and sub-suppliers, giving technical information to the Supplier for plant integration on Site and performing visits at sub-suppliers' sites for intermediate tests on components (mainly power supply components, pumps and heat exchangers).

A large effort was devoted to solving several critical integration issues arisen for plant assembly on-site.

Fig. 2.1.11: The steel structure for support of Cooling Towers on the roof of Building 2

The on-site activities started on 3rd November 2014. Most of the pipes for Secondary circuits have been delivered at PRIMA site and installed inside Building 2. The pumps of secondary and tertiary circuits have been installed at level -4.0 m and connected to the water basins. The installation of power supply transformers, cabinets and cables advanced and a large support structure has been installed on the roof of Building 2, ready for installation of the Cooling Towers.

Completion of installation activities, commissioning and acceptance tests for SPIDER and Shared Plant Units are foreseen in 2016. Design and installation activities for MITICA Plant Unit will also proceed in 2016.

2.1.2.3 Vacuum, gas injection and gas storage for SPIDER and MITICA

The procurement for the PRIMA Gas and Vacuum System (GVS) continued regularly and intensively during 2015 under F4E contract OPE-279. Some important milestones have been achieved. In particular manufacturing of SPIDER components has been completed, almost all the vacuum components are on-site ready for installation,

Fig. 2.1.12: SPIDER Cryo-compressors and fore pumping system installed inside the SPIDER Neutron Shield

SPIDER and MITICA Gas distribution are almost completed and the vacuum components have been installed on SPIDER Vacuum Vessel.

RFX performed the follow up activities verifying the documents produced by the Supplier (Angelantoni Test Technologies) and sub-suppliers and giving technical information and support to the Supplier for plant integration on Site.

Commissioning and acceptance tests of SPIDER and part of Shared Plant Units are foreseen at the beginning of 2016. Installation activities for MITICA and Shared Plant Units will proceed, aiming to complete also the final tests within 2016.

2.1.3. SPIDER

2.1.3.1. SPIDER Vacuum Vessel

The supply of SPIDER Vacuum Vessel has been completed in 2015 under F4E contract OPE-081, carrying out all the foreseen assembly operations, baking cycles and acceptance tests at PRIMA site.

During the first months of 2015 the factory tests were completed at ZANON (VI).

On 25th February, the SPIDER Vacuum Vessel has been delivered on Site and the assembly and vacuum test activities started. The RFX team has performed the follow-up of rails installation, dimensional checks of rails, follow-up and coordination of downloading and installations of modules and lids. Baking of Vacuum Vessel up to at least 120°C was then defined and organised among the different actors to remove as much as possible the impurities highlighted by the Residual Gas Analyses. Baking and repeated leak tests were performed in summer 2015 repairing some leaks due to local damage to o-rings and some ports welds. After successful vacuum tests and RGA analyses the large hydraulic and electrical bushings are under assembly on-site.

RFX performed the foreseen follow up activities verifying the documents produced by the Supplier and sub-suppliers, witnessing several factory tests and giving technical information to the Supplier during both assembly and tests activities. A large effort was devoted by RFX to solving several issues arisen during vacuum tests, baking cycles and RGA analyses on-site.

After completion of electrical tests planned in December 2015 and the final check of documentation, the Vessel release to F4E is foreseen in January 2016, after completion of all the contractual activities.

Some images of the Vessel during delivery, assembly, baking and tests on site are shown in the Fig. 2.1.13 - Fig. 2.1.16.


Fig. 2.1.13: a module of SPIDER VV


Fig. 2.1.14: **Assembly on-site of SPIDER VV**


Fig. 2.1.15 :SPIDER VV during baking


Fig. 2.1.16: **SPIDER VV during vacuum tests on-site**

2.1.3.2. SPIDER Beam Source

SPIDER Beam Source manufacturing progressed during 2015 under F4E contract OPE-081, with continuous and strong effort from RFX for technical follow-up.

Hundredths of documents, manufacturing drawings, procedures and tests reports uploaded by the Supplier in F4E-IDM during 2015 have been checked by RFX, revised and finally approved. Similarly for Control and Manufacturing Plans that needed to be checked and approved.

Furthermore RFX always guaranteed the foreseen presence at progress meetings, weekly meetings and notified tests meetings for witnessing intermediate tests on components at the different premises of suppliers and sub-suppliers.

Manufacturing of the main components of the beam source is almost completed at Cecom (I), Galvano-T (D) and relevant sub-contractors, while parallel activities are going on at Zanon for manufacturing of BS support structure, BS electrostatic shields and BS Handling Tool.

The support frames for the grids and the segments of Grounded and Extraction Grid are the last components of BS still to be finished and tested during the end of 2015 and January 2016.

Most of the BS components to be Molybdenum coated have been subjected to Physical Vapour Deposition by subcontractor HEF (F). The last few components will be coated in December 2015.

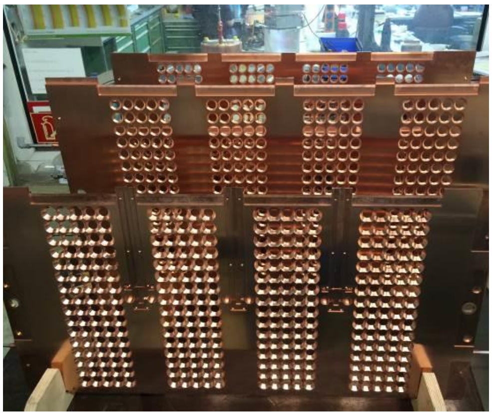


Fig. 2.1.17: Plasma Grid segments machined

Fives Nordon (F) will be the Thales sub-supplier for BS assembly and tests at the factory. These activities will start early in 2016 as soon as all the components are delivered to Fives Nordon premises.

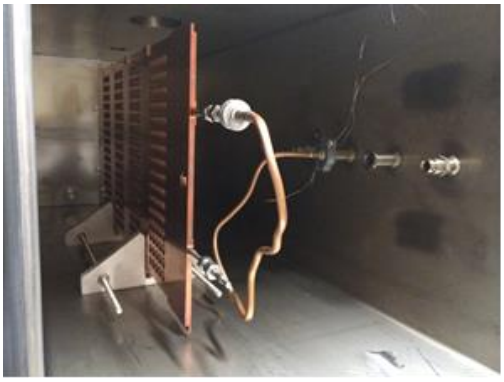


Fig. 2.1.18: In vacuum He pressure and leak tests of the cooling circuit of Plasma Grid segment

Further engineering activities have been carried out by RFX to study the implementation of additional electromagnetic shields around the RF drivers, as requested by IO and F4E on the basis of experimental results on RF sources at IPP (Batman and ELISE). CAD studies, electromagnetic and thermo-mechanical analyses have been executed to identify an optimized solution allowing the installation of the shields with minimal impact on the source components and sufficient shielding efficiency.

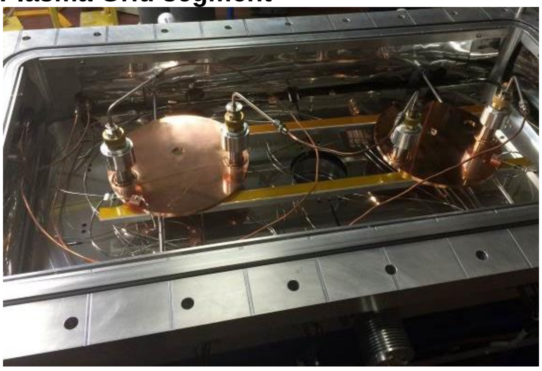


Fig. 2.1.19: He leak tests in vacuum of Faraday Shields Backplates at Cecom

2.1.3.3. SPIDER Cs Ovens

Design and R&D activities have been carried out by RFX to develop a final updated design of the Cs Ovens for SPIDER, given the unavailability of the Supplier to carry out the works contractually foreseen within the BS procurement.

The updated design includes now the liquid Cs level measurement to monitor Cs consumption, the SID diagnostic (Surface Ionization Detector developed by IPP), features to optimize heating/cooling of the ovens (aluminium heat-sink, heating cartridges with copper clamps) and a custom valve in-vacuum for Cs injection adjustment.

Fig. 2.1.20: SPIDER Faraday Shields Lateral Walls manufactured and tested by Galvano-T

Several detailed thermal analyses were carried out to simulate the thermal behaviour of the Cs Ovens in vacuum and to estimate the necessary power during experiments. The results will be verified in 2016 with thermal tests in vacuum of an oven prototype.

The part of Cs Oven requiring R&D during 2015 was the high temperature solenoid valve: the solenoid and the gasket of the plunger of an off-the-shelf valve were customized and tested. Aim of the R&D was to demonstrate the compatibility of the

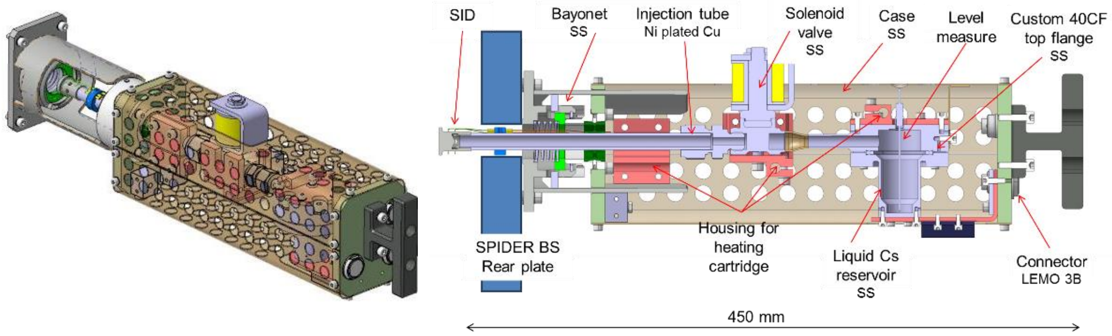


Fig. 2.1.21:SPIDER Cs Oven, CAD Model (left); Section view with main components (right)

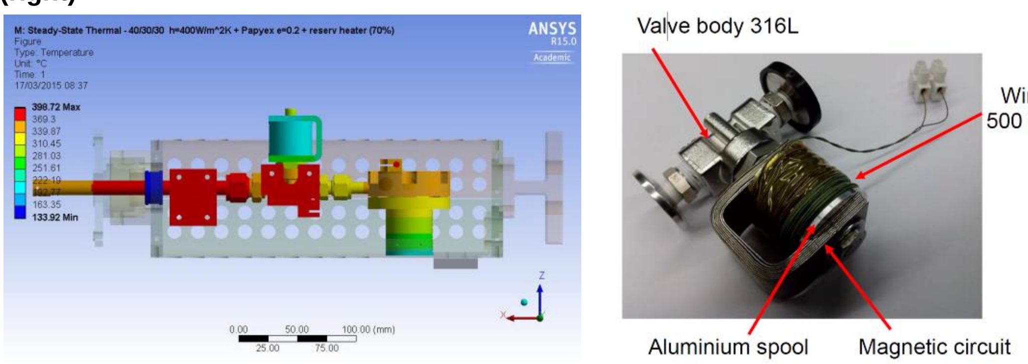


Fig. 2.1.22 Temperature contour plot of the Cs Oven in vacuum (left); Customized solenoid valve for controlled Cs injection in vacuum (right)

customized valve with its functional requirements up to 350°C in vacuum.

2.1.3.4. SPIDER Beam Dump

The SPIDER Beam Dump was delivered to PRIMA in December 2014 after completion of factory tests at PVA TePla (D) premises under ITER India procurement contract. The on-site tests were performed from June 8 to 18 2015 at the presence of IO, ITER India, F4E and RFX. Visual and dimensional controls, pressure test, He leak tests and electrical tests were executed and the whole technical documentation was checked. RFX personnel gave active support during all tests and carefully verified the interfaces and component conditions. Some phases of the on-site acceptance tests are shown in Fig. 2.1.23

A non-conformity (already identified during the factory acceptance tests) was confirmed: some excessive gaps between adjacent hypervapotrons, that would lead to beam shinethrough during SPIDER operations. The Beam Dump is now stored at

Visual control after unpacking

Dimensional control – Check of CuCrZr beam surfaces

Nitrogen pressure test

leak test: Internal cooling circuits evacuated and He atmosphere around the component

Fig. 2.1.23: SPIDER Beam Dump acceptance test

PRIMA site waiting for adjustments of the hypervapotrons positions to eliminate the gaps between adjacent dump elements. These activities will be carried out by IO with the support of RFX team in spring 2016, before installation of thermocouples and following installation inside the SPIDER Vacuum Vessel.

2.1.3.5. SPIDER power supplies

The circuit diagram of the SPIDER power supply system is shown in Fig. 2.1.24.

The High Voltage Deck (HVD), insulated for -100 kV, hosts the Ion Source and Extraction Power Supplies (ISEPS), electrically connected through the air insulated Transmission Line (TL) to the beam source, which is polarised at -100 kV by the Acceleration Grid Power Supply (AGPS). In Fig. 2.1.25 an overview of the SPIDER power supply system is shown.
The procurement of the Ion Source and Extraction Power Supplies (F4E OPE-046 with OCEM-Energy Technology) saw in 2015 start and completion of installation followed by the start of site tests, due to be completed in the first quarter of 2016. The second part of the in kind contribution of the Indian Domestic, the SPIDER AGPS (Acceleration Grid Power Supply) completed the factory tests and became ready for transport to site.

The High Voltage Deck (HVD & TL procurement, contract OPE-396 with COELME - Italy) was installed and successfully tested on site. Factory tests of the Transmission Line were also completed and manufacture subsequently released and completed.

In 2015 ISEPS installation and site testing has been followed closely. The installation phase has been supported on a daily basis and a number of issues identified and solved. The equipment passed the dielectric tests. An issue associated with the radiofrequency generators has been identified during the hydraulic tests and remedial actions are being discussed among the involved parties. Functional tests and

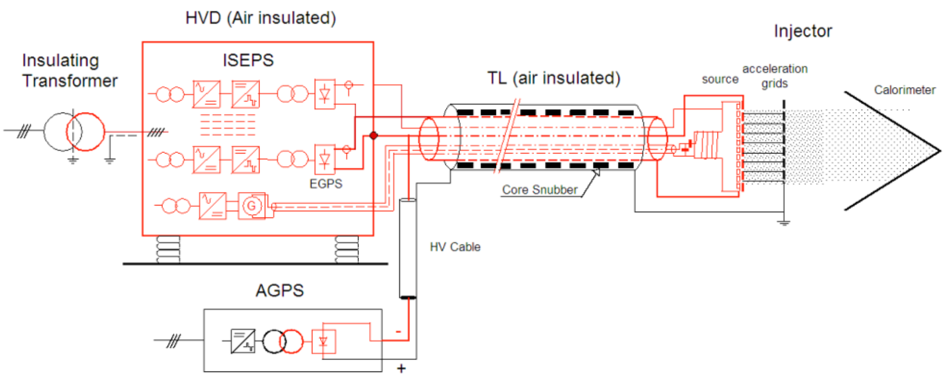


Fig. 2.1.24: Conceptual scheme of the SPIDER power supply system

integration with CODAS control are in progress. Fig. 2.1.26 shows the SPIDER ISEPS installation inside the High Voltage Deck.

With respect to the work with INDA for the procurement of the SPIDER AGPS, information and technical solutions were exchanged and finalised on the interfaces with buildings and their electrical services. An issue with the transformer supports in the bays was solved. A conflict between AGPS Dummy Load and Cooling Plant pipes was identified during a site inspection as part of the SPIDER Power Supply interface management meeting held in Padua in October. A viable solution was proposed and agreed, with an optimisation of the position of the Dummy Load within Building 6. An important effort has been devoted to supporting INDA in resuming discussion with potential suppliers of services for their electrical installation on site and in person meetings between INDA and three suitable companies already met in 2014. Though not involved in the commercial aspects, RFX continued to support the technical exchange and clarifications between the local companies and INDA as part of a new tendering exercise.

The 2015 activity in support to F4E procurement of SPIDER HVD&TL was significant. At the beginning of the year the HVD installation was followed closely, up to successful completion of the acceptance tests. Subsequently, part of the HVD walls and ventilation system were temporarily dismounted to allow positioning of ISEPS heavy components. In the first half of the year an important design issue with the

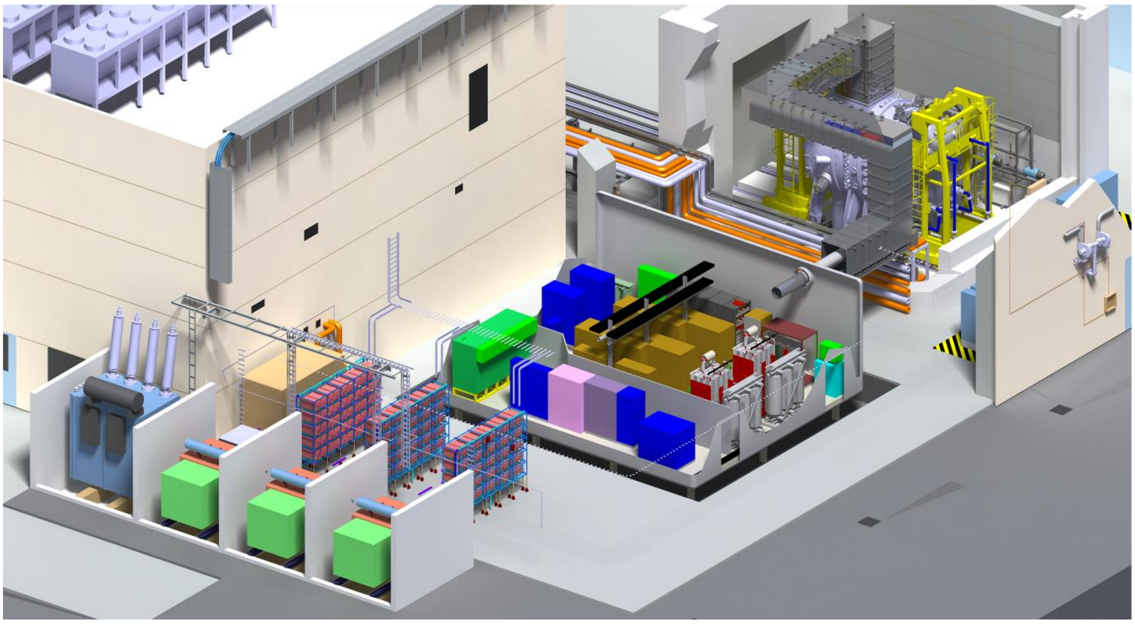


Fig. 2.1.25: Overview of the SPIDER PS's system

Fig. 2.1.26: ISEPS installation inside the High Voltage Deck

Transmission Line was tackled, allowing release of factory testing and later manufacture. The factory tests of the Transmission Line were witnessed in the summer and subsequently support was given to defining various aspects of the Transmission Line installation, due to start in January 2016.

2.1.3.6. SPIDER & MITICA diagnostics

Activities on design, R&D and manufacturing of diagnostics for SPIDER and MITICA were carried on either within the F4E Work Programme or, for a subset of SPIDER diagnostics, within the F4E OFC-531 procurement contract.

The Framework Contract for procurement of all NBTF diagnostics, which was signed in December 2014; the call for tender for the first specific contract was issued by F4E in March and after negotiation the contract signed at the end of June. It includes all diagnostics required at the beginning of SPIDER operation (vacuum windows, thermocouples, emission and laser spectroscopy, electrostatic probes, visible and IR imaging) and components of other diagnostics that need R&D (instrumented calorimeter STRIKE, neutron, tomography).

Fig. 2.1.27: Factory tests of the SPIDER Transmission Line

This latter set and the remaining SPIDER diagnostics will be completed within a second specific contract, starting late 2016.

Under diagnostic framework contract, technical specifications were delivered and approved through a Design Review by F4E and IO for thermal sensors, spectroscopy, vacuum windows, tomography prototype camera and STRIKE prototype mono-dimensional 1D-CFC tiles. The relative procurement processes started soon after and most orders for components are expected to be issued before the end of the year, thus guaranteeing a relevant set of diagnostics installed before the start of SPIDER

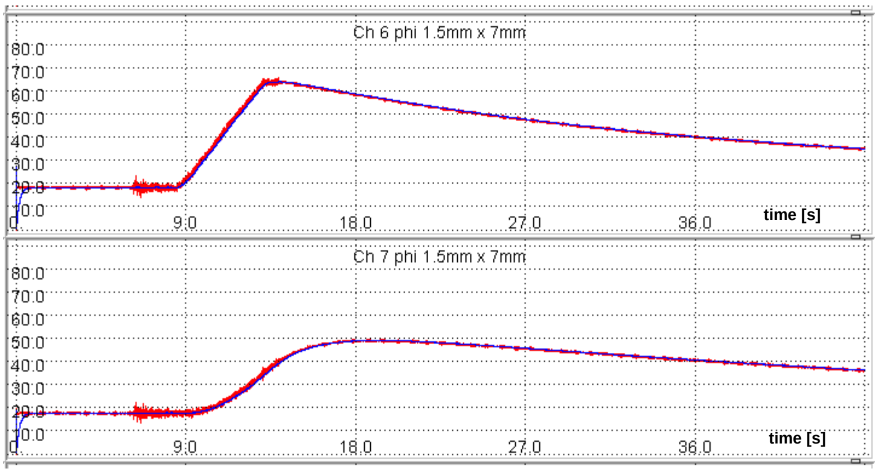


Fig. 2.1.28: Test at BATMAN of two thermocouple fixing methods: with a vacuum compatible cement (top), as used on SPIDER beam dump, and by peening (bottom).

operation. For STRIKE prototype tiles in particular, the first stage of the long manufacturing process has already been successfully completed.

Under the 2015 Work Programme, several activities were related to the follow-up of instrumentation provided with or interfaced to the SPIDER beam source, HV transmission line and the beam dump. In particular the design and procurement of the in-vacuum optical heads and fibers for spectroscopy and the follow up of thermal sensors and electrostatic probes production to be installed on the source, with direct provision of some components; the realization and commissioning of custom conditioning electronics for thermocouples, with remote control and good electrical isolation[2]; the follow-up of thermocouples for calorimetry provided with the beam dump, design of installation procedure of inertial thermocouples for local surface temperature measurement and test of this procedure on BATMAN beam source. Further activities were related to interfaces with other systems, like CODAS and with the buildings: definition of diagnostics layout and acquisition cubicles, definition of cables and fibers paths, design and preliminary implementation of cable trays.

As for STRIKE, main activities under WP2015 consisted in preparation of the procurement, including a revision of the design and development of alternative material with respect to 1-D CFC, in case these prototypes may fail. A mechanically machined castellated graphite tile with 2.5 mm pixels separated by 0.5 mm was modelled, manufactured (Fig. 2.1.29) and tested: first test revealed damage at the highest expected energy flux, but the design has space for optimization.[3] Progresses were made on analysis of mini-STRIKE data collected at NIFS in 2014, together with the first direct measurement of the beam current, on analysis of the mini-STRIKE data collected in BATMAN in 2014/2015 and on a more precise and faster data analysis method, including the first estimate of the 2-dimensional profile of the beam energy flux.

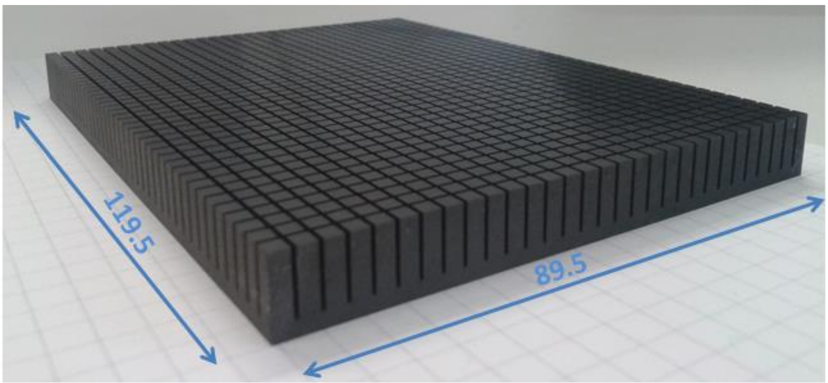


Fig. 2.1.29: Alternative mechanically machined castellated graphite tile for STRIKE

On the neutron imaging diagnostic, the design of the vacuum box that contains the GEM detector was revised, together with its installation procedure, the overall layout was finalized and manufacturing of the final GEM detector started. R&D progressed on GEMINI electronics board, which should replace the present CARIOCA electronics.[4]

As for MITICA diagnostics, the design focused on the finalization of spectroscopy lines-of-sight in the beam source and along the beam (through the ad-hoc cryopump apertures), and on electrostatic probes to be installed on RID and neutraliser.[5]

Several concepts, designs and prototype components of SPIDER diagnostics, especially spectroscopy and thermal sensors, have been tested on NIO1 facility during the first experimental campaigns with production of RF plasma both in air and in H.[6],[7]

2.1.3.7. NBTF Control and Interlock

In 2014 Consorzio RFX carried out the activities envisaged in the Task Order #1 of the F4E-OFC-280 Framework Contract that was signed in July 2014. Task Order #1 was originally expected to cover activities till Sept. 2015, but it was extended till March 2016 to synchronize the CODAS activities with the installation and commissioning of the plant systems that are interfaced with CODAS itself. These activities include the manufacturing design, implementation and commissioning of SPIDER Central CODAS, SPIDER Plant System CODAS and SPIDER Central Interlock. In this context, many contracts have been placed by Consorzio RFX to provide goods and services as, for instance, the procurement and installation of the CODAS IT cubicles, the CODAS I&C cubicles, the SPIDER CODAS computers and data storage equipment, IT networks, SPIDER plant system CODAS control, data acquisition and signal conditioning electronics, cable trays and cabling. All components were delivered and acceptance tests were executed. All hardware components were ready for installation on time. Installation was started taking into account the interference constraints from other plant system installations and the NBTF buildings and the maturity of the various plant units to be interfaced. Fig. 2.1.30 shows the SPIDER IT cubicles that were installed in PRIMA computer room.

The tools for the site acceptance tests (SAT) of the control interface of plant units,

[4] A.Muraro et al., Fusion Engineering and Design, 96-97 (2015) 311-314

[5] S.Spagnolo et al., Rev. Sci. Instrum. 87, 02B931 (2016)

[6] M.Barbisan et al. , Rev. Sci. Instrum. 87, 02B931 (2016)

[7] B.Zaniol et al., AIP Conference Proceedings 1655, 060010 (2015)

referred to as miniCODAS, was delivered to and accepted by F4E. It was ready, as required, to be used in the SAT of SPIDER ion source power supplies. The SPIDER Central Interlock System has been subcontracted and the development is undergoing.

Fig. 2.1.30: SPIDER IT cubicles installed in PRIMA Computer Room

Plant system CODAS software was completed and the system is now ready to start the SAT of ISEPS and AGPS. Fig. 2.1.31 shows a set of panels that was realized to implement the human machine interface of SPIDER ISEPS, AGPS, and gas and vacuum.

In last quarter of 2015 task order #02 of the framework contract F4E-OFC-280 was prepared. It was finalized to procure priority components of the PRIMA safety systems, to develop the SPIDER central interlock software and to complete the interface of systems, the construction of which is continuing in 2016, such as gas and vacuum system, cooling system, and medium voltage distribution board.

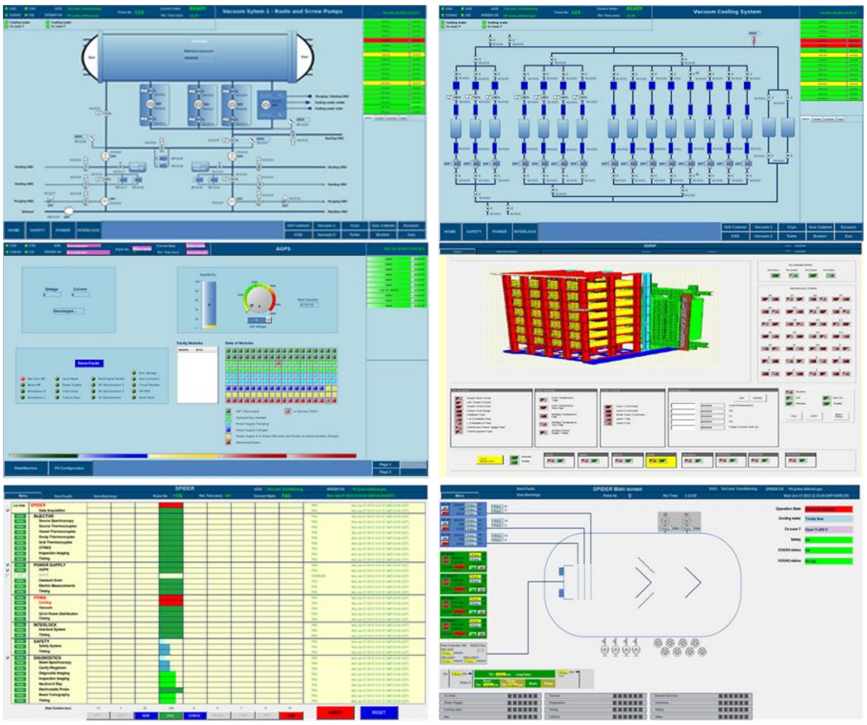


Fig. 2.1.31: Human machine interface panels to remotely control SPIDER, ISEPS and Gas and Vacuum System

2.1.3.8. PRIMA Safety

The overall scheme of the PRIMA Safety management and related systems-subsystems has been fully defined by the beginning of 2015.

During 2015 the design of the PRIMA safety systems progressed, focussing mainly on the SPIDER parts with the aim to be ready as soon as possible for SPIDER commissioning and operation.

In particular the design of the Central Safety System (CSS) has been developed in order to prepare the Technical Specifications (for the hardware) and purchase part of the CSS within the specific contract n.2 of the F4E-OFC-280.

Within the same specific contract other systems will be procured to manage the SPIDER-PRIMA safety, such as: trapped interlock keys for the bunker/power supply room access, doors interlock micro-switches, interface with fire detection system, safety and operational states light panels.

In parallel, the definition of the interfaces between PRIMA safety system and experimental plants continued together with the updating of the risks table as a present summary of the risk evaluation document (as prescribed by Italian Law).

2.1.4. MITICA

2.1.4.1. introduction

During 2015 the work focussed on:

- Support to F4E in the CfT activities relevant for the procurement of the MITICA Vessel, high voltage deck and bushing, power supplies, cryo-pumps and cryp-plant.
- Support to F4E in the preparation of the technical specification and CfT for the procurement of the SF6 Gas Storage and Handling Plant
- Finalization of the design of the Beam Source and Handling tool up to release of the technical specification
- Finalization of the design of the Beam Line Components up to the technical specification
- Completion of R&D in support of the design developments of Beam Source.

During this year the integration of the HV components to be delivered by the Japanese Domestic Agency has progressed including the finalization of the interfaces of the power supply overall system and transmission line with buildings and auxiliaries.

Moreover, activities aimed at the preparation of the installation of the components have been carried out and installation work began in December.

2.1.4.2. MITICA Vacuum Vessel

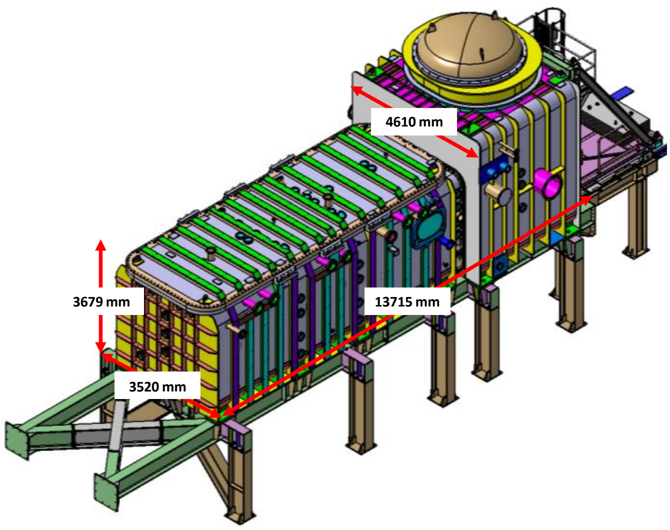


Fig. 2.1.32: The MITICA Vacuum Vessel

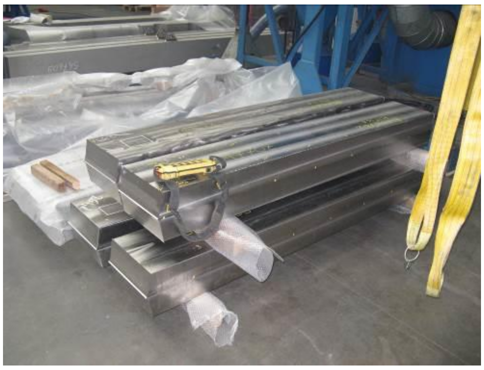
The kick-off meeting of the procurement contract for manufacturing the MITICA Vacuum Vessel was held January 21-22 2015, after awarding of the contract to De Pretto Industrie (I). An overall view of the MITICA Vessel is shown in Fig. 2.1.32. The procurement includes manufacturing, pre-assembly and tests at the factory and the final assembly at PRIMA Site.

RFX gave support to F4E during 2015 with technical follow up activities. Hundredths of documents, manufacturing drawings, procedures and qualification test reports uploaded by the Supplier in F4E-IDM during 2015 have been checked by RFX, revised and finally approved. Similarly for Control and Manufacturing Plans that needed to be checked and approved. Furthermore RFX always guaranteed the foreseen presence at progress meetings, weekly meetings and notified tests meetings for witnessing deliveries and intermediate qualification tests on welds at the Supplier's premises.

From January to 5th June 2015 the engineering activities were carried out by the Supplier to prepare all the manufacturing drawings and technical documents necessary to purchase of material and carrying out the manufacturing activities. The MDR (Manufacturing Design Review) closed this phase in August 2015, allowing the Supplier to start with the next purchase and manufacturing phases.

Almost all the materials for Vessel manufacturing have been purchased, welds qualifications have been completed and cut/weld of stainless steel forged parts and sheets is on-going. Further engineering activities regarding the Vessel support structure and the on-site assembly procedure already started in 2015 and will be completed within the first months of 2016. Delivery and final tests on-site are presently foreseen in the first half of 2017.

Delivery of SS sheets for vessel walls



Delivery of SS massive forged parts for flanges

Welding qualification process

Manufacturing of a first large connection flange for the Vessel.

Fig. 2.1.33 MITICA VV weld qualifications and first manufacturing

2.1.4.3. MITICA beam source

The MITICA beam source technical specifications have been finalised in 2015: more than 750 drawings have been completed and delivered to F4E for the tender preparation. In Fig. 2.1.34: MITICA beam source: the final design of the whole source is shown. R&D activities (Fig. 2.1.35) continued during 2015. Negative results on the first manufacture of post-insulator prototypes with solid cylindrical geometry started during 2013 led to the manufacturing and testing of a second set of prototypes, after the first set gave in 2014 good results for the electrical performances but not good enough during mechanical tests. A reference configuration has been identified, featuring a hollow ceramic insulator and a central rod of vespel® shrink fitted inside. Both mechanical (specific tensile test confirmed previous preliminary values >70 kN) and electrical (no breakdown up to 250 kV for several hours) tests were successful (2.1.35a).

The hollow shape allowed a higher mechanical strength, due to a more homogeneous and effective sinterization.

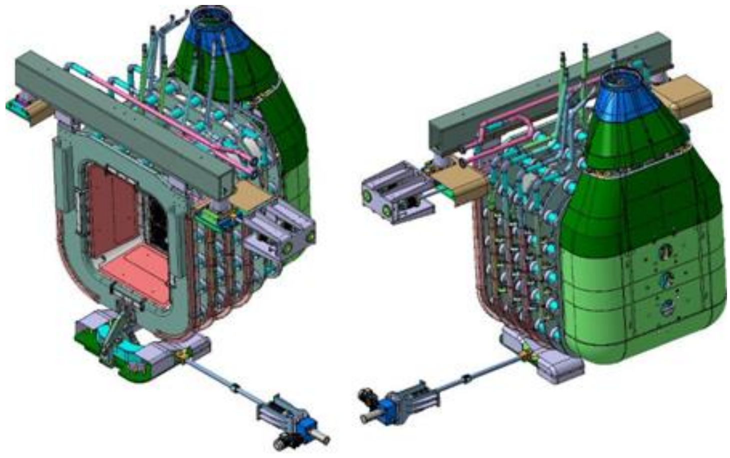
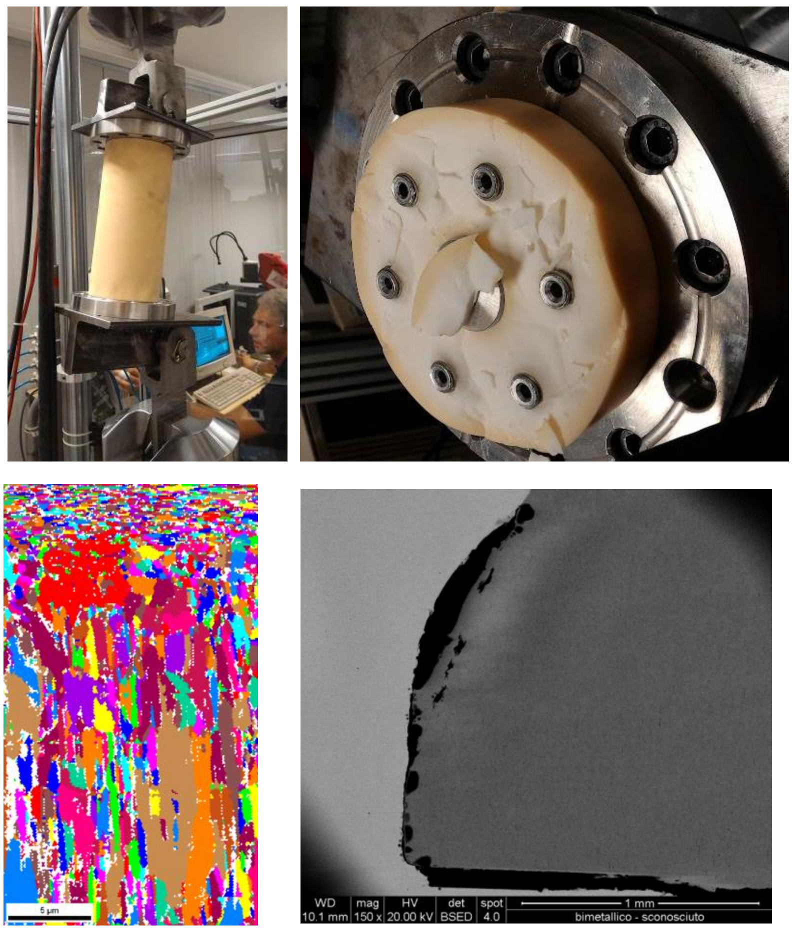


Fig. 2.1.34: MITICA beam source

Additional options for an optimized manufacturing cycle, especially with regard to the critical sinterization phase were identified and preliminarily tested, in order to assess the chance to obtain a solid ceramic (hence simplifying the overall configuration) insulator strong enough for the mechanical tests; so far only a unique part has been procured, but with positive preliminar results.

As for the copper electrodeposition on components of the source, an attempt to take a



(a)

(b)

Fig. 2.1.35: R&D on (a) ceramic insulators and (b) analysis of electrodeposited copper

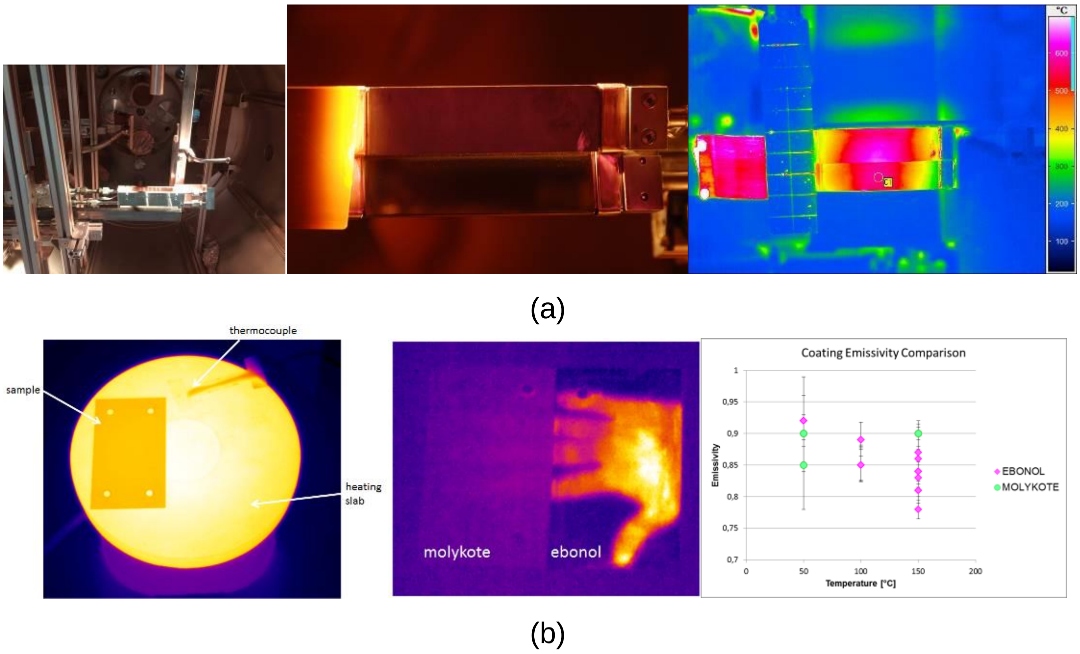


Fig. 2.1.36: R&D on (a) thick Mo layer and (b) enhanced emissivity

deeper look at the crystalline microstructure of the electrodeposited copper was done in collaboration with CNR-IENI, looking for a possible justification of different thermo-mechanical behaviour between different samples from different suppliers and/or lots. Unfortunately, no conclusive information has been derived yet. (2.1.35b).

Samples of thick Mo layer onto a copper substrate have been finally tested at GLADIS facility at IPP, in order to gather more information related to the behaviour of such armour, foreseen on the ion source rear vertical surfaces, to withstand the impinging highly energetic Back Streaming Positive Ions. (Fig. 2.1.36a)

Assessment of methods for enhancing emissivity of RF lines was completed, in order to maximize heat removal from coaxial conductors in vacuum [8](2.1.36 b)

A major effort has been dedicated to finalize the technical specification [9]After the finalization of the 3D model in 2014, all the mechanical details were completed and reported on a huge set of drawings, including requirements on manufacturing and assembly tolerances in the drawings, particularly tight and demanding for the accelerator (Fig. 2.1.37), and on all procurements phases, such as manufacturing, assembly and testing, both at the factory and on site.

[8] [Demuri]
[9] [Marcuzzi].

2.1.4.4. MITICA Beam Line Components

The design of the MITICA Beam Line Components (Neutraliser, ERID, Calorimeter) was completed during 2015. The design included the actions agreed with IO and F4E during the Final Design Review (FDR) meeting in order to fulfil recommendations and observations collected as FDR chits. Activities have been performed with the support of third parties, in particular CCFE for the Calorimeter and E-RID design, KIT for the E-RID design.

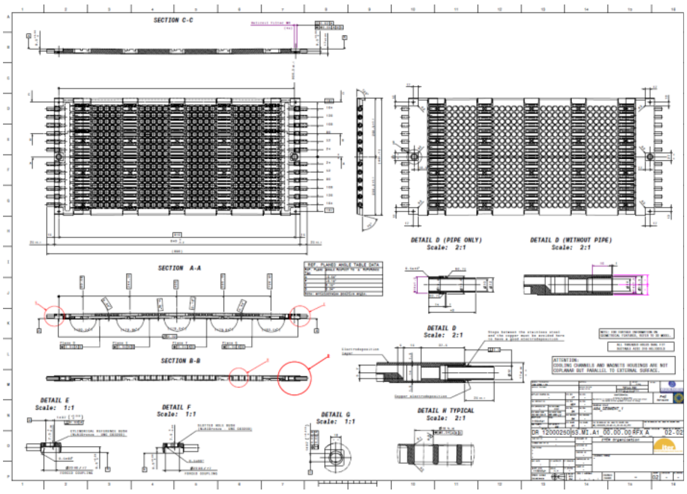


Fig. 2.1.37: Example of final 2D drawing

The main issues for CAD finalisation regarded details of the interfaces mainly with special tools for pipes cut/weld, positioning of target housings to verify position of walls and to align the component along the beamline inside the vacuum vessel, details for diagnostic sensors installation, review of some structural parts for vacuum compatibility, verification and design optimisation for welding sequence considering CuCrZr post welding heat treatment.

The scope of supply for this procurement is manufacturing design, prototypes and tests for qualifications (electrical insulators, heterogeneous welds), materials purchase,

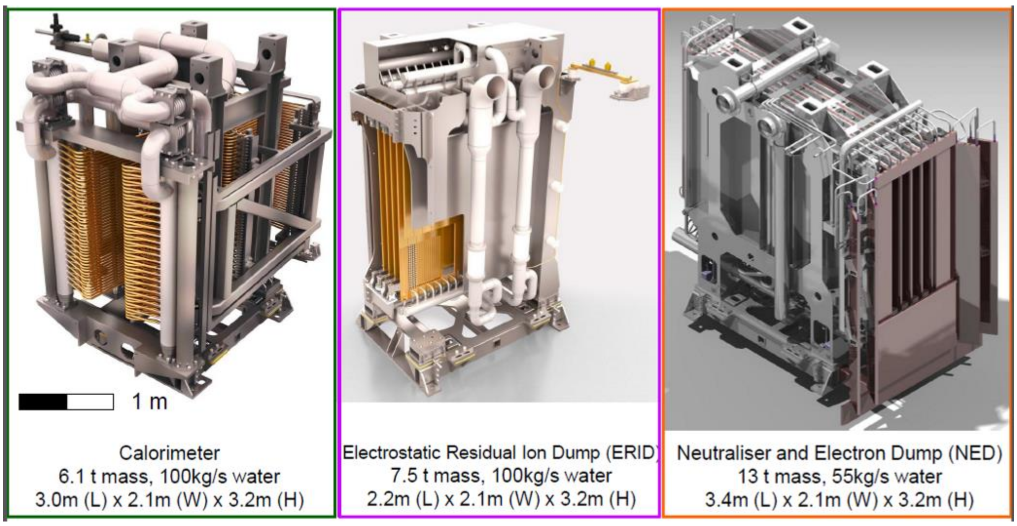


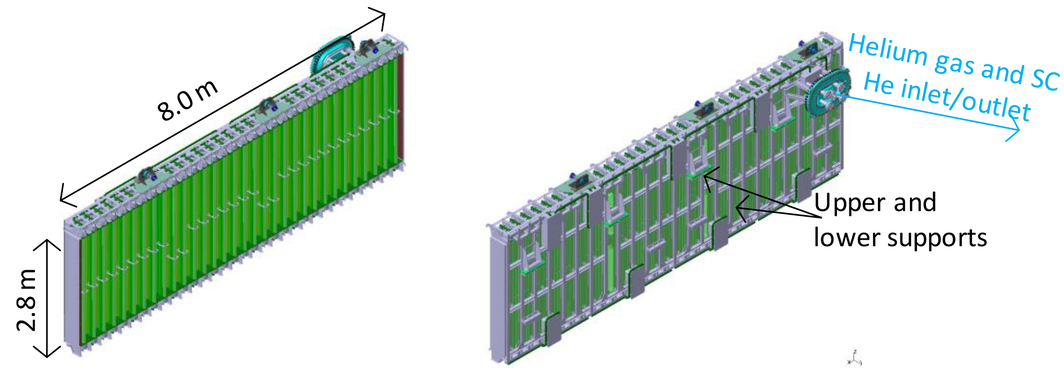
Fig. 2.1.38: The MITICA Beam Line Components as designed for Call for Tender

manufacturing, cleaning assembly, tests at the factory transport and delivery to PRIMA site acceptance tests on site (out of vacuum vessel).

The following tests at the factory are foreseen before delivery: visual inspection, dimensional checks, pressure test, leak test, functional closing/opening test of electron dump panels (for neutraliser only), electrical insulation tests (for RID only), functional closing/opening of panels (for calorimeter only), electrical tests on installed sensors. The Call for Tender for MITICA BLCs procurement is foreseen in middle of 2016.

2.1.4.5. MITICA Cryo-pumps

The Technical Specifications, drawings and CAD model have been delivered in April 2015 by ITER Organization (IO) for review and integration by F4E and RFX. The review process was carried out in May and June 2015 with particular emphasis to verification of interfaces (with vacuum vessel and cryogenic plant), requirements,



Pumping surface facing the BLCs Interfaces with vacuum vessel and cryogenic plant

Fig. 2.1.39: MITICA cryo-pump

acceptance tests and information to be added for on-site delivery and works.

RFX team contributed to several meetings in that period analysing the documents and drawings with F4E and IO. A final set of documents was delivered with the main requests for changes, further verifications and suggestions for integrations.

Three different tenders are foreseen for specific procurements regarding:

- the fabrication of aluminium extrusion profiles with expanded stainless steel tubes
- the charcoal coating on Al profiles cryosorption surfaces
- the surface finishing (blackening or electro-polishing) of Al surfaces and the complete assembly and tests of the cryopumps

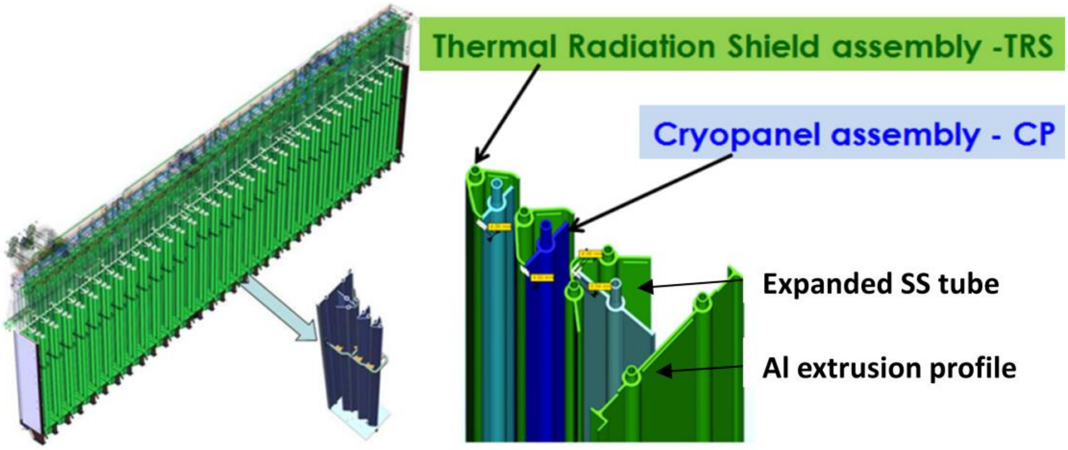


Fig. 2.1.40: MITICA cryo-pump – Isometric view of the pump and a pumping section made of the expansion profiles

The revised Technical Specifications were then delivered by IO on 28 October 2015 and again commented by RFX with some further observations.

The drawings and CAD model are under final preparation by IO and is expected to be delivered to F4E and RFX for final check within 2015.

The Call for Tender for MITICA Cryopump procurement is foreseen in 2016.

2.1.4.6. MITICA Cryogenic Plant

From January to April 2015 RFX supported F4E in the preparation of technical documents for the competitive dialogue phase that started in April 2015. A close and timely support was then provided in the following months by RFX to give technical answers to the two bidders participating to the dialogue phase. Several discussions, clarifications and studies of different proposals occurred up to the submission of 1st technical proposal by the bidders on July 1st 2015. Then individual meetings with the bidders took place and the first preliminary tender was submitted on August 3rd.

The following months were devoted to further discussions of alternative proposals from the bidders and integration of information about the Cryogenic plant interfaces. Two dedicated meetings were held on-site with the bidders to show them the site for installation and discuss any possible open problem, in order to give them a full and complete understanding of the work to be done on-site. A second preliminary tender has been sent by the bidders on October 13th. The final version of Technical Specifications has been prepared by F4E and RFX in compliance with the outcome of thedialogue phase. The launch of CfT by F4E is expected by the end of 2015.

2.1.4.6 MITICA power supply systems

The circuit diagram of the MITICA power supply system is shown in Fig. 2.1.41.The PS system of MITICA includes, similarly to SPIDER, a set of power supplies feeding the active components of the ion source (MITICA Ion Source and Extraction Power Supplies, MP-ISEPS) at a potential of approximately –1MV, a Ground Related Power Supply (GRPS) for the Residual Ion Dump and a further system, the largest in terms of power, feeding the beam accelerator composed of five stages of -200 kV each (MITICA Acceleration Grid Power Supply, MP-AGPS). The procurement of the latter system is split between JADA and F4E. In particular, the MP-AGPS DC Generation system (AGPS_DCG) including high voltage transformers with the rectifier diodes on top falls within JADA scope of procurement, as well as the SF_6 (6 bar) insulated transmission line; whereas the AGPS Conversion system (AGPS-CS) is part of the F4E procurement. The MITICA power supply system includes 2 High Voltage Decks:

- HVD1 and the associated HVD1-TL bushing for connection to the Japanese transmission line, procured by F4E and hosting MP-ISEPS
- HVD2, procured by JADA, feeding the ion source and the intermediate voltage stages with cooling water and operating gases

A 3D view of the MITICA power supply HV components is shown in Fig. 2.1.42. The European components are procured through 4 contracts:

- AGPS-CS & GRPS
- HVD1 and HVD1&TL Bushing
- MP-ISEPS
- SF6 Gas Storage and Handling Plant (GSHP)

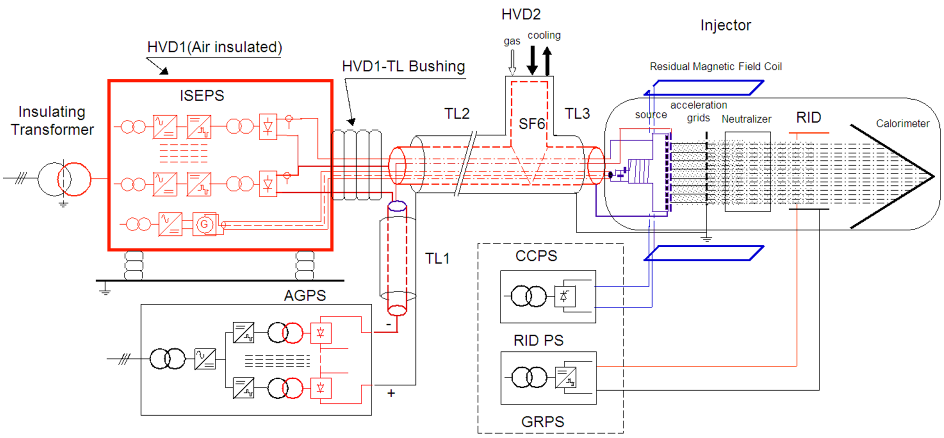


Fig. 2.1.41: circuit diagram of MITICA power supplies

In 2015 the Consorzio supported F4E during the various phases of the CfT process for the AGPS-CS and GRPS. After signature of the AGPS-CS contract, follow-up of the contract began.

Regarding procurement of the bushing connecting HVD1 and HVD1-TL (contract signed at end 2014) the 2015 activities are summarised below:

- Technical discussions of the issues associated to the ISEPS interface
- Technical discussions with the Supplier and review of documents for the delivery of the First Design Report
- Close follow-up of an issue raise with respect of the bushing insulator.

The 2015 activities for MITICA ISEPS (MP-ISEPS contractual stage released by F4E at the end of 2014) are listed below:

- Discussion of technical solutions for MP-ISEPS RF generators. The final choice agreed with F4E was to keep the same tetrode-based design as on SPIDER ISEPS (SP-ISEPS)
- Identification and finalization of design changes (deviations) to be implemented on MP-ISEPS, also on the basis of SP-ISEPS experience
- Discussions related to the HVD1 interface
- Finalisation of the layout of ISEPS equipment inside HVD1

The CfT of the SF6 Gas Storage and Handling Plant (GSHP) was launched in 2015.

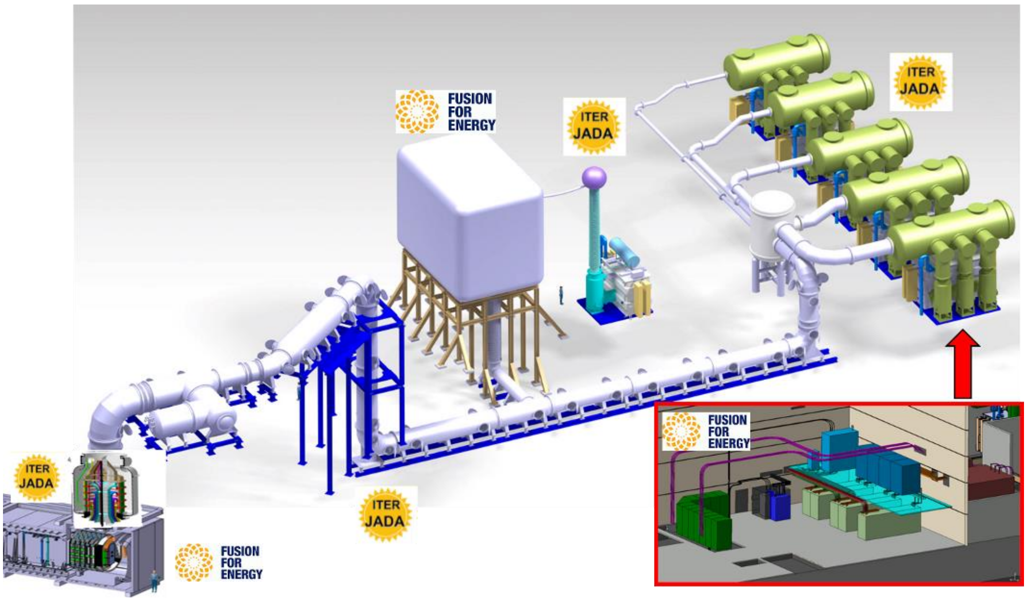


Fig. 2.1.42: 3D view of the MITICA power supply HV components

The Technical Specification documents were prepared directly by F4E with the support of RFX in the review of the CfT documentation. During 2015, RFX staff also contributed to an info day with potential suppliers held on the PRIMA site. An expert of the Consorzio was appointed member of the Tender Evaluation Group for the selection of the winning company.

In 2015 a significant effort was dedicated to guarantee the integration with the Japanese part of procurement. Four main goals were achieved:

- Solving interface issues between JADA components and buildings and auxiliaries;
- Solving interface issues between JADA components and other plant systems procured by F4E; i.e. cooling plant, AGPS-CS, HVD1-TL Bushing, Vessel, Beam Source, SF6 GHSP.
- Site preparations for positioning of the first delivered Japanese components.
- Support to the JADA on-site installation activities, following the signature of an agreement between RFX and JAEA and consequently of a contract between RFX and Synecom (Italian contractor for installation of all components manufactured by Hitachi). The first, important components (200kK, 400kV and 600kV step-up transformers, TL1 and TL2) were received at the beginning of December.

2.1.5. High Voltage Radio Frequency R&D

In the framework of the 2015 Work Program, the R&D activities proceeded with the development of the High Voltage Radio Frequency Test Facility (HVRFTF) which will be used to characterize the dielectric strength in vacuum of the RF drivers at 1 MHz. The aim of the HVRFTF is to study and understand the occurrence of breakdowns on RF coils of the RF drivers of the NBI ion sources.

The approach is to produce the High Voltage with a radio frequency inductive-capacitive resonant circuit, connected to a low voltage power amplifier. The voltage will be applied to a couple of electrodes of different shapes placed inside a vacuum vessel capable of producing a pressure range of $10^5 \div 10^{-3}$ Pa. The working principle is sketched in Fig. 2.1.43. The

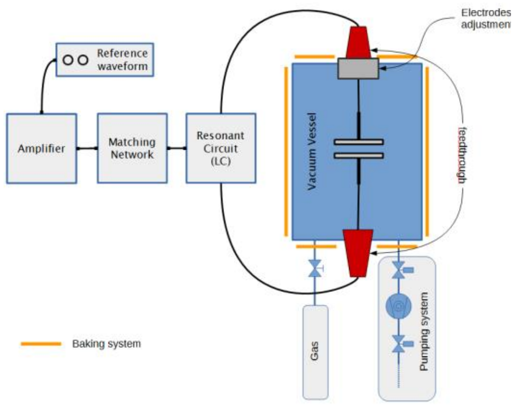


Fig. 2.1.43: Sketch of the HVRFTF

work done in 2015 was focused on the one hand to complete the arrangement of the HVRFTF and on the other hand to assess the RF circuit in order to reach the target voltage with the lowest power dissipation.

The setup of the facility progressed with the transportation to Consorzio RFX of the vacuum vessel used for the 300 kV HVPTF, and the design and procurement of the pumping system to produce the vacuum. Moreover, analyses for the evaluation of the EM field level around RF components were carried out in order to verify the need of a shield to cope with the limits imposed by the Italian regulation.

The assessment to maximize the efficiency of RF circuit required to improve the evaluation of the stray capacitances and the effective resistance of the inductor (main cause of power losses). Such task was the most difficult one; it required an iterative work including the design and realization of different sample inductors with different geometries, the development of a suitable inductor model and the execution of experimental tests to characterize the inductors operation, with the aim to validate the models to be used to finalize the design.

2.1.6. On Site Activities

During 2015 significant resourses were invested on the activities for construction supervision and coordination, both concerning buildings construction with their auxiliary systems and the installation of experimental plants.

Particular effort was required to manage interfaces between buildings and experimental plants, which are now in advanced procurement phase, but also to manage interfaces between plants themselves. Specifically to this end, an interface management structure, run by RFX personnel, has been set up with the aim of reducing as much as possible clashes during installation of plants and to be able to define in real-time the modifications required in any of the plants.

The support to F4E and the other DAs for the management of the Construction-Erection All Risks insurance contract for the NBTF, activated middle 2014 and directly managed by Consorzio RFX, continued.

The NBTF-yard management, with reference to Titolo IV of D.Lgs. 81/08 (Health and Safety on site), whose structure had been set up through the Implementation Agreement, continued in 2015: the Responsible of Work and the Safety Coordinator continuously monitored and periodically reported the state of the yard. Significant resources were spent to assistet F4E, in particular, by the Safety Coordinator who is in charge for the issue of all the Plans for Safety and Coordination (PSC documents), being the latter an essential part for both the procurement call for tenders and contracts management. RFX personell (contract Liaison Officer-LO and Deputy Liaison Officer-DLO) closely collaborated with the Safety Coodinator to this end.

Support for the definition of the on-site organization of F4E and more in general for the definition of the work-on-site rules continued.

As foreseen in the NBTF Agreement, the Coordinator of the Directors of Works (CDL) was appointed by Consorzio RFX in January: with his contribution a baseline schedule for SPIDER on-site activities was approved and issued in June (“PRIMA SPIDER Integrated Installation Plan BaselineB_Issue 10june2015_Approved”). Furthermore, as a coordination method, 45 weekly Site Progress Coordination Meeting (SPCM) have been held, and the minutes distributed and uploaded in F4E IDM. The preparation of the baseline for MITICA started in November.

With the aim to support RFX and the CDL monitoring the site activities, the Assistant to the CDL (ACDL) was appointed by Consorzio RFX, in January too, as foreseen in the NBTF Agreement. Particular support by the ACDL has been given to F4E and other DAs installation works having interfaces with the buildings (hanging points for brackets, holes to drilled, and other similar works requiring approval by building’s designers).

Several site inspections were performed by nearly all of the Companies and DAs that started operating (Coelme, Thales, Ocem, Zanon, Synecom, PVA-TePLA) and/or will possibly start working in the future (e.g. Linde, Air Liquide, SF6 companies).

General follow up activities were performed for all the Companies active on site and all the companies related to the Balance of Plant procurements (in example for the vibrations of Delta-Ti plants, temporary cooling skid for Ocem tests, vacuum pumping system exhaust pipes for SPIDER and MITICA) and to the two signed Framework Contracts (CODAS-Interlock-Safety and Diagnostics).

As for the Licence to operate the two experiments:

- for SPIDER the Nulla Osta cat.A (art.28 D.Lgs.230/95 e s.m.i.) arrived in November with some prescriptions. The latters were discussed with the Fire Brigades (VVF) officer and comments have been sent back within 30 days to the Ministry of Economic Development (“Ministero dello Sviluppo Econominco”), as required.
- for MITICA the preparation of all the necessary documents to be sent to the Italian Authorities started, with priority given to the radioprotection technical report that will

be ready for review by January 2016.

Furthermore, metrology on-site activities were performed mainly devoted to the definition of the SPIDER, MITICA and PRIMA networks. CAD-related metrological activities, complementary to the on-site ones, have been also carried out. The full metrology survey of the PRIMA site areas has been completed preparing, for example, the information (absolute coordinate system, reference coordinate systems and reference fiducial points) to be given to the Companies “as reference” or “starting point” for the installation/positioning of different components.

Periodical measurements of the positions of the fiducial points were perfomed to check the motion of the buildings both during their settlement period and during preloading phase (as for transformers areas). In addition, RFX metrology team had frequent interactions with people in the staff of the main contractors, or on behalf of them, in charge for metrology activities.

2.2. *NBI Accompaning Program*

2.2.1. Introduction

The operation of the negative ion source NIO1 and the activities within the EUROfusion framework covered most of the accompanying programme. On July 1 2015 a major vacuum leak occurred, involving a crack in the alumina insulator inside the RF coil; recovery from this failure required several months and caused some delay of the activities. However initial operation in air and H allowed the initial characterization of the source and prepared the experiment to be operated for extraction and acceleration. The collaboration with other European and Japanese laboratories was intensified and a collaboration in the field of Cs deposition started with Bari University. The experiments and the modelling of HV holding led to a better understanding of the underlying processes. The modelling activities extended to the study the feasibility of alternative concepts as the double beam.

2.2.2. NIO1 Operation

During 2015 the experimental programme with the NIO1 facility was included in the EUROfusion programme within the work package WPHCD. The activities were mainly devoted to the investigation of the source plasma and to the extraction of negative particles from the source. In preparation of these activities several components were realised and tested for the protection of various sub-system and for diagnostic purposes. Moreover numerical codes were used to investigate the behaviour of the device. Tests on NIO1 of the possibility of energy recovery devices in NBI systems progressed. Specifically the following activities were carried out in 2015:

- Operation of the RF source in air to test RF coupling and diagnostics up to 1kW
- Operation of the RF source in H to test RF coupling and diagnostics up to an RF power of 1.7kW (during the operation at this power level the vacuum leak occurred)
- Extraction of negative particles and conditioning of the extraction with H plasma
- Preliminary tests of the acceleration of negative H and O without caesium
- Test of the components of the energy recovery system
- Realisation/test of protection and interlock systems for accelerator breakdowns
- Investigation of currents and voltages during induced accelerator breakdowns
- Realisation of components for several diagnostic systems
- Field test and improvement of calorimetry thermocouples and their circuitry
- Test of a flow meter to improve the control of the gas pressure in the RF source
- Construction of a new extraction grid, with a configuration similar to the MITICA one
- Application of numerical codes to the evaluation of the background gas density profile; numerical simulation of the operation of a beam tomography system.

Moreover, some tests were done by exposing samples to Cs deposition using the NIO1 caesium oven in a dedicated vacuum chamber. Then the sample were analyzed by SEM and XPS techniques in order to study the chemical bonds of Cs on metallic substrates, its uniformity and the effect of the temperature on the distribution.

2.2.3. High Voltage Insulation in Vacuum

The activity related to the HV insulation issues carried out at the High Voltage Padova Test Facility (HVPTF) has been mostly dedicated to the investigation of Voltage Conditioning Process and to validate the design of the MITICA insulator prototypes (Fig. 2.2.1)

A new acquisition system and a new controlling PC (Fig. 2.2.2) were successfully installed and tested. Now it is possible to sample currents, x ray and pressure signals up to 5kHz continuously.

The bursts, that typically occur during the high voltage conditioning procedure, can be

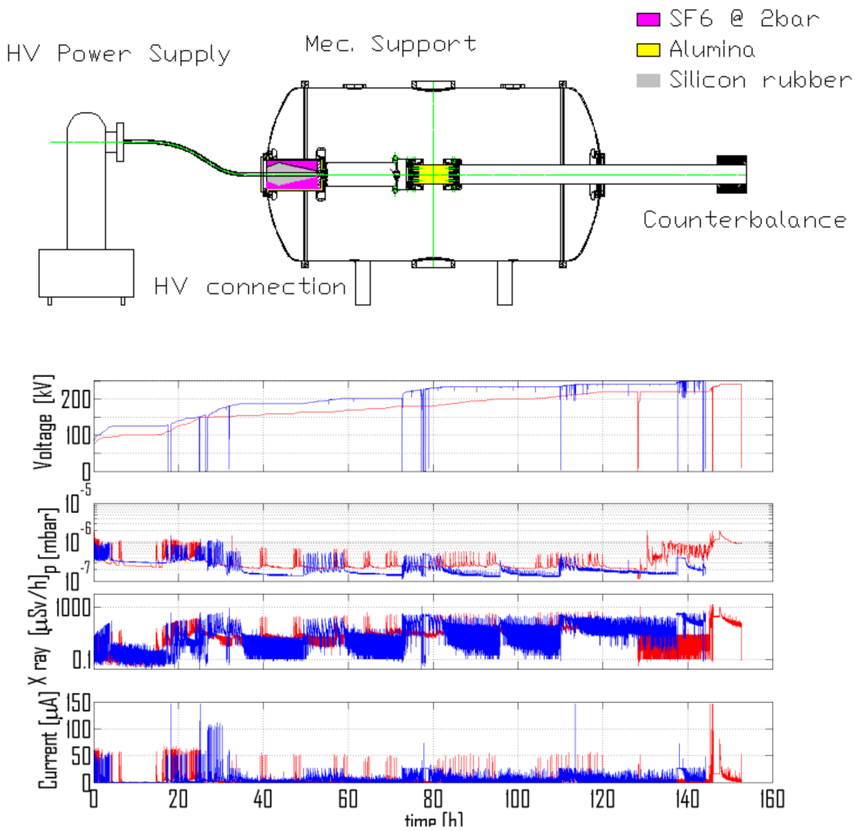


Fig. 2.2.1 Results of High voltage test on a MITICA insulator prototype

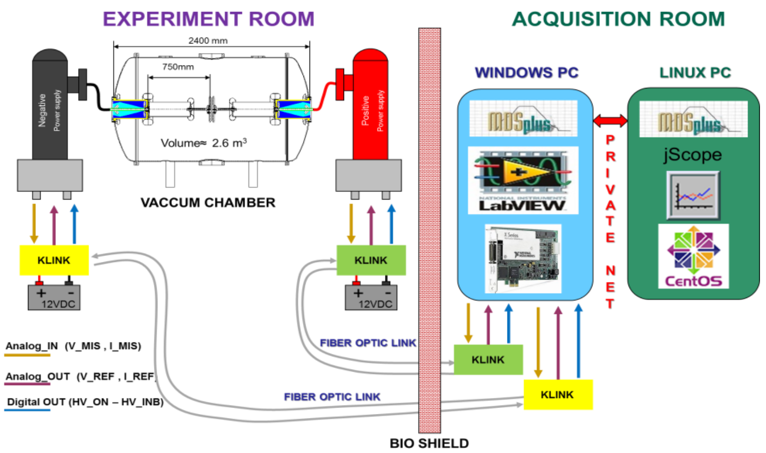


Fig. 2.2.2 scheme of new acquisition system

now recorded properly in order to obtain a suitable set of experimental data validate the Breakdown Induced by Rupture of Dielectric layer (BIRD) model, recently developed at RFX.

Non-symmetric electrode configurations (plane sphere) have been tested to investigate the different role of the cathode and anode in the initiation of breakdowns.

The improvement of voltage holding due to the introduction of H2 has been confirmed

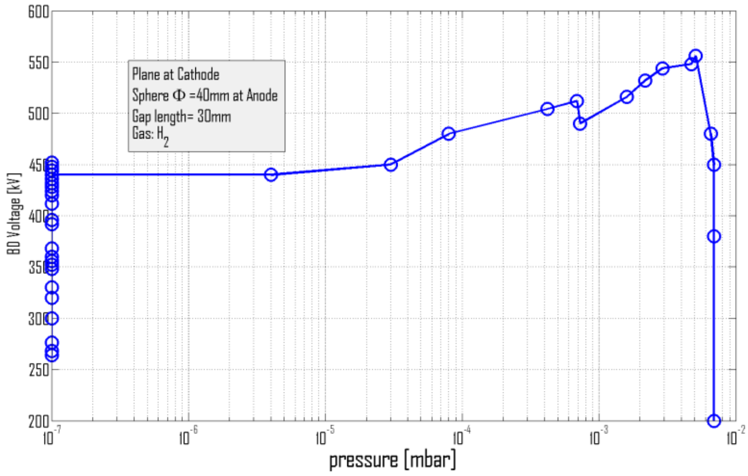


Fig. 2.2.3: Pressure effect on breakdown voltage in a conditioned system having stainless steel electrodes

experimentally, it has been possible to withstanding up to 556kV with a vacuum gap of 30 mm, the experimental data are shown Fig. 2.2.3.

A further step toward in benchmarking of the probabilistic code [10] has been carried out considering the recent experimental results with stainless steel electrodes.

2.2.4. Alternative concepts

2.2.4.1. Assessment of different neutralizer schemes

Within the EUROfusion workpackage WPHCD some resources were devoted to the study of alternative neutralization concepts: photoneutralization of negative ion beams is considered a promising approach to improve the neutralizer efficiency, thus reducing the required source power and pumping requirements of the NBI.

Activity on the photoneutralizer involved the validation of a recirculating optical cavity, based on laser second harmonic extractor. The concept (RING[11]) was introduced in 2014, highlighting both potential advantages (compactness, robustness) and criticalities (thermal loads, laser technology).

In 2015 the concept was developed and applied to a 20 mirrors cavity dimensioned on a DEMO NBI layout (**Fig. 2.2.4**). The optical performance and neutralization capability were evaluated with a dedicated Python code, while thermal loads were computed with

---

[10] [N. Pilan, P. Veltri and A. De Lorenzi IEEE Transactions on Dielectrics and Electrical Insulation Vol. 18, No. 2; April 2011 553]

[11] M. Y. Shverdin et al., *High-power picosecond laser pulse recirculation*, Optics Letters, Vol. 35, No. 13, July 1, 2010.

a COMSOL Multiphysics model.

The study assessed the possibility for the cavity to work in continuous regime.[12] In particular it was verified that the required mechanical stability of mirrors is attainable with standard optical mounting, while the thermal stabilization of the second harmonic extractor can be achieved with proper cooling. Available laser technology still remains the main open issue, even if a possible candidate for the optical source has been identified in thin disk Er:YAG lasers.

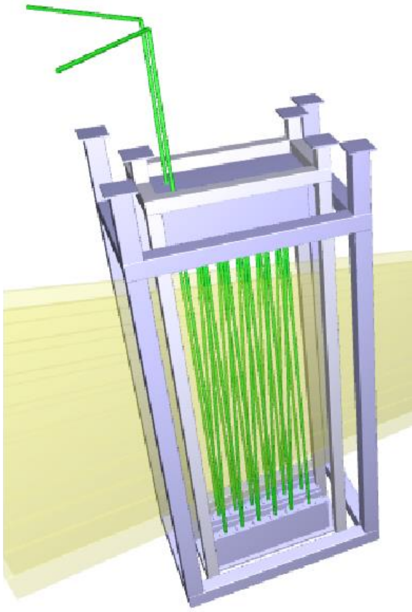


Fig. 2.2.4: Rendering of proposed Photoneutralizer device, integrated in the DEMO NBI layout.

A preliminary commercial survey of components was carried out to estimate the cost of a scaled mockup, which will be first bench top tested for optical and thermal behaviour and later installed on the NIO negative ion source and transiently operated as a beam neutralizer, employing an available Nd:YAG pulsed laser.

2.2.4.2. Study of neutralized double beam

The neutralized double beam concept proposed in 2014 was developed into a workable scheme for fusion application. A state-of-the-art survey was presented in spring 2015 and was positively evaluated by the EUROfusion community. Two different neutralization scheme based on the simoultaneous acceleration of beams containing opposite charges were compared. The first relies on the collective behaviour of the two charges, shielding the beam form external fields and allowing its propagation in high magnetic field. The second concept is based on the atomic neutralization of the charges, resulting in a net production of neutrals. In both cases the absence of residual gas would strongly enhance the NBI overall efficiency. The study showed the practical unfeasibility of the first concept, while the second method is the more promising. Hence the operational window of such a device has been thoughtfully explored, considering the influence of: beam current densities, beam energy difference, accuracy and ripple of the accelerating potentials, background gas, alignment error of the two species

[12] A.Fassina. F.Pretato et al, *Feasibility Study of a NBI Photoneutralizer Based on Nonlinear Gating Laser Recirculation,* to be published in: Rev. sci. Intrum, vol 87. (2) pp. 02B318 (2016)

beams, overall beam divergence. While substantial difficulties make the linear setup unfeasible, a breakthrough concept based on well proven accelerator physics was conceived to overcome the issues: the recirculation of charged beams into storage rings can, in principle, increase the rate coefficients for neutral production up to the levels required for an efficient neutralization. If high current beam recirculation is proven to be feasible with a relatively low emittance growth and current loss per turn, calculations show that the overall neutralization efficiency of a recirculating H^- beam can be up to 85%. This high value is achieved by a minimal gas target thickness. The cost of such a system was not estimated, however, multiple gas-based neutralizers combined with storage ring-based beamlines could provide the required heating power for DEMO while satisfying the volume constraints given for the integration in the plant. Many aspects require a further assessment, in particular: the emittance growth and the acceptance required to the storage ring when for continuous injection of H- beam (e.g. multi-turn injection with orbit bumpers), and the magnetic rigidity of high current beam.

2.2.4.3. Assessment of magnetically deflected beam

A scheme of a neutral beam injector (NBI) [13], based on electrostatic acceleration and magneto-static deflection of negative ions was proposed and analyzed in term of feasibility and performance. The scheme is based on the deflection of a high energy (2 MeV) and high current negative ion beam by a large magnetic deflector placed between the Beam Source (BS) and the Neutralizer.

This scheme could solve two key issues which presently limit the applicability of a NBI to a fusion reactor: the maximum achievable acceleration voltage and the direct exposure of the BS to the flux of neutrons and radiation coming from the reactor.

In order to solve these two issues it is proposed to screen the BS by a magnetic deflector from direct exposure to radiation and neutrons, so that the voltage insulation between the electrostatic accelerator and the grounded vessel can be enhanced by using compressed SF_6 instead of vacuum.

The proposed scheme results effective to accelerate and deflect negative ion beam at energy higher than 1MeV without compromising the beam optics and without loosing power in the magnetic deflector. Future activities could be addressed to improve the

[13] N. Pilan, V. Antoni, A. De Lorenzi, G. Chitarin, P. Veltri and E. Sartori “A new deflection technique applied to a consolidated scheme of electrostatic accelerator for High Energy Neutral Beam Injection in Fusion Reactor devices” , to be published in Review of Sci. Instr. (2015)

physical model and to study new magnetic field distributions aimed at focusing the negative ion beam on a smaller size

2.2.4.4. Alternative schemes for negative ion generation

In collaboration with Bari University a molecular dynamic model has been developed to study the deposition of Caesium on Molybdenum. The model shows the preferential sitedsof deposition and their respective bond energy. The weak bond Caesium caesium compared with that of Mo-CS give as a a result a maxium coverage of the surface close to 70% in good agreement with experimental findings in other faciliites. The results have been published in PPCF (paper featured on the journal coverage).

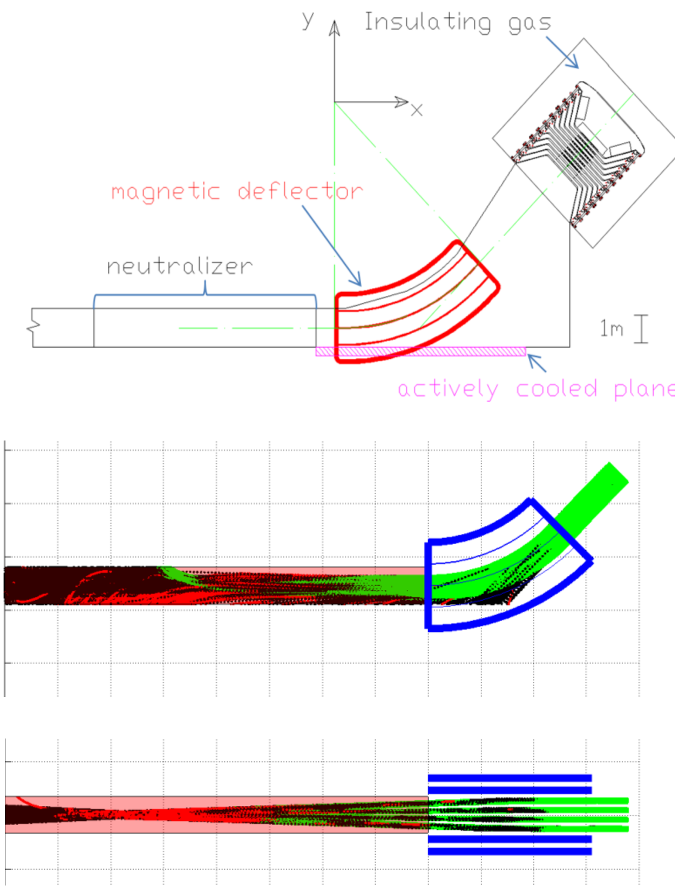


Fig. 2.2.5 Injector scheme and results of Monte Carlo simulations In green, red and black are shown respectively H- , H+ and H0

2.2.5. Modelling

The modelling activity carried out in 2015 mainly aimed at improveming the existing codes and developing of new numerical tools.

Concerning the beam transport, the SAMANTHA code was modified to calculate the generation of secondary particles along the beamline of MITICA and HNB injectors.

The BACSKAT code was the propagation of electrons trough the panels of the cryogenic pumps, to quantify the power loads. A novel approach was used which mapped the electrons trajectories into a five dimensional space that fully characterized the geometry of the simulation domain. This greatly reduced the number of particle required to explore different scenarios of electron populations.

A Particle in Cell code was developed to describe the space charge compensation of a negative ion beam in the drift region after the acceleration stage. The model included an extensive set of collisional processes, and could model the beam-induced plasma formation by gas ionization. The code was implemented in a parallel environment, exploiting Graphic Processing Unit, whch speeded up the execution and allowed to extend the computational domain to many beamlets, and to test different scenarios.

The EAMCC code was also modified to deal with huge computational domains and multi beamlet simulations.

With a renewed effort, the beam modelling activities at RFX are now aiming at the unification of the above codes into a single framework. This will ease future developments of beam physics models by offering, into a well-structured framework, all the needed functionalities – from state-of-the art parallel solvers, to particle tracking routines, and the user interface.

At the same time the benchmark of the SLACCAD and OPERA (for the electric field calculation) and EAMCC (for the secondary generation and relative power loads) codes against experiment continued, using the dataset collected at NIFS and IPP test stand with the MiniStrike diagnostic calorimeter.

2.2.6. Collaboration with other laboratories

In 2015 a scientific collaboration agreement between Consorzio RFX and JAEA entitled “Research collaboration on Neutral Beam Injection for the improvement of the plasma performance” was signed. The agreement has the aim of expediting the achievement of the NBI performance required for plasma heating and current drive in ITER.

In particular, some foreseen activities are:

- Improvement of the negative ion source and accelerator performance, proving a long pulse of ITER-relevant beam in the MeV test facility (MTF: 1 MV, 1 A, 60 s).
- Studies of the ion source and beam accelerator physics in the JAEA test stands: Negative Ion Test Stand (NITS: 60 kV, 6 A, cw, or, 40 A, 0.5 s) and High Voltage Test facility (HVT: 300 kV, 10 mA, cw).
- Development of the beam simulation codes, code to code benchmarks and comparisons with experiments.
- Development of the beam diagnostics.
- Development of operation techniques of the MeV-class beam accelerators.

- Joint analysis of experimental results between JAEA and RFX.

A first joint experiment proposal was discussed and agreed during a visit in Fall 2015. A new Extraction Grid (EG#1) for NITS, having aperture profiles similar to those adopted for MITICA, will be designed and built by RFX. The EG#1 aims to achieve a full code-code benchmark and code-experiment validation. On the upper half, the EG#1 will be provided with standard Co-extracted Electrons Suppression Magnets (CESM) and with Asymmetric Deflection Compensation Magnets (ADCM) to compensate the magnetic deflection (concept foreseen in MITICA and ITER NB). On the lower half of EG#1, only standard Co-extracted Electrons Suppression Magnets (CESM) will be used, to allow direct measurement of the effects of the ADCM. JAEA will prepare the CFC target, the target support and the IR camera and install all the components on NITS. The EG#1 is presently under construction at RFX and will be tested on NITS during the first months of 2016. The benchmark of the beam accelerator codes used at RFX (SLACCAD, OPERA) vs the one used at JAEA (BeamOrbit) is already in progress considering the geometry of NITS with EG#1. The experimental results on NITS will be jointly analysed and published by JAEA and RFX.

The collaboration between Consorzio RFX and NIFS (Toki, Japan), funded within the bilateral agreement between CNR and Japan Society for the Promotion of Science, continued in 2015. A new experimental campaign was carried out in June-July 2015, to characterize the negative ion beam of the NIFS test stand for LHD beam injectors by means of mini-STRIKE (a prototype of the diagnostic calorimeter for SPIDER). Besides the 2D temperature profile on the rear side of the CFC tiles, for the first time also the current collected by the calorimeter was measured: a dedicated circuitry was realised and the tiles were biased to collect the secondary electrons. Current was measured while varying the bias voltage, to find the optimal operating conditions. The beam was characterized in various experimental conditions, including the masking one of the beamlets to study of the effect of space charge repulsion among beamlets. The experiments were partially crippled by the above mentioned vacuum leak.

The characterization of the BATMAN beam by mini-STRIKE continued up to April 2015 (operation for less than 2 months) in various conditions in H and D, with the synergy of spatially resolved Beam Emission Spectroscopy and by comparing with data provided by the BATMAN calorimeter. The non-homogeneity of the BATMAN beam was investigated, finding clear dependencies on the bias voltage of the plasma grid, on the gas species and on strength and direction of the magnetic field, and studying the

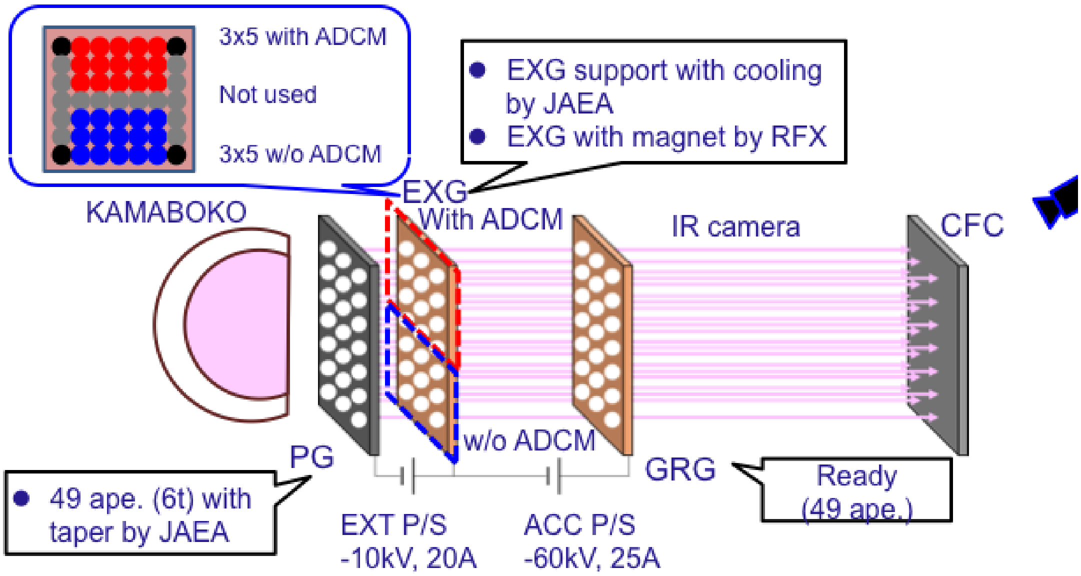


Fig. 2.2.6: The experimental set-up of NITS for the first RFX-JAEA joint experiments

effectiveness of Cs in generating negative ions during its formation over a clean plasma grid surface. The present detailed investigation highlighted some new evidences, such as the influence of the acceleration voltage on the beam properties, requiring an interpretative effort.

The mini-STRIKE data collected in BATMAN and in the NIFS test stand were analysed by means of a newly developed data analysis method based on the transfer function technique allowing the reconstruction of the 2D beam energy flux profile hitting the front side of the CFC tiles from the temperature pattern measured on their rear side.

2.3. *ITER Modelling and ITPA related activities:*

In 2015 the activity on disruption modelling focussed on the 3D nonlinear simulations, mainly employing the M3D code, in the framework of an ITER contract which ended in November 2015.The results have been summarized in a final report approved by the ITER Organization. The original request of the contract was to simulate the asymmetric halo currents rotation during disruptions at different frequencies. The task however proved to be too difficult to be fully accomplished. In particular the physical mechanisms that induce halo rotation are not yet well known. Therefore the study analysed at least some of the possible mechanisms that can produce such effect, within a single fluid plasma model.

One important result was that the plasma velocity and plasma angular momentum can change during asymmetric Vertical Disruption Events (VDE's) due to the presence of a

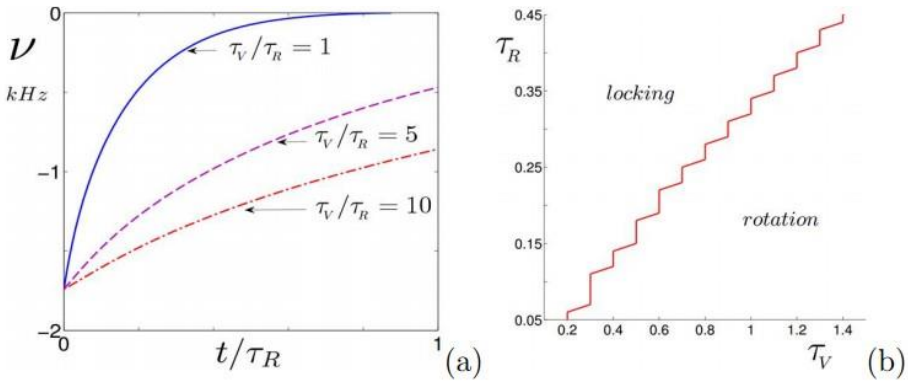


Fig. 2.3.1: mode rotation vs. time (a) and locking threshold (b)

normal field at the wall. An increase of the plasma toroidal velocity and a positive correlation with the plasma displacement during the VDE was observed in simulations and discussed theoretically[14].

Another interesting result was that the plasma rotation, during VDE's is often observed in simulations, to have a zonal structure, i.e. the rotation of the outer plasma region is faster than the volume averaged one. Therefore, if the modes producing the non axi-symmetric halo currents are localized to the outer plasma layer, they rotate faster than the volume averaged velocity. Since in ITER the dangerous frequency range (to excite mechanical structures resonant response) is peaked at low frequency (< 100 Hz), this result suggests that rotation of halo asymmetry should not be a problem in ITER.

Simulations showed also that plasma viscosity has a strong effect on mode growth and toroidal rotation. Above a certain viscosity and for a given plasma resistivity (or Lundquist number) the mode is not rotating. In Fig. 2.3.1(a), for example, using a simplified cylindrical model (RFXlocking code) it is shown that when the viscous time is long (viscosity is low), mode locking is avoided. In Fig. 2.3.1(b) the locking threshold is shown to happen for each value of the viscous time at slightly different values of the resistive time (i.e. at different plasma temperatures). However the mode remains locked above a critical viscosity Simulations also showed that both non-axisymmetric wall force and rotation decrease with the wall time constant. This fact, suggests that in ITER, where the wall penetration time is of a few hundreds ms, these effects should be less important, if compared with those present in existing devices.

[14] H. R. Strauss, L. Sugiyama, R. Paccagnella, J. Breslau, S. Jardin, Nuclear Fusion **54**, 043017 (2014)

During 2015, under the ITPA (International Tokamak Physics Activity) framework, a comparison between ExB driven particle transport around magnetic islands and in open field line layers in the RFX-mod reversed field pinch and TEXTOR as cylindrical tokamak with ergodic divertor was done[15]. A model of ambipolar potential, developed within the guiding-centre (GC) code Orbit for the RFX-mod reversed-field pinch[16], was upgraded for the tokamak. The model guarantees the ambipolar condition $\Gamma_i=\Gamma_e$ over the helical flux surfaces of the edge 4/1 island, produced via resonant magnetic perturbations (RMPs) in TEXTOR. The modeled potential (Fig. 2.3.2b) was compared to existing measurements of plasma potential, performed within the 4/1 island by a sweeping probe (Fig. 2.3.2a): a very good agreement is found between model and measurements, suggesting that a large part of the electrostatic response to RMP islands in the tokamak is due to an ambipolar mechanism. This also suggests that a magnetic island in the plasma edge can act as *convective cell*, which dominates heat and particle transport Such result is quite relevant for the operation with resonant magnetic perturbations (RMP) in DIII-D and ASDEX, and, in perspective, for ITER.

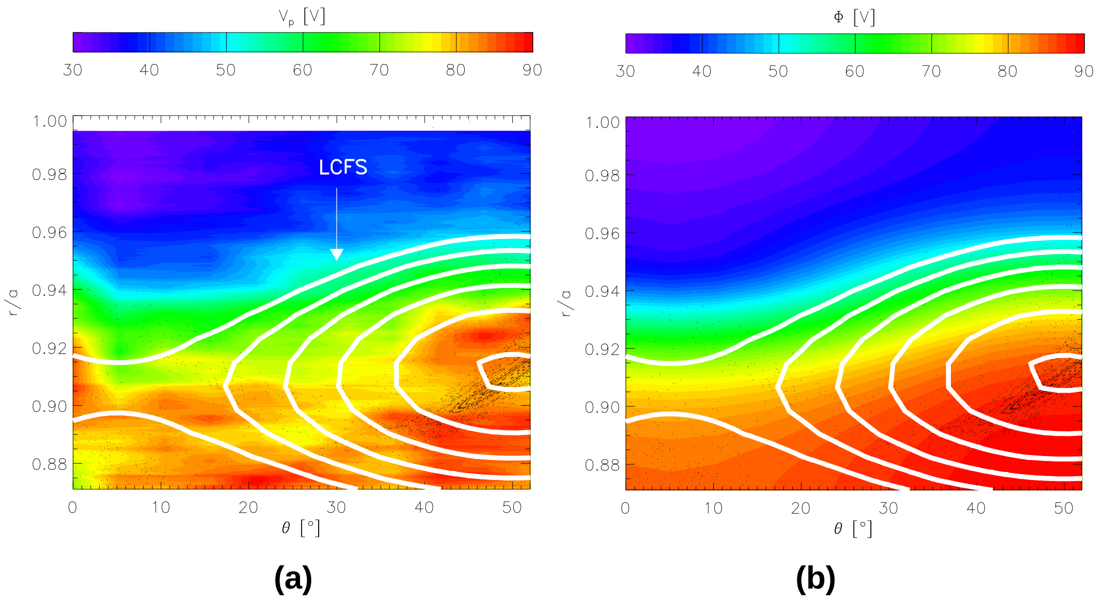


Fig. 2.3.2: (a) measured plasma potential near an edge 4/1 island (pulse # 109269, imposed perturbation 3/1); (b) model of potential with ORBIT, which guarantees the ambipolar condition $\Gamma i=\Gamma e$ over the helical flux surfaces. The potential follows closely the LCFS outside the island.

[15] G. Ciaccio, O.Schmitz, G.Spizzo et al., Phys. Plasmas **22** (2015) 102516

[16] Spizzo G, Vianello N, White R B et al., Phys. Plasmas **21** (2014) 056102

3. EUROFUSION Programme

3.1. *Activities related to the RFX-mod device*

The operation weeks in 2015 were extended to 29 instead of the planned 25 (15 in RFP configuration, 14 in Tokamak configuration), due to the promising results of the last experiments and in the perspective of a long shut-down, which started in Fall 2015.

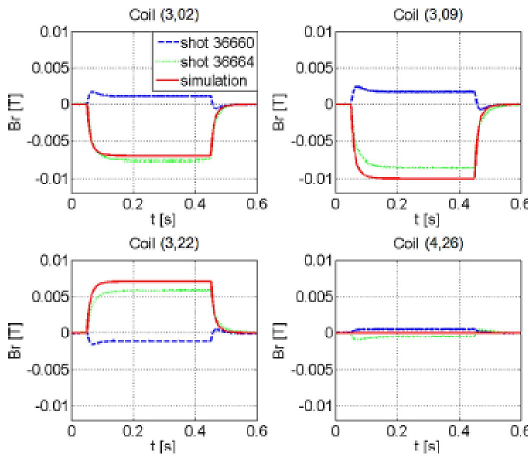


Fig. 3.1.1: pulse 36660 (dashed blue) with 4 coils disabled compared to 36664 (green dots) in which the compensation strategy is applied. Red line: reference

The high current RFP experiments were limited to 1.5 MA due some broken control saddle coils (a total of 6 at the end of the campaign, whilst all of the 192 saddle coils will be substituted during the shut-down).

Most of the experiments carried out were included in Enabling Research projects ranked as “B” by the STAC, i.e. of interest for the Eurofusion programme though not funded for budget restrictions: indeed the results described in the following contribute to issues relevant to fusion science and included in the Roadmap.

3.1.1. Strategy for failed saddle coil compensation

The failure of some saddle coils introduced a significant disuniformity in the error field correction, which lead to localized field deformation, thus limiting in particular the high current operation. To compensate such disuniformity, a frequency dependent decoupler could be in principle developed. However, given the difficulty of implementing a frequency and time dependent decoupler in real-time operation, a static matrix approach was chosen[17]. The matrix is calculated from actuator–sensor mutual inductances at a given frequency and can be applied in both experiments and simulations. A numerical plant model obtained from the CarMa code was used for dynamic simulations in which different experimental setups and decoupling strategies were tested. The local effect of a non-uniform boundary on the magnetic field produced by active coils was studied and a compensation taking the actuator–sensor coupling into account has been introduced. An example of the result is given in Fig. 3.1.1.

[17] L. Pigatto et al., Fusion Engineering and Design 96–97 (2015) 690–693

3.1.2. Advancements in understanding the helical RFP configuration

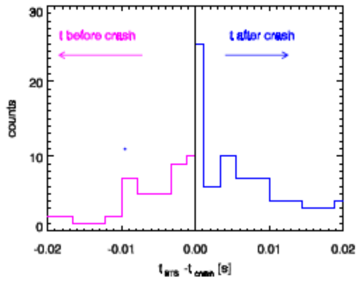


Fig. 3.1.2: Time distribution of profiles with multiple structures, vs distance from previous or next DRE event; STS occurs typically near a DRE

The analysis of the helical states observed in RFX-mod has been extended over a large database, in particular studying the effect of externally applied helical boundary conditions. Data from the DSX3 T_e diagnostics, based on the double filter technique and with high time resolution, were used. It was found that a non-zero reference perturbation increases the average *Vloop* with respect to standard discharges (by 2−5*V*) for both H and D pulses. However, while the application of an external perturbation significantly deteriorates global confinement in H plasmas, its impact is lower in D[18].

The occurrence and localization of small temperature structures (STS), observed in RFX-mod T_e profiles measured by Thomson scattering, has been analysed. Strong evidence has been found that such STS can be ascribed to secondary mode islands, transient structures whose lifetime is in the ms range or less, which develop preferentially around a dynamo relaxation event (DRE), i.e when a burst of secondary modes occurs (Fig. 3.1.2).

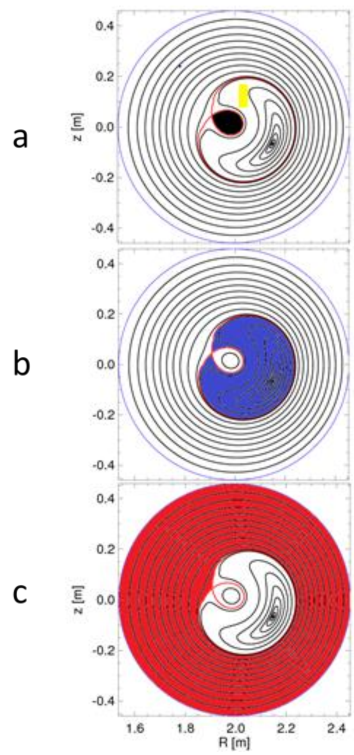


Fig. 3.1.3: the 3 zones in the multi-domain scheme: (a) from main magnetic axis to separatrix, (b) from island O-point to separatrix, (c) from separatrix to edge.

A study was started concerning the impact of magnetic islands on thermal and particle transport (developments of such work are also proposed as Enabling Research project 2017-18). Indeed the islands modify the magnetic topology leading to changes in the transport properties. Transport codes currently applied (JETTO, ASTRA) are 1.5D and relatively user-friendly tools to study the main features of transport. However, they are presently built assuming that magnetic surfaces are nested around one axis. Hence a new tool to study transport phenomena in plasmas with islands has been developed in 2015. As shown in Fig. 3.1.3, a multi

[18] M. Gobbin et al., Plasma Phys. Contr. Fusion **57** (2015) 095004 doi: 10.1088/0741-3335/57/9/095004

domain scheme has been assumed, which describes the so-called DAX regimes, characterized by an electron temperature profile as shown in Fig. 3.1.4. The 3 zones share the separatrix, which is the common boundary. In each domain the helical magnetic flux is chosen as the effective radial coordinate, and the metric elements are computed accordingly, including the discontinuities arising at the separatrix. The new tool (MAxS) was used to compare the thermal conductivity in different regimes, characterized by the presence of narrow or wide islands.

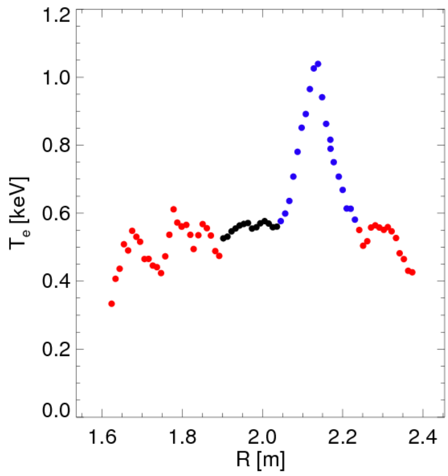


Fig. 3.1.4: Te profile in a DAX regime: the code color is the same as for Fig. 3.1.3

First results show that in regimes with narrow thermal structures, as in the DAX case, the thermal conductivity is lower than in SHAxs, where the thermal structure is much wider, though of course this low conductivity region is much smaller and therefore the global confinement is lower. This is shown in Fig. 3.1.5, where blue points correspond to DAX regimes, while red points to the widest thermal structures observed in SHAXs. This tool is applicable also to Tokamak and Stellarator, where the presence of magnetic islands can also impact on transport. Indeed in 2015 first applications to the TJ-II Stellarator have been done, where the radial location of the low order resonances leads to the onset of internal transport barriers around the resonant surfaces. At the same time, a collaboration with NIFS has started, whose aim is the description of transport when a *m=1, n=1* island is induced by RMP in the LHD device.

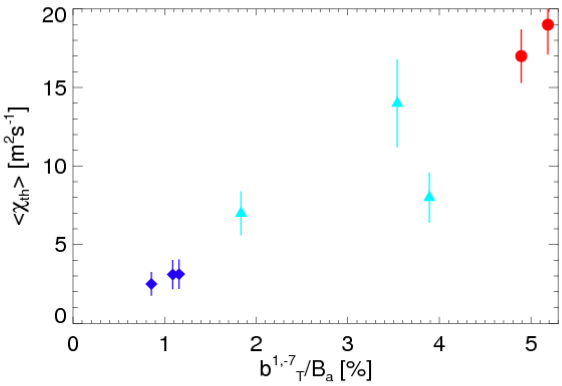


Fig. 3.1.5: thermal conductivity from MAxS vs dominant tearing mode amplitude; blue are DAX states, cyan and red SHAx of increasing wideness

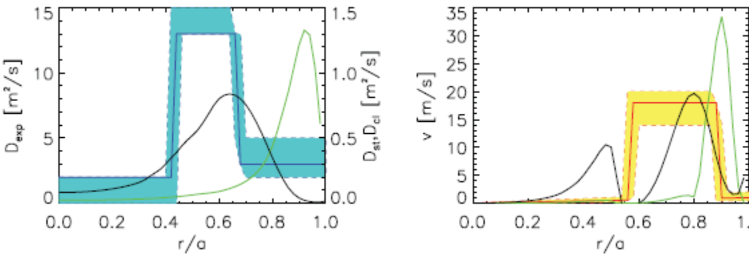


Fig. 3.1.6:Transport coefficients determined for C in QSH regime (uncertainty shown by colored areas). In black stochastic transport, in green the classical one.

Advancements have been done also in light impurity transport studies. A 1-D CR impurity transport code has been used to reconstruct experimental emission pattern of Li and C solid pellet injection experiments, in MH and QSH regimes, aiming at a transient experiment, where the transport coefficients can be discriminated, with a impurity source in the internal plasma region. It is found that an external outward velocity barrier counters impurity plasma penetration in both regimes.

Such barrier is even more effective during QSH regimes, as shown in Fig. 3.1.6.

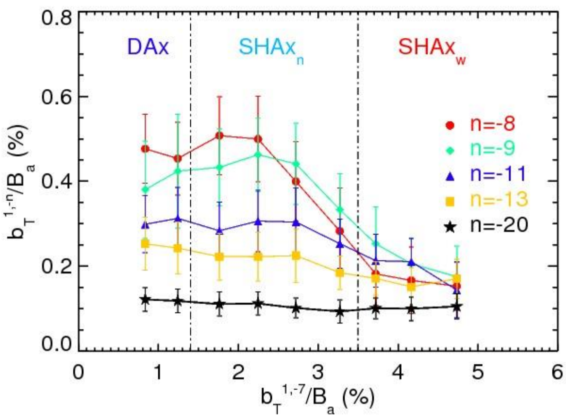


Fig. 3.1.7: ensemble average of secondary mode amplitude vs dominant m/n=1/-7 one. SHAx$_n$ narrow barriers, SHAX$_w$ the wid ones

No strong mass/atomic number dependence of the transport coefficients is found. Indeed the main features of Ni and W transport, already investigated in RFX-mod by LBO injections in QSH plasmas, did not show impurity core penetration, which is an appealing feature of the RFPs.

The transition from DAX to SHAx states (from narrow to wide barriers) was analysed on a large database. It was found that onset of wide thermal barriers is related to the reduced overlapping of the two tearing modes resonating close to the barrier (*n=-8* and *-9* in RFX-mod, Fig. 3.1.7), allowing the development of thermal gradients between the two resonance radii. In this approach, the sub-dominant modes play a crucial role in determining the region enclosed by the the high T_e gradients observed in RFX-mod, producing an Internal Transport Barrier (ITB).

An intense theoretical activity was devoted at studying the effect of an edge helical magnetic perturbation (MP) and also stimulated dedicated experiments. On the theory side, the 3D non linear MHD codes used were SPECYL (cylindrical geometry, β=0) and PIXI3D (toroidal geometry, finite β). An example of PIXI3D simulation is given in Fig.

3.1.8, where it is seen that toroidal sidebands induce magnetic islands and stochastic layers. Including an helical boundary in the simulations resulted in helical RFP states similar to the experimental ones. The possibility of inducing helical states with helicity different from the natural one was also highlighted and, then, experimentally demonstrated. An example is shown in Fig. 3.1.9, with a *m=1, n=-8* MP applied; helical states can also be induced (in simulation and in experiment) by applying non-resonant MPs. Simulations also show that, when a non-resonant MP is applied, the regions of conserved magnetic surfaces are larger (Fig. 3.1.10).

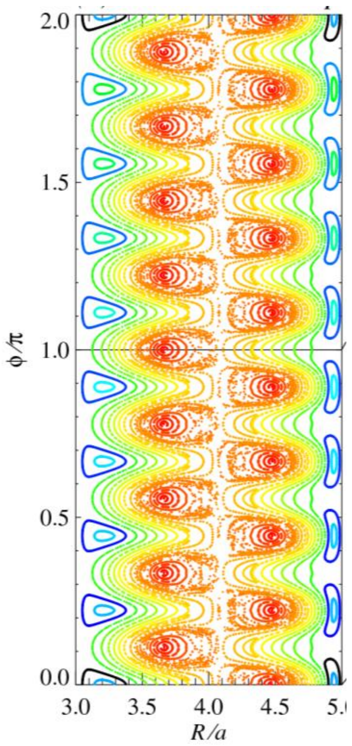


Fig. 3.1.8: z=0 Poincare' plot from PIXI3D with m,n=1,-9 helical boundary; m=1 helical core induces m=0 islands at the edge (2015 ISH workshop)

The application of new techniques for topological characterization in weakly chaotic regimes (a first implementation of the "*ridge*" technique borrowed from fluid biological and pollution diffusion studies[19]) is currently in the development phase, aiming at testing both simulation and experimental cases.

This methodology relies on the calculation of the Finite Time Lyapunov Exponent (FTLE) associated with the magnetic field in regions weakly chaotic. The FTLE ridges are recognized as lagrangian coherent structures, and identify quasi-conserved structures in the chaotic sea.Fig. 3.1.11, where ridges are drawn as black lines, shows that they can be viewed as barriers to the magnetic field line diffusion.

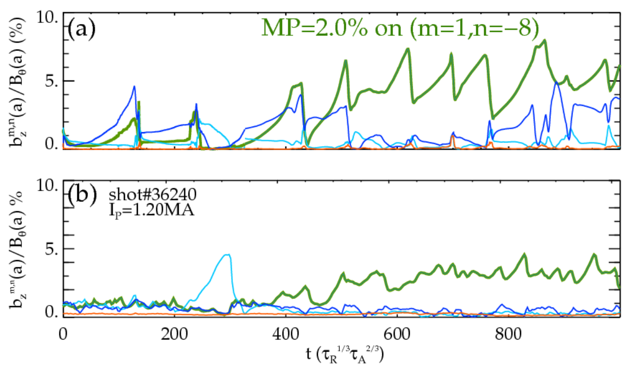


Fig. 3.1.9: RFP helical states as obtained by SPECYL simulations (a) and in the experiment (b) with 2% m=1, n=-8 applied MP.Green lines are the m=1, n=-8 tearing mode amplitude

19 Rubino S, Borgogno D, Veranda M et al Plasma Phys. Contr. Fusion 57 085004 (2015) doi:10.1088/0741-3335/57/8/085004

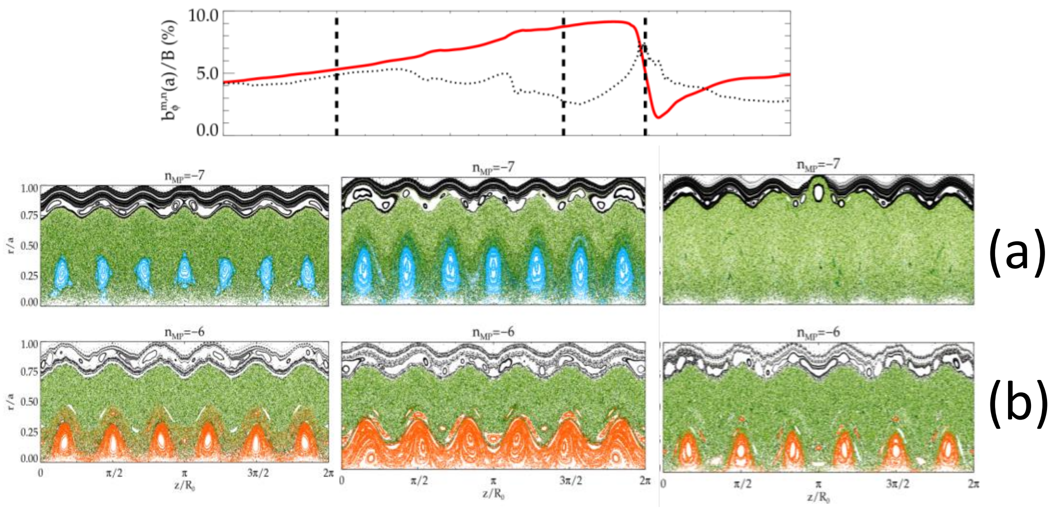


Fig. 3.1.10: Poincare plots at 3 times (dashed lines in top plot), with n=-7 MP (a) and with n=-6 MP (b), showing larger conserved regions in the latter case

The widening of theoretical studies and experimental data analysis on helical states in RFPs and other magnetic configurations are included in a submitted Eurofusion Enabling Research project 2017-2018. Indeed it is worth mentioning that in 2015 the PIXI3D code has been also applied to Tokamak and Stellarator, to describe the magnetic topology in toroidal geometry (see sec.3).

3.1.3. RFP contribution to understanding the isotope effect

The comparison of deuterium and hydrogen discharges, already started in 2014[20], has been advanced. Dedicated algorithms have been developed to calculate the maximum temperature gradient, the size of the thermal structure and the peaking of the electron temperature profile in the core[21]. Discharges with and without external perturbation applied have been considered in the analysis.

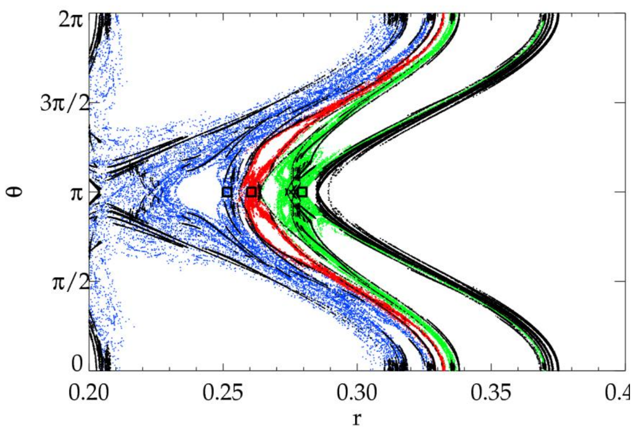


Fig. 3.1.11: ridges (black lines) superimposed to the Poincare' plot (NEMATO code) after 100 turns.

20 R. Lorenzini et al 2015 Nucl. Fusion 55 043012

21 M. Gobbin et al., Plasma Phys. Contr. Fusion 57 (2015) 095004 doi: 10.1088/0741-3335/57/9/095004

The results are summarized inFig. 3.1.12. Both with and without external perturbation higher temperatures and confinement times are observed in D discharges (panels (d), (e), (g), (m), (n), (p)). Panel (a) shows that the average amplitude of secondary modes is lower in D plasmas, with a lower difference between the two gas species when external perturbations are applied (panel (h)). In addition, the comparison between panels (c) and (l) shows that a non-zero reference perturbation increases the average *Vloop* with respect to standard discharges (by about 2−5*V*) for both the gas species. However, while the application of an external perturbation deteriorates the confinement properties in H plasmas, it does not affect significantly the thermal quantities in D discharges.

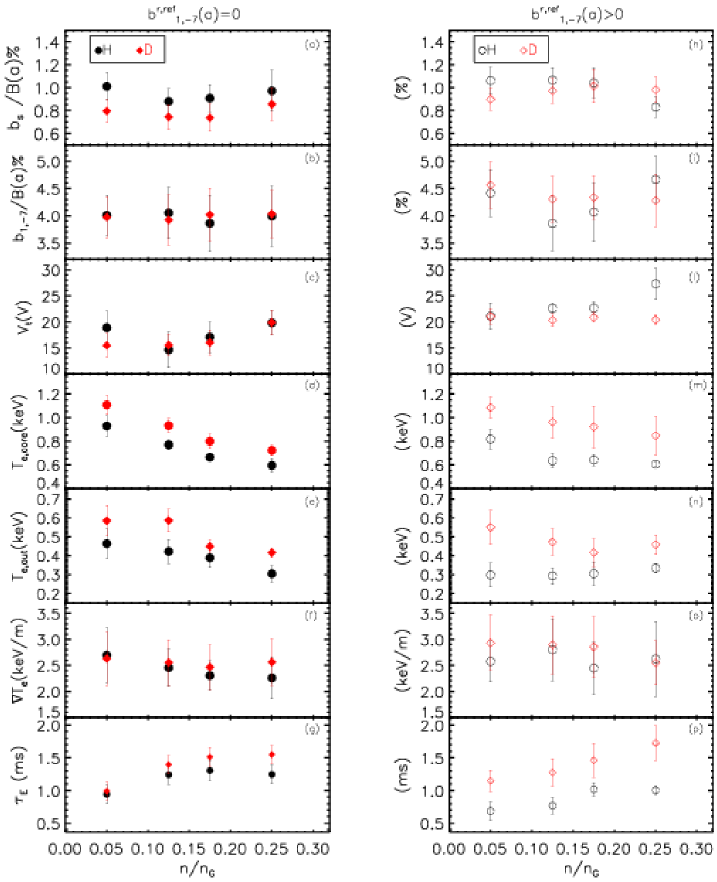


Fig. 3.1.12: left: w/out MP secondary mode amplitude applied; right: with MP applied; from top, dominant mode amplitude, loop voltage, core T_e, T_e outside the barrier, temperature gradient, energy confinement time. Red points: D; black points:H

3.1.4. ITG turbulence studies in the RFP

Turbulence induced by the ion temperature gradient (ITG) has been investigated iin both helical and axisymmetric plasma by means of gyrokinetic calculations (GENE code), to evaluate the impact of the geometry on the instability and its ensuing transport. Despite its enhanced confinement, the high-current helical state demonstrates a lower ITG stability threshold compared to the axisymmetric state, so that ITG turbulence is expected to become a significant contributor to the total heat transport. As an example, Fig. 3.1.13 shows the ITG growth rate vs the ion temperature gradient in the helical and axisymmetric geometries[22].

3.1.5. Edge and high density studies

A detailed study of the effect of magnetic perturbation on edge flow and small scale turbulence has been done, exploiting the versatility of the device which offers the possibilityto of analysing the same phenomenology in two different configurations, RFP and Tokamak, on the same machine and with the same diagnostic[23,24]. Both the configurations reveal a modulation of the electron density and of the radial electric field which exhibit the same periodicity of the underlying magnetic topology. It has been

demonstrated that the presence of magnetic island close to the wall modifies the pattern of E × B flow consistently with the geometry of the island, with the appearance of a convective cell around the island. The observed flow acts as convective motion which contributes to the observed modulation of plasma density with local accumulation, for the RFP case at the X-point of the islands[25]. Particle fluxes induced by electrostatic turbulence is

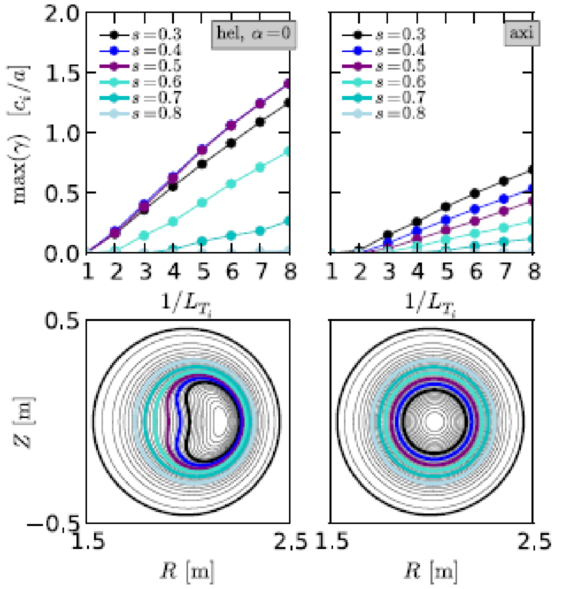


Fig. 3.1.13: ITG growth rates (from GENE) in helical (left) and axisymmetric (right) configuration as a function of the ion temperature gradient

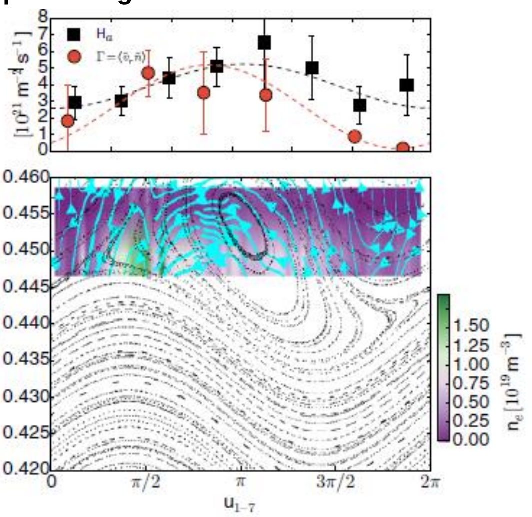


Fig. 3.1.14: Top: particle influx from Hα emission vs helical angle (black square) and particle flux (at *r* = 0.446) from electrostatic fluctuations (red circle). Bottom: density map in colour code superimposed to the E×B streamline of electric drift flow and Poincare map.

22 Predebon I., Xanthopoulos P.,Phys. of Plasmas 22,052308 (2015)

23 Vianello N. et al., Plasma Phys. Control. Fusion 57 (2015) 014027

24 Spolaore M. et al., Phys. Plasmas 22, 012310 (2015); http://dx.doi.org/10.1063/1.4906869

25 Spizzo G. et al., 2015 Nucl. Fusion 55 043007

found to be modulated as well, still exhibiting the same symmetry (Fig. 3.1.14). The variation of transport is ascribed to a modification of small scale turbulence which is not homogeneous in presence of magnetic perturbation.

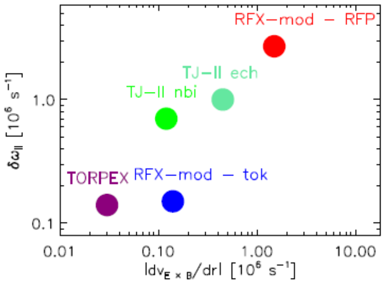


Fig. 3.1.15: Vorticity associated to structure vs local average ExB flow shear.

An inter-machine study of turbulent structures has been carried out, indicating that the intensity of the vorticity associated to the filament exhibits a clear dependence on the local ExB shearing rate (Fig. 3.1.15).

To better characterize the 3D response of plasma edge to the magnetic topology, toroidally and poloidally distributed diagnostics are needed. In RFX-mod, an internal magnetic sensor system (ISIS[26]) system and e Thermal Helium Beam (THB) diagnostic at two poloidal locations[27] are available. While in the toroidal direction both floating potential from ISIS and He I emission from THB show a good correlation with the edge magnetic deformation, along the poloidal direction the correlation is less clear: an example is shown in Fig. 3.1.16.

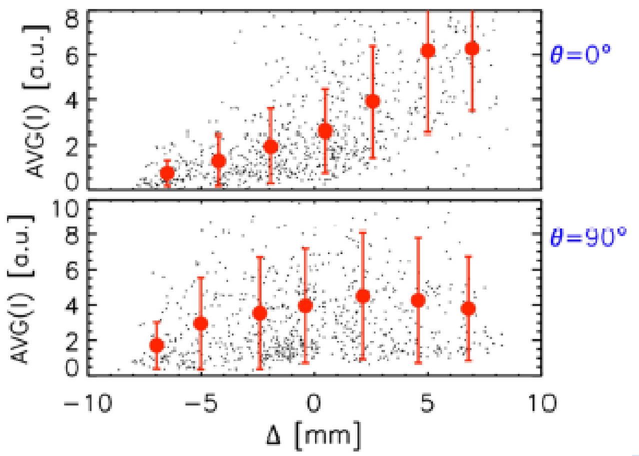


Fig. 3.1.16: He I brightness from THB measured on equatorial plane (top) and at 90^0 on top vs the local radial magnetic shift. Red points correspond to conditioned averages

The effect of increasing the density was studied, showing that, as the magnetic topology moves from (1,-7) to (0,1)[28], the edge plasma parameters reproduce such behavior (Fig. 3.1.17).

3.1.6. Design and operation of a shape control system for Tokamak operation

Active feedback stabilization of m=2, n=1 mode was obtained in RFX-mod operating as a low q Tokamak (1.3≤q≤2). In addition to the circular shape, a divertor-like

---

[26] Serianni G. et al., Rev. of Sci. Instrum. ***74*** *1558 (2003*

[27] Agostini M. et al., accepted for publication in Rev. of Sci. Instrum.

[28] Puiatti M.E. et al., Plasma Phys. Control. Fusion **55** (2013) 124013

configuration with a Single Null has been achieved.

This required the design and implementation of a plasma shape feedback control system. A fully model-based approach was adopted, which included the design of Double and Single Null equilibrium configurations by means of a MHD non linear equilibrium solver, and the derivation/validation of the corresponding linearized plasma response models.

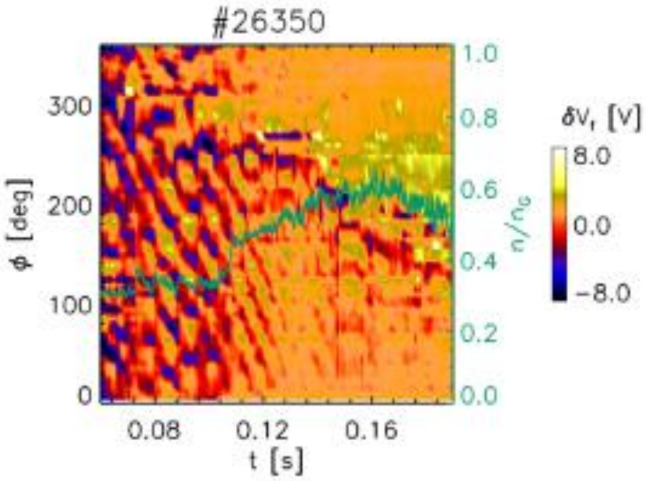


Fig. 3.1.17: floating potential toroidal pattern evolution vs Greenwald fraction (green line)

For each case the steps were the design of an inner, faster feedback control loop for plasma vertical stabilization, the order reduction of the stabilized model, the preparation and testing of a reliable real time algorithm for plasma boundary reconstruction, the design, implementation and operation of the shape control system.

A Linear Quadatric regulator and a Kalman state estimator were designed and implemented in the real time MARTe framework together with an algorithm for the real-time plasma boundary reconstruction. A solution similar to the effective Clean Mode Control strategy used in the active control of MHD modes was adopted to remove the aliasing error caused by the high order harmonics introduced by the 16 coils making up the Field Shaping Winding (FSW). The design had also to take into account the highly connected poloidal field electrical system, the presence of the conducting shell, the current and voltage limits of the available power supply. The typical operating scenario consists of an initial nearly circular discharge, a transition phase from limiter to diverted configuration by feedback control of the FSW currents and finally the insertion of the shape control system which works out the voltage reference variations for the FSW power supplies.

The LQG control system can be operated in regulation and tracking mode. The latter being used when the experiments require the modification of the plasma shape during the discharge to make easier the achievement of different regimes. In Fig. 3.1.18 an example of both is given.

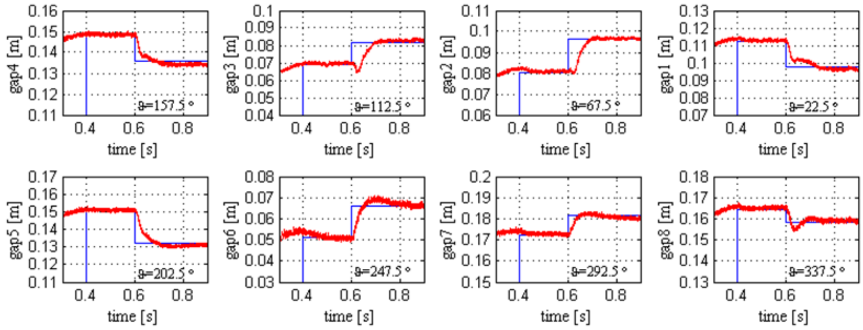


Fig. 3.1.18: Shot 37829 (Single Null): Gap ehvolution (red) in an example of regulation and reference (blue) tracking operation of te shape control system. The corresponding poloidal angle increases counterclockwise from the outside

The closed loop shape control is started at t=0.4 s and the sampled gap value is kept constant until a reference input step variation corresponding to a 2nd cosine harmonic of the plasma radius is applied at t=0.6 s. After a transient phase where neglibile overshoots are observed in a few gaps, the desired gap amplitudes are substantially reached in about 100 ms and maintained till the end of the pulse. The boundary reconstruction is shown in Fig. 3.1.19. A pictorial camera view of the plasma in a Double Null discharge is provided in Fig. 3.1.20.

3.1.7. Experiments with shaped plasma aiming at ohmic H-mode achievement

All conditions favouring ohmic H-mode in other tokamaks were sought: main gas was D, direction of toroidal field and location of X-point was chosen in order to operate with ∇BxB in the “favourable” direction.

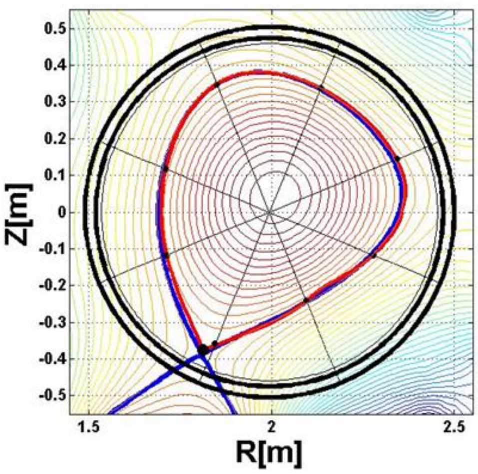


Fig. 3.1.19: (pulse 37829) plasma boundary reconstruction at t=0.8 s by MAXFEA (blue line) and real time algorithm (red)

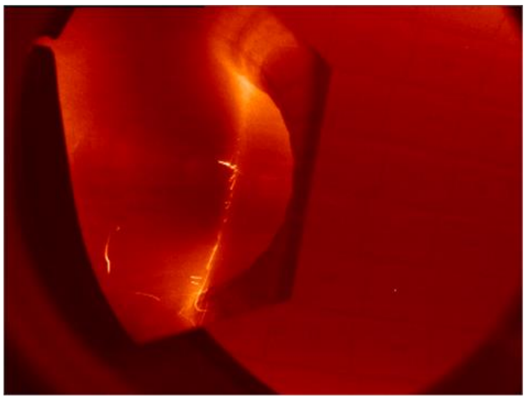


Fig. 3.1.20: (Pulse 36380) camera view with the upper two tracks (brighter areas) of the interaction between scrape-off layer and first wall in a Double Null discharge.

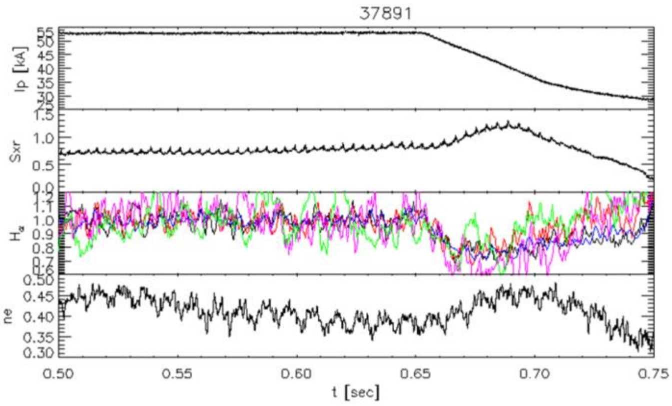


Fig. 3.1.21: Example of transient transport reduction, compatible with an H-mode transition, during plasma current ramp-down.

Wall conditioning was performed by means of Li pellets and with boronization. Li pellets proved to be significantly perturbative, while boronization did improve the possibility of low density operations, even though radiated power was comparable to pre-boronized discharges. As boronization is performed with B_2H_6 diborane, a significant fraction of hydrogen (30%) was still present in the discharges after boronization. A significant reduction (down to 95%) was obtained by performing Glow Discharge Cleaning (GDC) in D_2 followed by He.GDC. The graphite wall loading effect did not allow to perform a controlled density scan, necessary in order to investigate the accessibility to ohmic H-mode. This was due to the lack of a density feedback control during that campaign (a density feedback loop was then implemented an used for the last part of the tokamak campaign with an insertable electrode). Transient signatures of H-mode behavior were observed during ramp-down of plasma current: increase of SXR emissivity and density and decrease of H_α along all available lines of sight (Fig. 3.1.21).

3.1.8. Tokamak experiments with polarized electrode

In order to acive more reproducibile transitions to H-mode on RFX-mod, an insertable electrode was designed and implemented. The aim of the experiments was to study H-mode transitions and obtain ELMs in the RFX-mod tokamak operating conditions. The electrode has been realized in house by using some parts of the electrode previously designed and operated for the RFP[29]. The electrode head, which was designed to withstand currents up to 1kA and voltages up to 1kV, is realized in graphite (Fig. 3.1.22). The electrode was installed on a multi-purpose insertable manipulator.

Fig. 3.1.22: The insertable electrode

[29] D.Desideri, et al, Fus. Eng. Des. V 45 (1999), 455

A power supply unit, used for the magnetizing winding in the RFP and not used in tokamak operations was adopted to feed the electrode. A voltage divider and protection circuit was designed using existing loads and a real time control and protection was implemented. A thermal camera was used to measure the graphite surface temperature both during and after the discharge and an interlock was implemented in order to prevent plasma operation until temperature decreases below a given threshold.

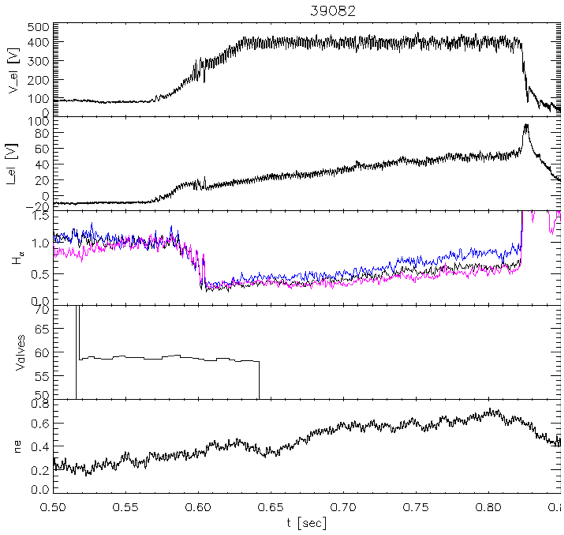


Fig. 3.1.23: Transition to H-mode with polarized electrode. a) electrode voltage, b) electrode current, c) H_a signals, d) gas feed signal, e) electron density.

Systematic H-mode transitions are obtained with negative polarization in all conditions explored by RFX-mod, i.e circular low q and very low q and in X-point discharges. Conditions are that density is sufficiently high and applied voltage is above a threshold, though lack of experimental time did not allow to perform an accurate characterization.

An example is shown in Fig. 3.1.23. When the transition takes place the Hα signals drop abruptly after a dithering phase, and density continue to increase even though the gas valves are closed.

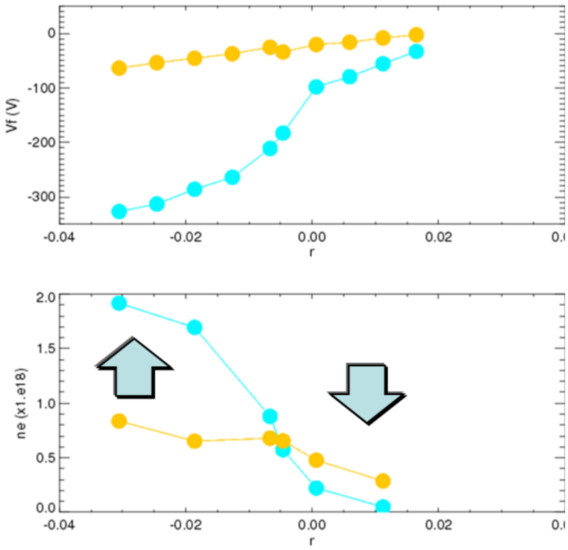


Fig. 3.1.24: PlasmaA floating potential and electron density profiles, before (yellow) and during (cyan) the H-mode transition in an X-point discharge.

Thanks to the U-probe, a detailed reconstruction of the edge density and radial field profile has been performed as shown in Fig. 3.1.24. During the transition a significant increase of the floating potential and a steepening of the density profile are observed.

3.1.9. Activities related to physical aspects of RFX-mod upgrades

Though the main physical objectives of RFX-mod upgrades were defined in 2014, both regarding the magnetic front-end and the definition of the new first wall.

Additional simulations by the RFXLOCKING code have been performed to address the

	Present	Minimum	Desirable	Optimal
Bt	4x48	5x72	6x72	6x72
Br	4x48	5x72	6x72	6x72
Bp	4x48			6x72
Br gap	48			
Bt	8x4			28x6
Bp	8x4	14x6	28x6	28x6
Vloop Tor	6	24	24	24
partial Vloop Halo sensors	32	32	32	32
Ftor	10	12	12	12
ISIS: bt dot br	 2x48 8x1			
Total	**840**	**872**	**1100**	**1700**

Table 3.1.1: summary of the magnetic sensors for the upgraded RFX-mod

problem of m=0 mode control[30]. The insertion of an array of 48 poloidal coils would improve the slinky mode toroidal mobility. However, it has been found that the removal of vacuum vessel leads by itself to an increased slinky mobility, from about 200deg/100ms to about 600deg/100ms. The addition of the poloidal coils would push this value up to 1200 deg/100ms. Moreover, the m=0 mode control will also benefit from the increased time response of the toroidal winding.

A study of the optimum number of magnetic sensors for the upgraded device has been carried out, and the result is summarized in Table 3.1.1.

In order to identify a new first wall, allowing a good power load withstanding capability with a lower hydrogen retention, new tiles have been exposed to high current RFP plasmas. They were made by different graphite (in particular an extruded graphite with higher thermal conductivity has been considered), with a smoother shape compared to the present ones. Some were also coated with W layers of different thickness.The tiles have been extracted (after about 100 discharges) just in the last days, and the analysis

[30] Zanca P., internal note FC/89 (2015)

is still to be done, however a picture is shown in Fig. 3.1.25. First indications are that tiles with smoothed shaping, thin W coating (3-5 mm) and extruded graphite show the lowest damage (high-left in the figure). The full analysis, complemented by that of small samples exposed by an insertable manipulator and by mechanical stress test, will allow the decision for the new first wall.

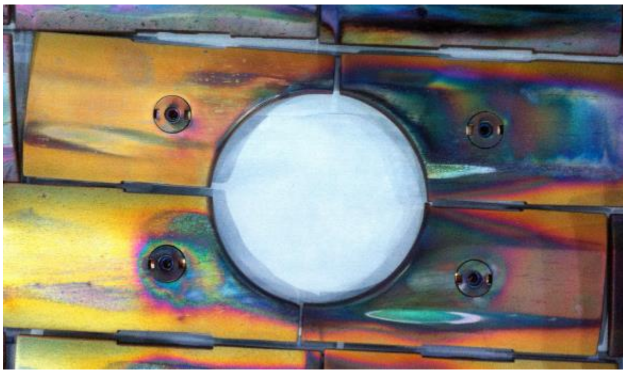


Fig. 3.1.25: 4 tiles with different graphites and W depositions after the exposure to about 100 high current discharges

In addition to a lower first wall retention, the density control will also benefit of an improved GDC efficiency and uniformity. During 2015 tests have been made showing that the efficiency of the GDC is not decreased when the electrodes are placed at the tile convolution instead of the vacuum vessel centre. This will allow the exploitation of additional ports in the shell which, without the vacuum vessel, will be available for GDC electrodes.

3.2. *ITER PHYSICS*

In the following a brief survey of the activities carried out by Consorzio RFX within the ITER Physics branch of the Eurofusion research plan is given. Most of the contributions have actually concentrated on WPMST1 and WPJET1. In these work packages in particular Consorzio RFX has had a role of responsibility with the MST1 Project Leader and the scientific coordination of several experiments and tasks. Nonetheless Consorzio RFX has contributed to many other work-packages, with a particular attention to those where a more significant involvement can be envisaged in a near future, such as WPS1/2 and WPSA, because new experiment have started or are about to be start. There have also been few activities outside the formal Eurofusion coordination, yet always about themes of direct interest for the Roadmap, such as the collaborations with DIII-D and LHD. To be noticed that in 2015 some activities have been redirected or extended towards edge and divertor studies, with , for instance, impurity penetration through SOL and pedestal on JET and study of the “Snowflakes” configuration on TCV, in order to better support the DTT project, on to which the entire Italian association is converging. The latter move adds to a well established competence on edge transport studies in all of the main magnetically confined schemes.

3.2.1. JET1

3.2.1.1. Characterization of pedestal turbulence at JET

This activity has regarded the analysis of the data obtained by the correlation reflectometer installed on JET and providing information on the high frequency density fluctuations in the pedestal region of the JET plasma.

In this work we presented the first characterization of ELM-related edge fluctuations observed during the LH transition experimental campaign on JET. These fluctuations have been detected in both the fast density measurements and the magnetic measurements: their typical frequency range (40-100 kHz) and their radial position (pedestal top) have been assessed. Moreover, we investigated the relation of the fluctuations amplitude with the pedestal temperature and density. A preliminary attempt to reconstruct their toroidal and poloidal structure has been also given. Their physical interpretation has been preliminary discussed and a simulation activity will shortly start.

This work has been also presented in different internal Task Force meeting at JET and at last APS conference[31].

3.2.1.2. W behaviour in JET plasmas

Analysis of data collected in 2014 has continued in order to document the way different heating schemes impact on W behaviour in the core of JET in both hybrid and standard H-mode plasmas. It has been found both in experiments and modelling that both in scenarios ICRH with narrow central deposition plays a major role in counteracting W

accumulation, with a key role played by fast ion screening and anisotropy, and appears a promising tool to extend the duration of the high performance phase in next JET campaigns[32],[33] .

In addition, new experiments have been proposed and started to understand how W behaves at the edge of the plasma and in particular what is the role of ELM’s in the W overall concentration in the plasma core. In particular, ITER-like conditions are sought

31 G. De Masi, et al. , “Characterization of the edge fluctuations on JET during the LH transition studies”, 56th APS Conference DPP, Savannah, GA (2015)

32 P Mantica, et al , EPS Conf. 2015

33 F Casson et al PPCF, 57, 014031 2015

where W is screened at the pedestal level and remains concentrated at the edge forming locally a hollow profile. In such conditions, the diffusive nature associated to ELM's, if any, is expected to inject W inside the plasma, opposite to the typical ELM behaviour associated to impurity flushing. Activities therefore are converging towards an integrated description of the W transport from the edge to the core.

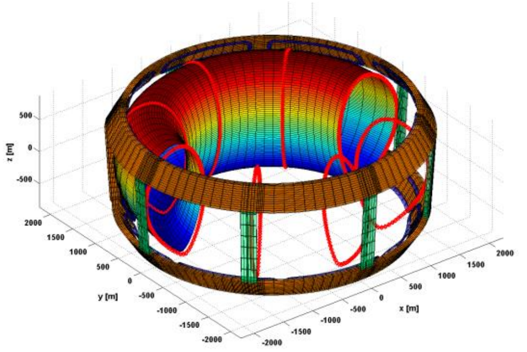


Fig. 3.2.2 Mapping code results on experimental AUG flux surfaces.

3.2.2. MST1

3.2.2.1. Development and validation of 3D modeling strategies for dynamic MHD active stabilization studies

This activity is part of a multi-annual project started in 2014 that already lead to the implementation of relevant AUG passive and active components in two 3D numerical codes, CAFE and CARIDDI, used also for ITER studies. In 2015 the 3D numerical model of AUG relevant structures was further refined and first estimates of time varying external fields produced by active coils were performed. In this way a quantitative study of shielding effects expected by PSL, wall and other passive structures close to AUG plasma is possible. A mapping of the field produced by the active coils on an experimental flux surface is shown as example in Fig. 3.2.2.

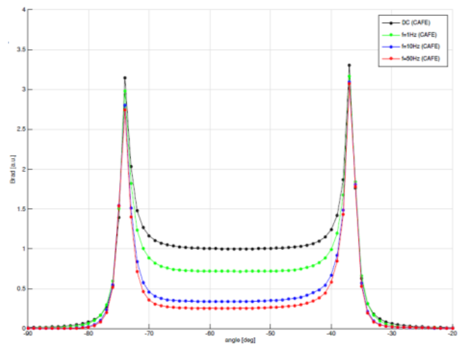


Fig. 3.2.1: 3D model (Bcoils + PSL) normal field produced along a toroidal path by a given Bu coil. Results by CAFE code.

Synthetic magnetic diagnostics can be also implemented in the numerical tool to study in detail how 3D features of external fields depend e.g. on frequency. In Fig. 3.2.1 the toroidal structure of the field produced by one single upper coil is shown for the DC case (black) and for 3 different frequencies: 1 Hz (green), 10 Hz (blue) and 50 Hz (red); virtual measurements refer to a toroidal pattern radially located at the coil position and at a poloidal angle corresponding to the coil axes.

3.2.2.2. RAPTOR simulations of improved H-mode scenarios in ASDEX Upgrade

The investigation of MHD stability limits and 3D effects in high beta plasmas, which is the mission of the AUG15-1.4-1 proposal, has been carried out in ASDEX Upgrade on improved H-mode plasmas.

This scenario, which is characterized by a flat and slightly elevated q-profile, has been simulated with the RAPTOR code[34], a control-oriented 1D transport code that is currently embedded in the real-time control system of ASDEX Upgrade.

Offline RAPTOR simulations have been validated with the experimental data and benchmarked with TRANSP[35], a more sophisticated time dependent core transport solver. This activity allowed to test and highlight the potentialities of the most up-to-date version of the RAPTOR code, which succeeds in reproducing both the experimental data and the TRANSP results.

A representative result of this work is reported in Fig. 3.2.3. This plot compares the time evolution of the core safety factor predicted by RAPTOR and TRANSP, which are plotted in red and green, respectively. In this ASDEX Upgrade experiment the safety factor profile has been elevated by injecting on axis counter electron cyclotron current drive. Besides the RAPTOR models for the plasma dynamics and the energy sources are simpler than the ones in TRANSP, the agreement between the predictions of these code is fairly good.

3.2.2.3. Investigation of beta limits and 3D effects in ASDEX Upgrade and DIII-D

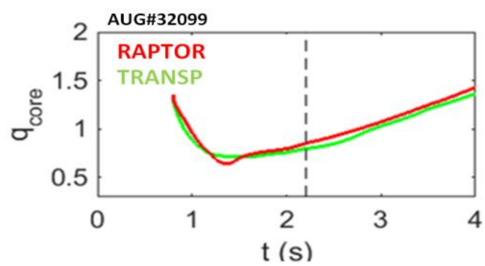


Fig. 3.2.3: RAPTOR (red) and TRANSP (green) reconstruction of the time evolution of the core safety factor in an ASDEX Upgrade improved H-mode discharge

ASDEX Upgrade experiments were performed during the MST1 campaigns 2014 and 2015 to characterize the MHD stability limits of high-beta plasmas, by probing them with slowly rotating external 3D magnetic fields applied with non-axisymmetric coils. These experiments had ample participation from Consorzio RFX scientists, who contributed both on experiment design and coordination, data analysis and modelling. The experiment evidenced for the first time

[34] F. Felici, et al. , Plasma Phys. Control. Fusion 54, (2012).

[35] Hawryluk, Physics of Plasmas Close to Thermonuclear Conditions 1 (Brussels: CEC), (1980)

in ASDEX Upgrade the effects of error field amplification on high-beta operation, with clear impact on rotation profiles, NTM formation, and performance deterioration. These effects were investigated for the first time in hybrid plasmas, revealing a significant contribution of the internal kink to the 3D plasma response, which is normally localized at the edge in other types of high-beta plasmas, e.g. in Advanced Tokamak discharges. This is due to the q profile being flat and just above 1 in the core of hybrids, as confirmed by MHD modelling with state-of-the-art codes like MARS-F/K, VMEC and M3D-C1[36] .

These results stimulated similar experiments at DIII-D, proposed by Consorzio RFX scientists, who are currently underway and will continue in 2016. DIII-D experiments also aim at investigating the role of MHD modes, and in particular of the internal kink, in sustaining the hybrid configuration through an MHD dynamo effect and take advantage of unique diagnostic capabilities of this machine like high-resolution CXRS and MSE. Nonlinear MHD modelling with SpeCyl and PIXIE3D predict that the dynamo effect present in hybrids is very similar to the electrostatic dynamo discovered in RFP helical states. This represents a good example of cross-fertilization between different configurations.

3.2.2.4. 3D equilibrium reconstruction with V3FIT / VMEC

The V3FITcode[37] is being implemented on AUG in order to reconstruct from experimental measurements 3D equilibria using the VMEC code[38] as direct equilibrium solver. To this end a detailed modelling of AUG windings has been implemented including all axi-symmetric and non axi-symmetric coils.

Some magnetic diagnostics have been implemented in V3FIT and kinetic diagnostics are presently being added to the modelling including the interferometer and SXR measurements.

An axi-symmetric test case has been considered to benchmark the free-boundary equilibrium against the corresponding fixed-boundary equilibrium. As shown in Fig. 3.2.4 the two match very well.

Interface routines have been written to read Cliste equilibria in order to provide an axi-

---

36 P. Piovesan et al EPS 2015

37J.D. Hanson, S.P. Hirshman, S.F. Knowlton, L.L. Lao, E.A. Lazarus and J.M. Shields, Nucl. Fusion 49 075031 (2009)

38S.P. Hirshman and J.C. Whitson, Phys. Fluids 26 3554 (1983) symmetric input file for VMEC which will be taken as the starting point for the full 3D inverse equilibrium reconstruction problem to be solved by V3FIT with diagnostics information. Ongoing work is now devoted to implement additional magnetic diagnostics as well as main kinetic diagnostics to provide information on internal profiles.

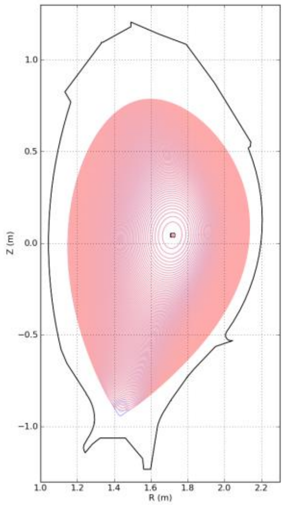


Fig. 3.2.4: Equilibrium reconstruction benchmark: comparison between fixed and free-boundary.

3.2.2.5. Disruption avoidance using RAPTOR both on ASDEX-Upgrade and TCV

The Raptror code has been used to study disruption avoidance both on ASDEX-Upgrade and TCV. The principle of the disruption avoidance explored is based on sawtooth period monitoring. The RAPTOR code is capable of real time prediction of the sawtooth period [39] and the behavior of the sawtooth crashes is significantly modified due to perturbation causing density limit, impurity accumulation LM or RWM disruption. The disruptive change is not reflected in RAPTOR prediction. Therefore a difference between the sawtooth period in RAPTOR and in experiment is observed before the disruption. If the difference is too high, the disruption alarm is activated.

Possibility of disruption prediction using the principle described above was tested in density limit cases on TCV with promising results. On AUG, the situation is more complicated: the ICRH heating not contained in RAPTOR model and the fast particle population stabilizing the sawtooth are significant factors that disable precise modeling of sawtooth crashes. However, the results for pulses without ICRH heating show good agreement between the sawtooth period in RAPTOR and in experiment.

3.2.2.6. AUG15-1.3-6, TCV15-1.3-6. Decorrelation of runaway electrons by magnetic perturbations and role of 3D plasma response.

The main aims of these proposals were: test methods to de-correlate runaway electrons (RE) either during the RE avalanche or afterwards, when the RE beam is fully formed, by applying magnetic perturbations as done in DII-D and TEXTOR; assess the role in enhancing RE decorrelation of spontaneous MHD instabilities (e.g. kink,tearing);

39 [C. Piron et al, EPS 2015]

study the possible impact on RE decorrelation of 3D helical deformations forming in response to applied RMPs; study the 3D equilibrium that forms after application of RMPs using various numerical codes (ORBIT,VMEC,PIXIE-3D, MARS etc).

During the year 2015 the first experiments on these issues have been performed both in Asdex-Upgrade (AUG) and TCV and will be completed the next year.

A series of 5 pulses has been executed in AUG with the application of n=1 RMPs by using the B-coils in post-disruption phases of discharges with B_T=2.5T. A clear effect of perturbations on the final RE beam has not yet been detected; nevertheless, in shots where the RMP was applied before the disruption, with 0° phasing between lower/upper B-coils, a lower RE beam current and duration has been observed together with a decrease of the HXR level but a greater statistics is required to draw more reliable conclusions. The experiments have been supported by a significant amount of modeling activity. To this end the impact of RMPs by the B-coils has been investigated by the code PIXIE-3D and ORBIT; simulations have shown that the destabilization of the RE beam equilibrium is prevented because of the high safety profile at the edge (around 10-15). These numerical studies confirm that a stronger impact could be possible in discharges with lower toroidal field or greater plasma current (q(a) lower than 5-6). Some attempts in this sense have been done during the experimental campaign but RE beams have not been produced in these discharges.

3.2.2.7. Implementation of software for the new ICRF reflectometer on ASDEX

Within the MST2 work package “Implementation of multichannel edge density profile reflectometer for ICRF antenna on ASDEX Upgrade”, an on-site activity at ASDEX concerned the implementation of the elaboration software for data analysis purposes. The code has been written in IDL partly importing a piece of code operational on the JET density profile reflectometer. Due to the delay in the reflectometer hardware delivery, the program has been tested against JET signals and proved itself to be able to produce reliable density profiles starting by raw signals. The tests against real ASDEX signals (the reflectometer has been finally delivered in November 2015) will be conducted between the end of 2015 and the beginning of 2016

3.2.2.8. Disruption prediction and classification in ASDEX-Upgrade and JET

Machine learning techniques have been applied in order to develop a real time disruption prediction system. The predictor is based on the complementary information provided by signals holding information about the physical mechanism leading to disruptions studied during the on-site work.

A multivariate analysis of disruption precursor has been developed by combining the prediction capability of a set of precursors in common between the two machines. For what concern the data used for JET, 116 flat-top disruptions occurred between 2011-2012 have been considered, while 102 flat-top disruptions occurred between 2011-2014 have been selected for AUG. The data set has been divided in training and test set. The signal used for the analysis are: q95, locked mode, total radiated power, total radiated power/total input power, loop voltage, line-averaged plasma density/Greenwald limit, internal inductance, time derivative of the total energy, vertical position of plasma centroid. For each signal a set of thresholds, which allows to achieve pre-defined PD rates, is identified A score (SC) is assigned to each threshold depending on the corresponding PD rate. The Locked Mode signal demonstrated to be the most promising in terms of disruption prediction, with the fraction of disruptions correctly predicted reaching 0.5 in AUG and 0.61 in JET.

3.3. *WPS1*

3.3.1. Assembly of SXR cameras, tests and calibration procedure specification

During 2015 a calibration of soft x-ray (SXR) cameras of the W7-X tomography has been performed at RFX-mod. Two SXR probes have been sent to RFX at the beginning of the year and essembled with electronics. The calibration has been performed with modulated light from a LED at variable frequency . The diode array (22 photodiodes in total, but only 18 will be used) has been scanned, first with a 2 kHz light to find the DC calibration, then at higher frequency to find the -3 dB cut-off (bandwidth) and phase delay of the amplifier. This procedure has been repeated for both probes. In addition, the two cameras have been calibrated using the same diode array to compare the boards. Moreover, the two diode arrays have been also compared using a single SXR probe. From all these tests it is clear that the amplifiers have similar response and bandwidth. The diodes in each array are uniform but there can be differences between arrays up to 10-20% in the response at high frequency (> 160 kHz).

3.3.2. Development of the Laser Blow Off system for W7-X

The design of the preliminary LBO system for OP1.2 using the Multi-Purpose Manipulator has been defined. In particular, the optical system of the W7-X LBO system has been modeled with OSLO ray tracer package, identifying the best optical solution as sketched in Fig. 3.3.1.

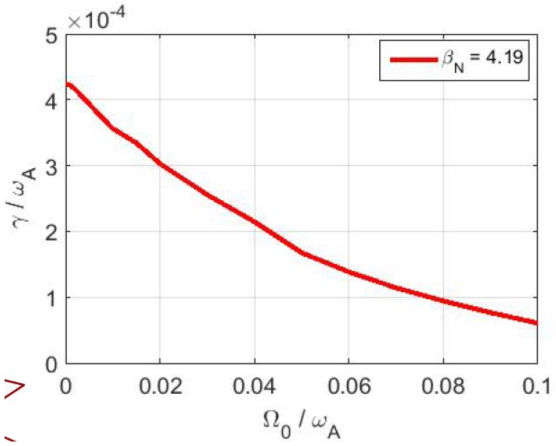


Fig. 3.5.1: Normalized RWM growth rate versus plasma rotation for a high β_N, scenario 5-like, JT-60SA plasma.

impurity injection system of W7X

3.4. *WPS2*

3.4.1. Turbulent optimization S2.2.4

The activity has concerned ion-temperature-gradient (ITG) turbulence optimization based on W7-X plasma scenarios. The optimization procedure has been carried out by minimizing the ITG mode growth rate, acting on modifications of the plasma boundary which can suitably reflect in changes of the metric coefficients in the plasma core. To this aim, we relied on the codes GENE and VMEC.

3.5. *WPSA*

3.5.1. MHD studies

Consorzio RFX contributes to studies in support of JT-60SA preparation with the role of coordination of European efforts in the field of MHD stability and control and with a direct involvement on the modeling of high β plasmas passive and active MHD stability.

The collaboration with Y.Q. Liu (CCFE) on the use of the MARS-F/K codes was further developed in 2015 with visits to Culham of a Consorzio RFX researcher. The influence of plasma fluid rotation on RWM stability was studied with MARS-F. Starting from a reference scenario, 5 profiles were developed [40], the dependence of the most unstable RWM growth rate with plasma rotation was studied, as shown in Fig. 3.5.1. Then kinetic effects were included by using MARS-K and the study will continue in 2016.

The 3D modeling of passive and active conductors was further refined in collaboration

40 S. Ide, et al. , Proc. IAEA-FEC, FTP/P7-22 (2012)

with Consorzio CREATE, leading to 2 publications[41],[42]. The two subjects are now ready to converge on the modeling of feedback stabilization of RWM instabilities with realistic 3D boundaries, which will be the main target of 2016.

3.5.2. JT-60SA polarimeter design and determination of q profile

The work started in 2014 has been carried on modelling polarimetric measurements with the V3FIT code[43] using equilibria obtained with the VMEC code[44]. New equilibria for scenario 2 and scenario 5 have been considered as computed with the Cronos code and were used to assess effectiveness in the positioning of the chords as determined from actual engineering constraints (Fig. 3.5.2). The aim in this work is to assess the limit in the determination of q on axis using polarimetric information. As in the previous study a limited set of diagnostics was used for the modeling: the polarimeter under design, some local magnetic filed probes, some full flux loops and one rogowski coil. We are still lacking information on possible parametrization for internal profiles so spline modelling is used to obtain a more general result. As in previous analysis vertical chords are fundamental and in particular a chord going through plasma centre is necessary though it still might not be sufficient to completely infer q on axis as all simulations tend towards a reversed shear scenario, but miss the actual q(0) value. Additional diagnostics might be necessary to properly simulate the actual procedure that is adopted in a running experiment.

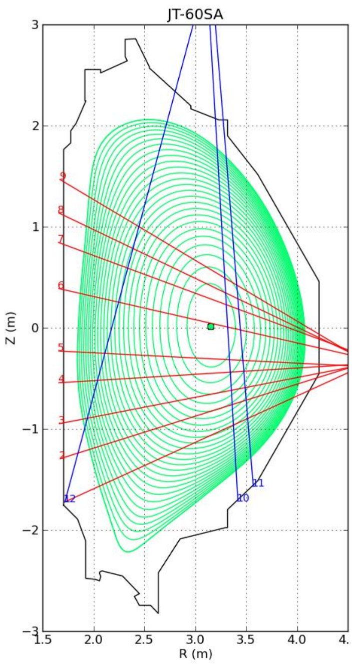


Fig. 3.5.2: Modelled equilibrium for scenario 5 with tentative polarimetric chords layout.

3.6. *IEA implementing Agreement on Stellarator-Heliotron Concept*

3.6.1. Analysis of LHD NBI-plasma interaction with upgraded FIT3D module of

41 P. Bettini, et al. , IEEE Transactions on Magnetics, 51, 7204105 (2015)

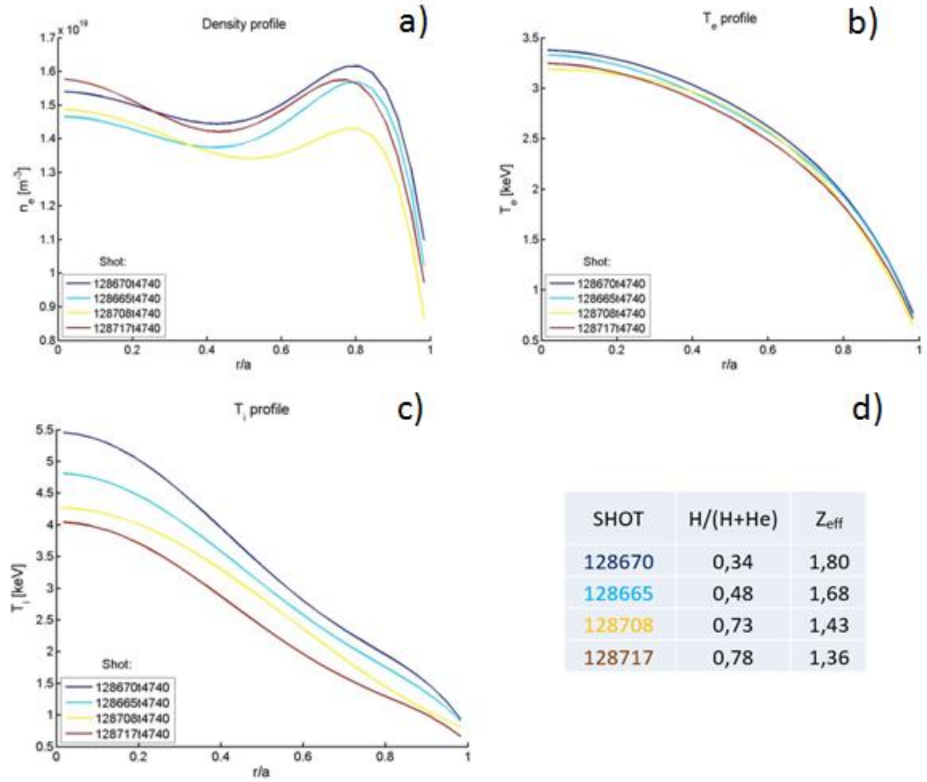
42 S. Mastrostefano, et al. , Fusion Eng. and Design 96–97 659 (2015)

43 J.D. Hanson, S.P. Hirshman, S.F. Knowlton, L.L. Lao, E.A. Lazarus and J.M. Shields, Nucl. Fusion 49 075031 (2009)

44 S.P. Hirshman and J.C. Whitson, Phys. Fluids 26 3554 (1983)

TASK3D-a analysis transport suite

LHD experiment is equipped with 5 NBI systems currently working with H and injecting a maximum power of 28MW: 2 perpendicular positive injectors (pb4 and pb5 lines with



SHOT	H/(H+He)	Z_{eff}
128670	0,34	1,80
128665	0,48	1,68
128708	0,73	1,43
128717	0,78	1,36

Fig. 3.6.1: n_e (a), T_e (b), T_i (c), $n_H/(n_H+n_{He})$ and calculated Z_{eff} (d) of the 4 shots analysed

40-50 keV) and 3 tangential negative injectors (ctr1, co2 and ctr3 lines with 180-190 keV). TASK3D-a analysis suite[45] is a tool for interpretative transport analysis of LHD experiments, built for the analysis of hydrogen and multi-ion species plasma[46,47]. FIT3D is the module of TASK3D-a code which performs the analysis of LHD NBI-plasma interaction, calculating radial profiles of NBI absorbed power, beam pressure, beam source and induced momentum.

A collaboration on NBI-plasma interaction started in 2014 between Consorzio RFX and NIFS. Within this framework, a project for the application of the FIT3D code to isotope

45 M. Yokoyama et al., Plasma Fusion Res. 8 (2013) 2403016

46 A. Sakai et al., Plasma Fusion Res. 9, (2014) 3403124

47 H. Yamaguchi and S. Murakami, Plasma Fusion Res. 9 (2014) 3403127

effect studies was carried out by Consorzio RFX. FIT3D was upgraded[48] to analyze D plasmas, which will be performed in future LHD campaign. The upgraded FIT3D is capable to analyse H, D and T plasmas with multi-impurity species, including He. The work was presented at the EPS conference 2015.

During a mission to NIFS of 4 weeks in 2015, stand-alone NBI-plasma interaction investigations were performed in steady-state approximation, analysing 4 similar pulses with different H/He concentration. In these experiments, an increased ion temperature was observed with an increased He concentration in the plasma. Aim of the study was to analyze the role of NBI heating to the observed better confinement properties with He majority in the plasma. Density and temperature profiles of the 4 pulses are shown in Fig. 3.6.1 for time 4.740s, together with the measured ratio $n_H/(n_H+n_{He})$ [49] (assumed radially constant). The result, presented at the International Toki Conference 2015[50], is that the ion birth profile is not affected by H/He concentration, and also fast ion confinement and the consequent power deposition profile seems to be unaffected both

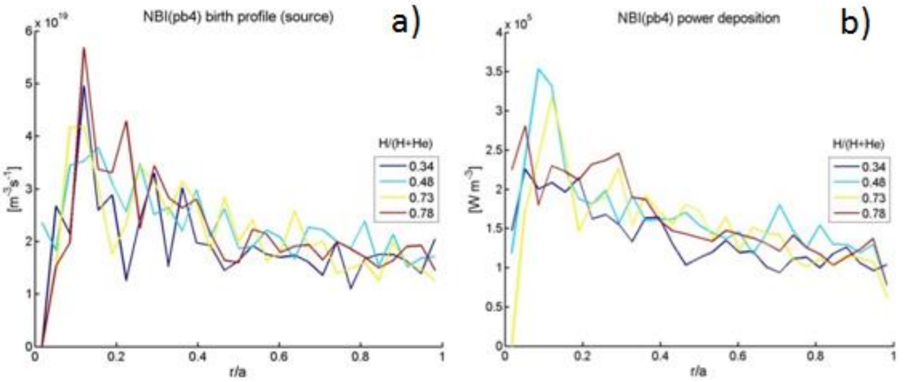


Fig. 3.6.2: Ion birth profile (a) and power deposition profile (b) of NBI pb4 for the input shots at t=4.74s

for tangential and perpendicular injection as shown in Fig. 3.6.2.

This means that NBI heating is not playing a relevant role in the observed increased ion temperature, and the improved ion confinement may be due to the dependence of transport properties on plasma mass difference[51]. These studies are critical in order to predict the performances of LHD experiments in the next first D campaign (2017) and

48 P. Vincenzi et al., 42nd EPS Conf. on Plasma Physics (Lisbon, Portugal, 2015), P1.150

49 M. Goto et al., Phys. of Plasmas, 10, (2003) 1402

50 P. Vincenzi et al., 25th International Toki Conference, 3-6 Nov. 2015, Toki-city, Japan, P1.86

51 S. Maeta et al., 25th International Toki Conference, 3-6 Nov. 2015, Toki-city, Japan, P1.116

investigate the isotope effect in heliotron devices.

3.7. *Power Plant Physics & Technology Projects*

3.7.1. WPPMI: Plant Level System Engineering, Design Integration and Physics Integration

3.7.1.1. PMI-4.1.2-T01. Definition of Plant Electrical System Concept

The work of this year was based on the official new DEMO1 Reference Design, issued in April 2015. This Reference Design consists in the set of input and output data of a specific run of the PROCESS code. In June 2015, Consorzio RFX produced a first report[52] giving an update of the information collected for the design of the Plant Electrical System, basing on this Reference Design, with the aim of establishing an agreed set of requirements and highlighting the missing or questionable information. The ratings of the main poloidal and toroidal magnet power supplies have been tentatively outlined. In August 2015, Consorzio RFX delivered a second report [53], which includes an update of the DEMO Electrical System Plant Breakdown Structure (PBS). With respect to 2014, this PBS has been extended, embracing, in addition to the "Magnet System Power Supply & Distribution", also H&CD power supply systems and Steady State Electric Power Supply Networks. In a third report [54], distributed in November 2015, a first estimation of input active power profiles has been given. For the poloidal magnet system, the power consumptions have been tentatively calculated basing on the available Process data in few pulse times. Being unknown the voltage and current waveforms versus time, the power profiles have been obtained by joining these power values with straight lines in Fig. 3.7.1- The input powers required for H&CD and Steady State Electric Power Supply Networks have been considered too, on the basis of the DEMO1 Reference Design and making some assumptions on H&CD system efficiencies. This analysis evidenced a very high power demand during poloidal magnet pre-charge (1.4 GW in total) and high power peaks delivered to the grid at plasma ramp-up and final magnet discharge (up to 1 GW).

---

52 A. Ferro and E. Gaio, Update of input data and missing information for DEMO Plant Electrical System design, Memo RS01 for task PMI-4.1.2-T01, June 15th, 2015, EU IDM link: 2MNYN9

53 A. Ferro, C. Finotti, L. Zanotto and E. Gaio, Update of Electrical Power Supply Systems Plant Breakdown Structure (PBS) and first estimation of profiles of DEMO input power, Memo RS02 for task PMI-4.1.2-T01, August 1st, 2015, EU IDM link: 2MLSZM

54 A. Ferro, C. Finotti and E. Gaio First estimation of DEMO input power profiles, Memo RS03 for task PMI-4.1.2-T01, November 30th, 2015, EU IDM link: 2MRBJU

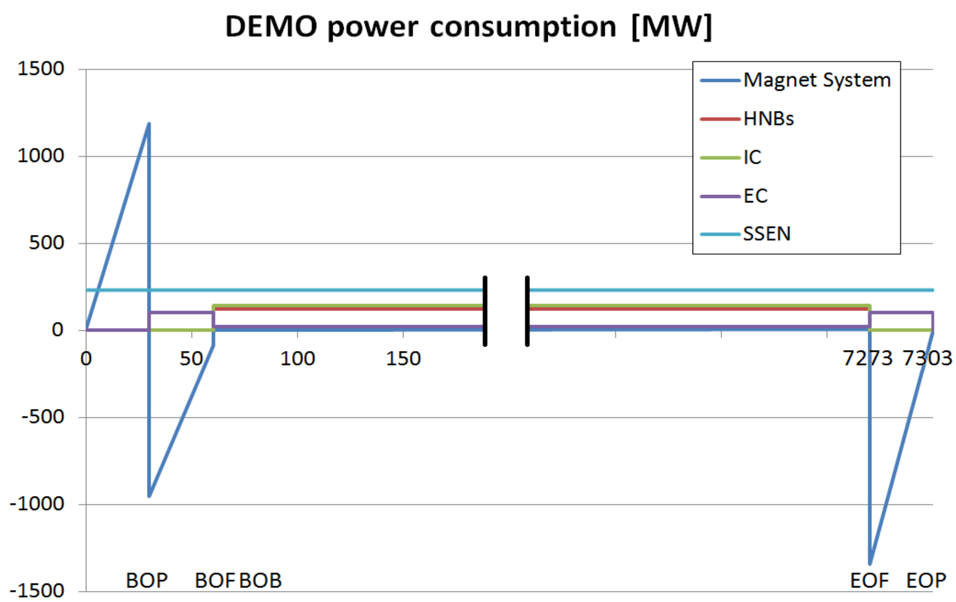


Fig. 3.7.1: Active power profiles of different DEMO loads based on Process DEMO1 reference design

These values will be clearly unacceptable for the grid network, wherever DEMO will be built, and this has been highlighted at the level of WPPMI working group and PMU. These power peaks are due to the very short duration adopted in the PROCESS run for magnet pre-charge, plasma ramp-up and ramp-down phases (30 s each).

This duration is very short also in comparison with the ITER plasma scenarios, as found in literature. To keep the power peaks exchanged with the grid network under reasonable values, the active power required from magnet system has been recalculated, considering longer and more realistic phase durations; the beneficial effect of this solution has been proven (Fig. 3.7.2). The final deliverable is being completed [55]; it is spread in a set of documents covering the different topics of the work: the collection of input data and power supply ratings, the PBS, the input power profiles and Electrical Load List, and the results of first analyses of circuits and electrical system schemes. This structure will allow an easy update of the specific topics as needed for the future WPPMI tasks.

55 A. Ferro C. Finotti, L. Zanotto and E. Gaio., Further steps in the definition of the Plant Electrical System Concept of DEMO, Final report for task PMI-4.1.2-T01, December 15th, 2015

3.7.1.2. Economics assessment of the pulsed DEMO

An assessment regarding the economics part of the pulsed DEMO (DEMO1) derived from the PROCESS code - officially recognized as the European system code – was carried out by means of the FRESCO code (Fusion Reactor Simplified COst) developed by Consorzio RFX. Special attention was paid to the length of the operational phases, namely the plasma current ramp up, the plasma heating phase, the burn phase, the plasma shut-down and the dwell time. It emerged that strict assumptions on the operational cycle of a pulsed reactor hold in PROCESS. Specifically, the duration of the cycle phases are hardcoded, burn phase apart. On the contrary, the FRESCO code estimates the length of each sequence as function of physical and technical constraints. Therefore, while the duration of the burn period agrees with the results of PROCESS, the total cycle length differs. Assessments on the effects of these differences on the economics of DEMO1 are in progress. The power supply requirements for the start up phase and the physical constraints related to the current ramp-up phase form an integral part of the assessment.

3.7.1.3. WPPMI DEMO Scenario Modelling

The 2015 contribution of Consorzio RFX to WPPMI DEMO Scenario Modelling activities focused on the study of DEMO ramp-up and ramp-down phases from the physics integrated point of view.

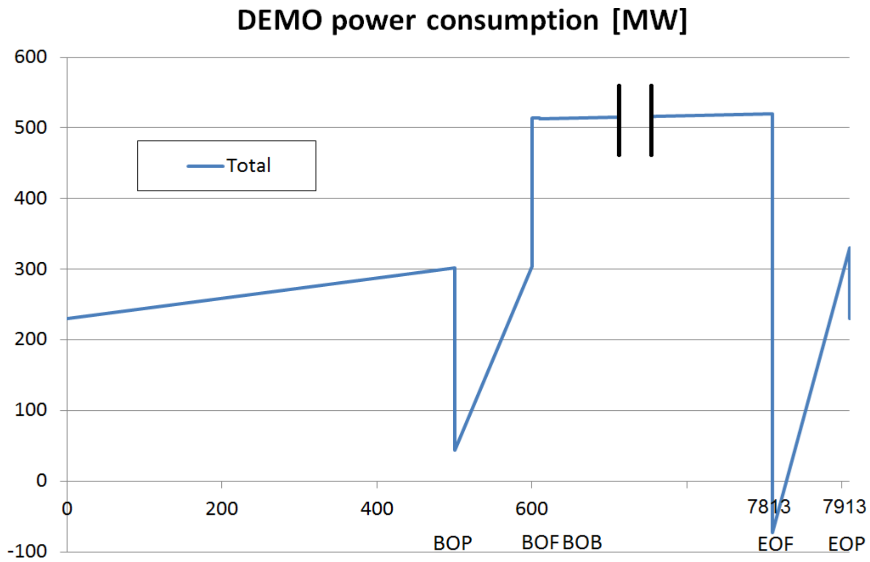


Fig. 3.7.2: Active power profiles of different DEMO loads based on Process DEMO1 reference design

During the first part of the year, the modelling of the previous EU DEMO design was finalized in support to a general Nuclear Fusion paper titled "Modelling of pulsed and steady-state DEMO scenarios"[56]. In these simulations the role of different additional systems during discharge transients was analyzed and some preliminary requirements were deduced. These studies were partly presented at the 2015 SOFE conference[57]; Fig. 3.7.3 shows the effect of different choices of EC additional power during ramp-up on the burn phase beginning.

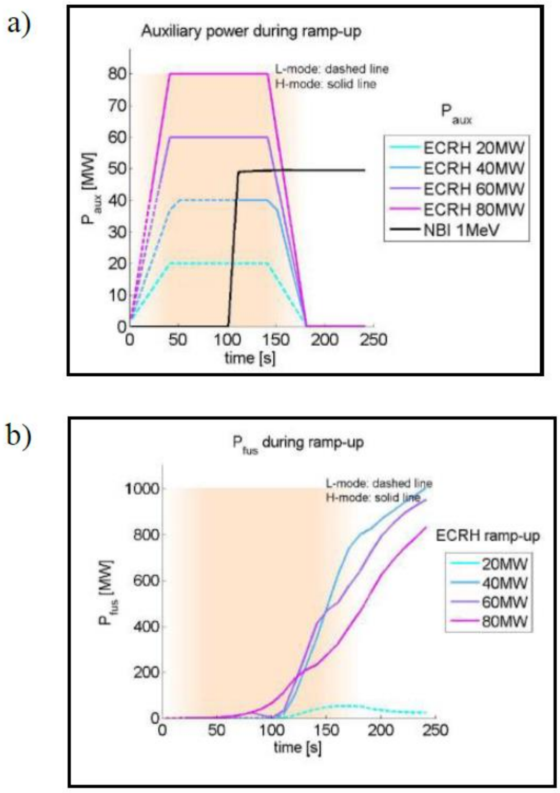


Fig. 3.7.3: METIS studies: 6a) Paux over time during ramp-up for different EC power values plus NB, 6b) Pfus over time[56]

In the second part of the year the reference EU 2015 DEMO1 concept was studied with the help of METIS 0.5D transport code (for the ramp-up) and of the JINTRAC suite of codes, including the JETTO 1.5D transport code (for the ramp-down).

As for the ramp-up, a sensitivity study over different parameters was performed investigating in particular the conditions for a robust L-H transition.

The ramp-down modeling was performed having in mind that in that phase a robust and safe discharge termination have to be ensured against impurity accumulation and H-L back transition issues. In collaboration with Consorzio CREATE a ramp down trajectory was simulated fulfilling some requests in terms of plasma shape and internal inductance, essential to control plasma position in that critical phase. A plasma current ramp-down rate of 80 kA/s (approx. 250 s ramp-down duration) was estimated as maximum acceptable slope able to keep the internal inductance within acceptable

[56] G. Giruzzi, et al. , Nucl. Fusion 55, 073002 (2015)

[57] T. Franke, et al. , "On the Present Status of the EU DEMO H&CD Systems, Technology, Functions and Mix", poster SP13-63 presented at 26th SOFE conference, Austin, Texas USA (2015); also submitted for publication to IEEE Transactions on Plasma Science.

values. Additional heating was also found to be essential to compensate for the risk of radiative collapse during H-L transition. A collaboration with IPPLM has been established in order to include in future studies a more realistic time behavior of impurity concentrations.

3.7.2. WPHCD

In the framework of the EUROfusion WPHCD activities in 2015 an optimized design of the DEMO NBI based on the “closed recirculating cavity with nonlinear gating” (RING) concept was developed. The RING type of photoneutralizer uses two lasers with 35 kW power and 1.5 nm wavelength (infrared). By means of a second harmonic generator, only the second harmonic is circulated in the photoneutralizer, having a wavelength of 0.75 nm, half of the initial one injected by the laser. This harmonic remains trapped in the mirror system, given by 10 upper mirrors, 10 lower mirrors and 4 mirrors with a 45° angle. The beam must have the some width of the laser (limited to 70 mm for technological limitations) and intercept the laser many times. The RF source is modular with 20 sub-sources, located with two vertical arrays of 10 sources each.

This layout permits to obtain at the same time:

- Good alignment between the corresponding apertures of the grids, also in presence of thermal expansion. This is due to the fact that the modules have a significantly smaller size than the whole accelerator, hence the horizontal and vertical deformations are also reduced compared with a non-modular solution. In the ITER NBI, for instance, the modularity is only in the vertical direction (where there are 4 separated modules), but not on the horizontal one. This fact makes the alignment between the corresponding apertures of each grid very difficult.
- High neutralization efficiency, comparing with the present choice of RING photoneutralizer, but also with a gas neutralizer. In fact, with this modular solution two blade-like beams can be generated, which is the most convenient choice to limit the size of the neutralizer and increase its efficiency.

Fig. 3.7.4 shows the current status of the DEMO NBI conceptual design.

The dimension of each sub-source is 0.35 x 0.35 x 0.4 m^3. Each sub-source features 4x15 apertures (4 in the horizontal direction, 15 in the vertical direction) with 20 mm horizontal step and 22 mm vertical step (like in the SPIDER and MITICA experiments). The PG apertures have a 14 mm diameter, similarly to SPIDER and MITICA.

The ion beam is formed by two “blades” with large height (some meters) and small

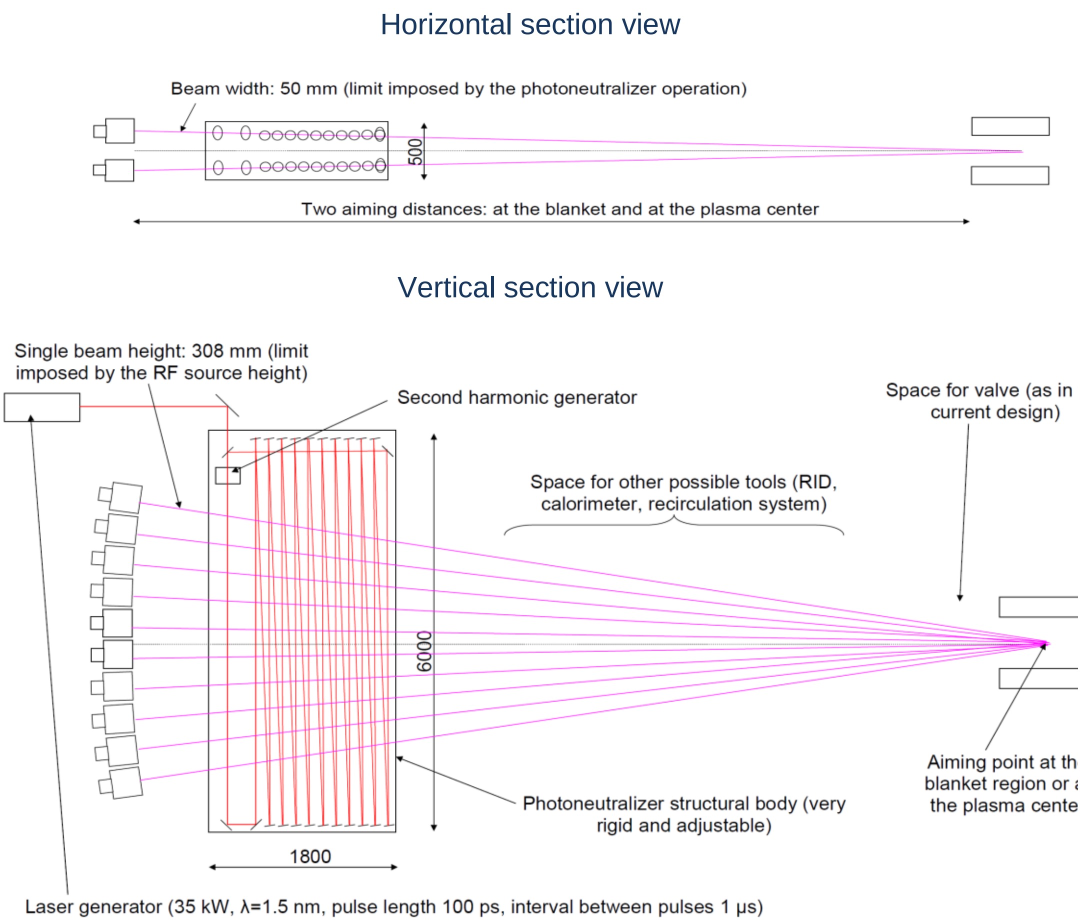


Fig. 3.7.4: Conceptual scheme of the DEMO NBI.

width (about 70 mm). Each of these blades is formed by 10 sub-beams, one per sub-source. The blades are strongly convergent in the vertical direction, with a fan shape.

The main parameters are:

- From each sub-source, 4 x 15 beamlets are extracted. The total extracted current is 36.9 A
- 200 A/m^2 extracted current of negative deuterium ions (D^-), about 30% lower than the one foreseen for ITER
- 7 mm of PG aperture radius
- 20 sub-sources
- 4 x 15 beamlets extracted per sub-source
- Total energy of the beam: 800 keV

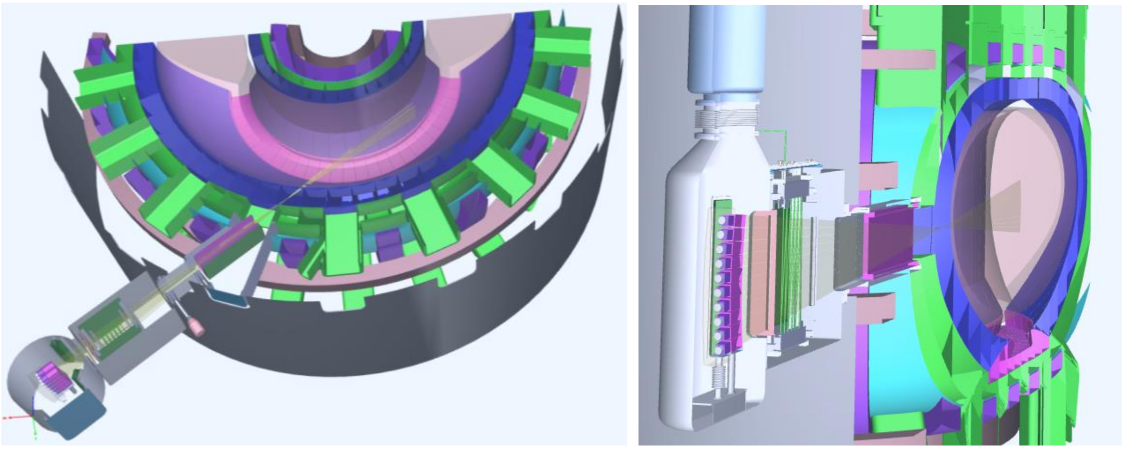


Fig. 3.7.5: DEMO NBI Horizontal section view Vertical section view

- Total power of the beam: 36.9 A * 800 keV * 0.7 = 20.7 MW, with the assumption of 0.7 total efficiency of the photo-neutralizer

The conceptual design of the DEMO NBI was developed in collaboration with the EUROfusion WPHCD group, which includes researchers from several laboratories throughout Europe. Several meetings were organized to share information on the DEMO NBI conceptual design and to gather the observations of the other research groups. An exchange of information was established also with the group working on the Breeding Blanket (WPBB), whose feedback is important for developing the interface between the NBI and the breeding blanket in DEMO.

3.7.3. WPTFV

The TFV task related to the development of an NBI pump based on getter technology got into full swing during 2015. Thanks to SAES company efforts, the “ZAO” getter alloy - optimized for H_2 and D_2 sorption - has been fully characterized in experimental tests. The study ranged from measuring the pumping speed in single-shot tests, to long hydrogenation/dehydrogenation tests to characterize the getter performance after months or years of operations. Simultaneously, the independent characterization of the getter alloy at KIT started: the Pegasos facility was commissioned, and the first results are fully aligned to SAES’s. During the final year meeting of the TFV work package, the test results were positively accepted by the EUROfusion community. A middle scale mock-up of a getter pump module is now in concept design phase and will be prepared during 2016 for experimental tests in a large KIT vacuum facility.

3.7.4. WPMAG

The main topics of the 2015 specifications are summarized below:

- Completion and update of the requirements for the Quench Protection System (QPS) of TF circuit.
- Contribution to the definition of the Toroidal Field (TF) circuit
- Start of the conceptual design for TF QPS
- Start of studies on EF and CS circuit and QPS (where inputs are available)

The first part of the 2015 work[58] was devoted to the collection of input data from the DEMO1 Reference Design and the relevant run of Process code, with the aim of updating TF QPS requirements and highlighting missing information.

Then, the activity was concentrated on the analysis of the TF circuit topology[59], since its definition is necessary for any design study on QPS. Aim of the work was to verify if grouping of coils is viable in a reasonable number of sectors; to this end, it is necessary to analyse the transient voltages in the circuit to verify the acceptability of the peak voltages.

A survey of similar studies carried out for ITER and JT-60SA was done first; suitable models were developed to derive the voltages waveforms across the coils and at the coil terminals in normal and fault conditions. The literature also shows that the voltage distribution among the coil turns is non uniform, so that the peak of the potential versus ground inside the coil can also exceed the value at the coil terminals, therefore suitable models of the coil too were carried out to obtain a full description of the transients.

On this basis, first models of the DEMO TF circuit were worked out with the aim to reproduce the transients at QPC intervention and in case of ground fault, thus deriving useful inputs for the design of the coil insulation. Both the cases with 18 and 9 sectors have been evaluated with two different topology of the earthing circuit, similar to ITER and JT-60SA cases, respectively. Fig. 3.7.6 shows first results obtained in terms of transient voltage at the coil terminals and across the coils in the case of an ITER-like topology of the TF circuit.

---

[58] A. Maistrello and E. Gaio, Status of work progress including progress report on the definition of the TF circuit of DEMO and on the update of the QPS requirements, Report RS01 for task MAG-2.4, Sep 11th, 2015, EU IDM link: 2GE4R8.

[59] A. Maistrello and E. Gaio, Status of work progress including progress reports on the definition of the TF circuit of DEMO and the conceptual design of TF QPS for DEMO, Report RS02 for task MAG-2.4, upload expected next week.

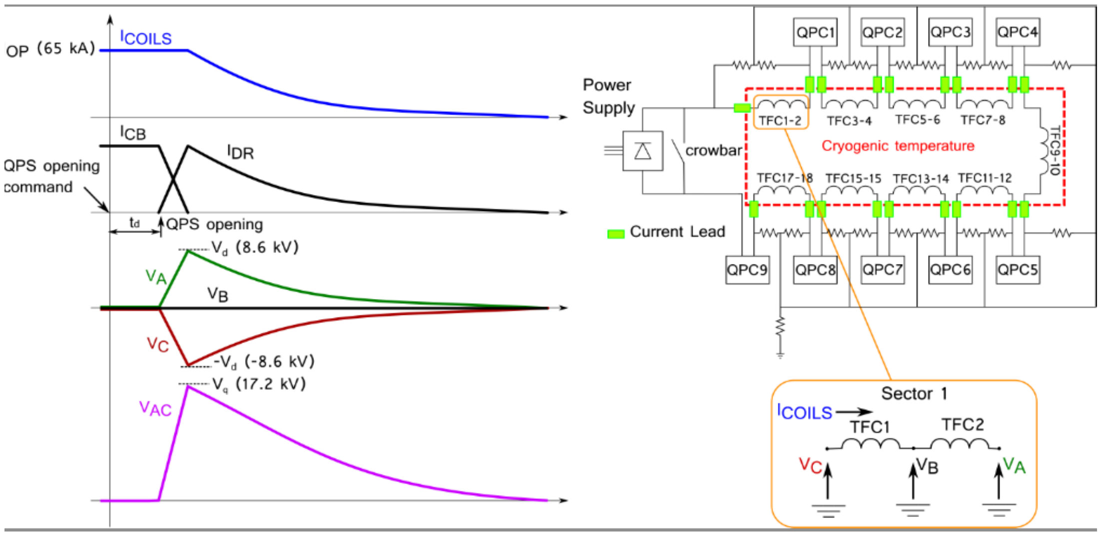


Fig. 3.7.6: ITER-like TF circuit topology for DEMO (right), Waveforms during fast discharge (left, from top to bottom): coil current, current commutation to discharge resistors , voltages at TF coils terminals , voltage across a sector of two coils

The final deliverable, which is being prepared, is structured in three sections to make easier their completion and updates in the next years: the collection of input data and QPS requirements, the studies on the TF circuit topology and the first analyses on QPS design, highlighting how their requirements change in dependence of the circuit structure[60].

3.7.5. WPDC

The Work Package Diagnostics and Control (WPDC) for DEMO is a 5 years (2015-2020) project involving scientists from the laboratories of the EUROfusion Consortium.

The primary objective of the WPDC is to deliver a feasible, integrated concept design of the DEMO diagnostics and control systems that, with an acceptable confidence level, meets the measurement requirements. The concept design will be substantiated and verified to an appropriate level for a plant-level Conceptual Design Review and minimum R&D development on radiation resistant diagnostic and actuators.

DEMO diagnostics and associated control systems are constrained by the extreme environmental conditions, mostly due to the high neutron flux and fluence, and the stringent requirements on reliability, availability and maintainability. At the same time, plasma operations must be even more robust than in ITER since e.g. the pulse length

[60] A. Maistrello and E. Gaio, Studies on TF circuit topology and Quench Protection System design, 2015 deliverable, upload expected within 2015.

is increased and disruptions have to be fully avoided.

The top-level Work Breakdown Structure for the Project comprises the four main work areas foreseen in the Work Plan:

- Project Management
- System Engineering and Design Integration
- Control R&D: Development of the overall DEMO control concept
- Diagnostic R&D: Studies on the feasibility, lifetime and performance of components and subsystems

The Italian research association (Consorzio RFX, ENEA, IFP-CNR) is involved in the last two areas with its well established expertise in the control systems and diagnostic development. In particular, Consorzio RFX participated with a total of 0.3 ppy in 2015.

The first activity in which Consorzio RFX is involved concerns the R&D of the diagnostic microwave system: a collaboration started in 2015 with the IST association (Portugal) to design the reflectometric system for plasma position and shape control purposes neede to fully exploit the DEMO reactor. This work involves:

- Developing a List of Candidate Diagnostic Systems
- Assessing of the Implementation of Diagnostic Systems
- Conceptual Studies on Diagnostic Feasibility, Lifetime and Performance
- Testing of Prototype Components

Consorzio RFX is the owner of a specific task related to the “Contribution to initial conceptual studies for microwave diagnostics - Determination of the number of channels needed to accommodate the control requirements”. Within this task in 2015, the work concerned an accurate literature survey about the different control algorithm models successfully applied on existing tokamaks and ITER based on magnetic measurements. On the other hand, it also involved the analysis of the unique (at present) example of control algorithm integrated with one or two reflectometric measurements (ASDEX[61]).

Afterwards, an initial assessment of the diagnostic reflectometric system capabilities against the control requirements was undertaken. Reflectometric system should meet the time resolution needed for the fastest plasma dynamics (set by vertical stability) as

[61] Santos J. et al., Nucl. Fusion 52, 2012, 032003

obtained by the stability analysis on the different DEMO scenario performed by CREATE. The spatial resolution is, instead, more difficult to be fully assessed since the reliability of the reflectometric signals is not the same along the poloidal direction. In particular, the measurements in the poloidal positions close to the divertor and in the upper plasma will be particular difficult. Alternative strategies are under considerations and will be discussed in the future work.

However, this preliminary shoed the need to gain deeper insight into the different nature of a control scheme based on reflectometric measurements instead of the traditional magnetic measurements (that will be no longer available for steady state DEMO operations). Different questions arose around several topics:

- Type of variables to be estimated through these measurements;
- Full self-consistency of the measurements;
- Dealing with transition phases (breakdown, ramp-up, ramp-down);
- Alternative strategies when one or more reflectometers get no signal.

In order to answer these questions, a first joint meeting was held involving research groups working on both control model and diagnostic R&D (namely, Consorzio RFX, CREATE, IST). In this respect, Consorzio RFX will contribute to the integration of the signals derived on the basis of reflectometric measurements into a full model of the plasma response to be used for the design of the control system.

3.8. *WPSES: Socio-Economic studies*

The 2015 activities focussed on the assessment of the correlation between the level of safety of a commercial fusion power plant and the cost of the electricity generated. The EFDA TIMES model, i.e. the model of the future global energy system developed by means of TIMES[62], assumes that the fusion technology will become commercial in 2050 and the power plant economics will be quite similar to that of PPCS (Power Plant Conceptual Study) models C and D. The PPCS study links the power plant safety to the economics through the LSA (Level of Safety Assurance) factors, i.e. multiplication factor which reduce the direct costs of the plant components as much as a full passive-safety configuration is achieved. However, the values of the LSA factors - inherited from the American nuclear fission experience - look now obsolete and must be overhauled. The cost estimation of the PPCS models is based on the assumption of

[62] TIMES model generator

LSA = 2, which means that a large-scale passive protection is available. The analyses carried out so far demonstrate that if the LSA factors were neglected, the capital cost rises by 20% and the cost of electricity by 18%. Such an increase would negatively affect the technology penetration in a future energy system so that the fusion electricity generation share would decrease in favour of fission. Assessments of the relation between the fusion cost of capital and the electricity generation share is underway with the reviewed EFDA TIMES model version and studies for the identification of new safety-related cost multiplication factors is being carried out with the support of the Nuclear Safety group of ENEA Frascati.

4. Broader Approach

In 2015 the main achievement of the Consorzio for the BA was the completion of the procurement of the JT-60SA "Quench Protection Circuits" (QPC) on time and within the allocated cost.

In parallel, Consorzio RFX team continued to collaborate with the International Project Team, with particular reference to the Power Supply system [63], and working on the second procurement for JT-60SA: the "Power Supplies for the in-vessel sector coils for RWM control". Consorzio RFX also participates in the JT-60SA physics studies and in the preparation and update of the Research Plan. An additional contribution is in the development of the Remote Experimentation Centre for the IFERC project.

4.1. *Quench Protection Circuits*

The Agreement of Collaboration (AoC) activities for the procurement of the QPC included the detailed design, the manufacturing of prototypes for the Poloidal and the Toroidal QPC and relevant type tests performed to thoroughly qualify their operation and verify the design choices and margins, the manufacturing of the 13 units and the routine tests in factory, the packing, the delivery to the Port of Entry, the installation on site, the commissioning, functional and final acceptance tests. In addition, preliminary R&D were carried before the AoC signature from 2007 to 2009, addressed to identify the whole set of QPC requirements, to investigate possible design solution suitable for JT-60SA QPC and to verify their feasibility.

The QPC of the JT60-SA poloidal and toroidal SuperConducting (SC) magnets have to protect the SCs in case of quench by quickly discharge the stored energy, commutating the circulating current to suitable resistors. The design is based on the use of a hybrid mechanical-static circuit breaker, composed of a mechanical by-pass switch connected in parallel to a static circuit breaker based on IGCT technology. The ratings of the QPC units are recalled in Table 4.1.1.

Fig. 4.1.1 summarizes the QPC procurement phases and milestones achieved, the Procurement Arrangement (PA) was closed on 28 July 2015, according to the original schedule, with the approval by the Project Leader of the Final Report (Acceptance Data

[63] Luca Novello , Olivier Baulaigue, Alberto Coletti, Nicolas Dumas, Alberto Ferro, Elena Gaio, Alessandro Lampasi, Alberto Maistrello, Makoto Matsukawa, Katsuhiro Shimada, Kunihito Yamauchi, Pietro Zito: "Overview of the new Magnet Power Supply Systems of JT-60SA procured by EU" Fus Eng and Design, **98–99**, 1122-1126, October (2015)

Table 4.1.1- Ratings of QPC units

Coils	Number of units	Rated value (assumption)
Toroidal	3 units	25.7 kA / 2.8 kV
Central Solenoid	4 units	20kA / 4.2 kV
Equilibrium Field	6 units	20kA / 4.2 kV

Package) collecting the update version of the whole technical documentation generated during the procurement evolution.

QPCs were procured by a contract awarded by Consorzio RFX to the company Nidec ASI (formerly Ansaldo Sistemi Industriali) in December 2010. The detailed design was completed in Summer 2011, the prototypes development and qualification were completed end 2012 and the manufacturing and factory tests of the 13 units beginning 2014. After the packaging and the transportation in Japan, the QPC installation in Naka Site started in December 2014 and was concluded on February 18 2015. It represented the first occasion of activities directly managed by European personnel at Naka Site for JT-60SA: the installation work was performed by Nippon Advanced Technology, a Japanese supplier subcontracted by Nidec ASI for the on-site activities. After the commissioning the was performed. These insulation tests were carried out from February 16th to 24th, 2015.

Then, after the commissioning and the withstand test at the maximum operating

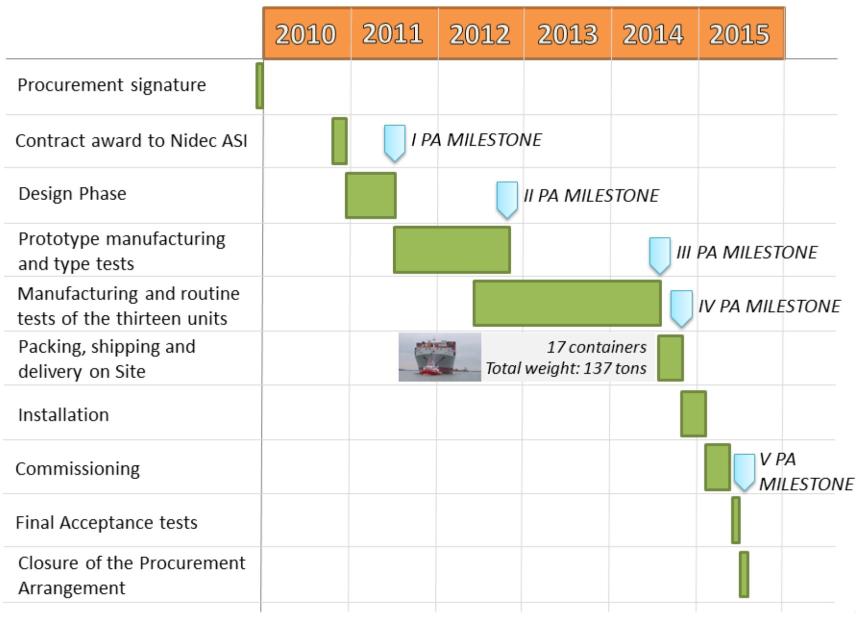


Fig. 4.1.1: Summary of the QPC procurement milestones achieved and closure on time

Fig. 4.1.2: View of the QPC units installed in one of the Power Supply Halls at Naka Site

voltage (2.8 kV rms for TF QPC and 5 kVrms for PF QPC, 10 m), a comprehensive set of functional tests was carried out on each unit, including the verification of the input/output signals, the check of the measurements, the simulation of the faults and verification of the relevant protection signals. An unexpected issue arose due to ElectroMagnetic Interferences (EMI) causing noises on the measurements at the occurrence of the Pump Exchange of the Pyrobreaker Cooling System. The problem was studied, suitable provisions were implemented and their effectiveness proved with dedicated tests. the test procedures were updated in parallel. Finally, an additional pressure test of the whole cooling water circuit of the Pyrobreaker was performed.

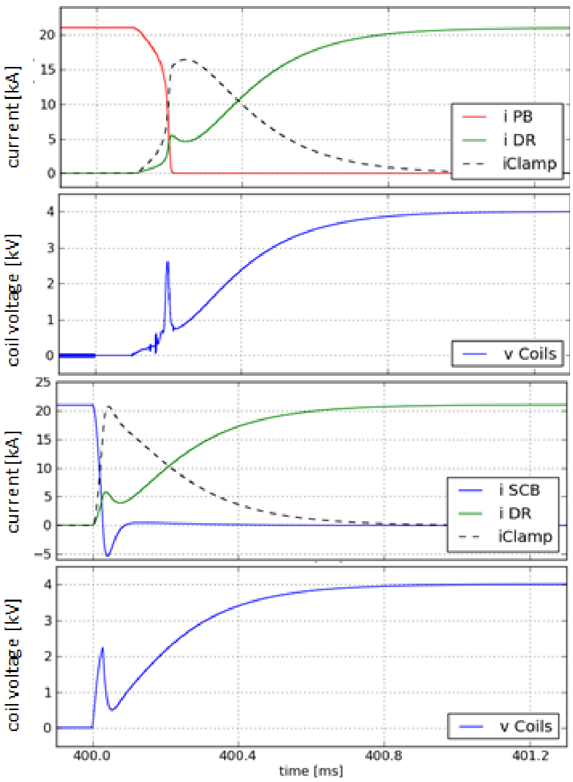


Fig. 4.1.3: Current and voltage waveforms at SCB and Pyrobreaker current interruption

At the end of the commissioning, the acceptance tests of the 13 QPC units were carried out and completed in June 2015; the operating sequences were tested both in local mode (from cubicle door and from HMI) and from the JAEA Reflective Memory Test Stand.

After the installation of the busbars and of the QPC units it was possible to perform direct measurement of the stray parameters of the connections, allowing to complete the models of the QPC units and update the calculation of the voltage waveforms across the coil at the main Circuit Breaker and Pyrobreaker intervention [64]. Fig. 4.1.3 shows the updated results.

64 Alberto Maistrello, Elena Gaio, Luca Novello, Makoto Matsukawa, Kunihito Yamauchi, Analyses of the impact of connections' layout on the coil transient voltage at the Quench Protection Circuit intervention in JT-60SA Fusion Engineering and Design, Volumes 98–99, October 2015, Pages 1109-1112

4.2. *Power Supply System for in-vessel sector coils for RWM control*

The purpose of this Power supply system is to feed the 18 in-vessel coils of JT-60SA devoted to control a set of plasma instabilities called Resistive Wall Modes (RWM). The PS reference scheme[65], confirmed after the feasibility study in 2014, is shown in Fig. 4.2.1 Each coil will be fed by a dedicated inverter (300 A, 240 V), which has to guarantee very high dynamic performance. In particular, a current bandwidth of 3 kHz and latency between output voltage and reference lower than 50 μs are required.

To prove the feasibility of the inverter and the availability of suitable power switches at reasonable cost, in 2013 Consorzio RFX launched a call for tender for the development of a prototype. A contract was placed with E.E.I. and the company proposed a design based on new semiconductors (hybrid Silicon-Silicon Carbide IGBT), to achieve the

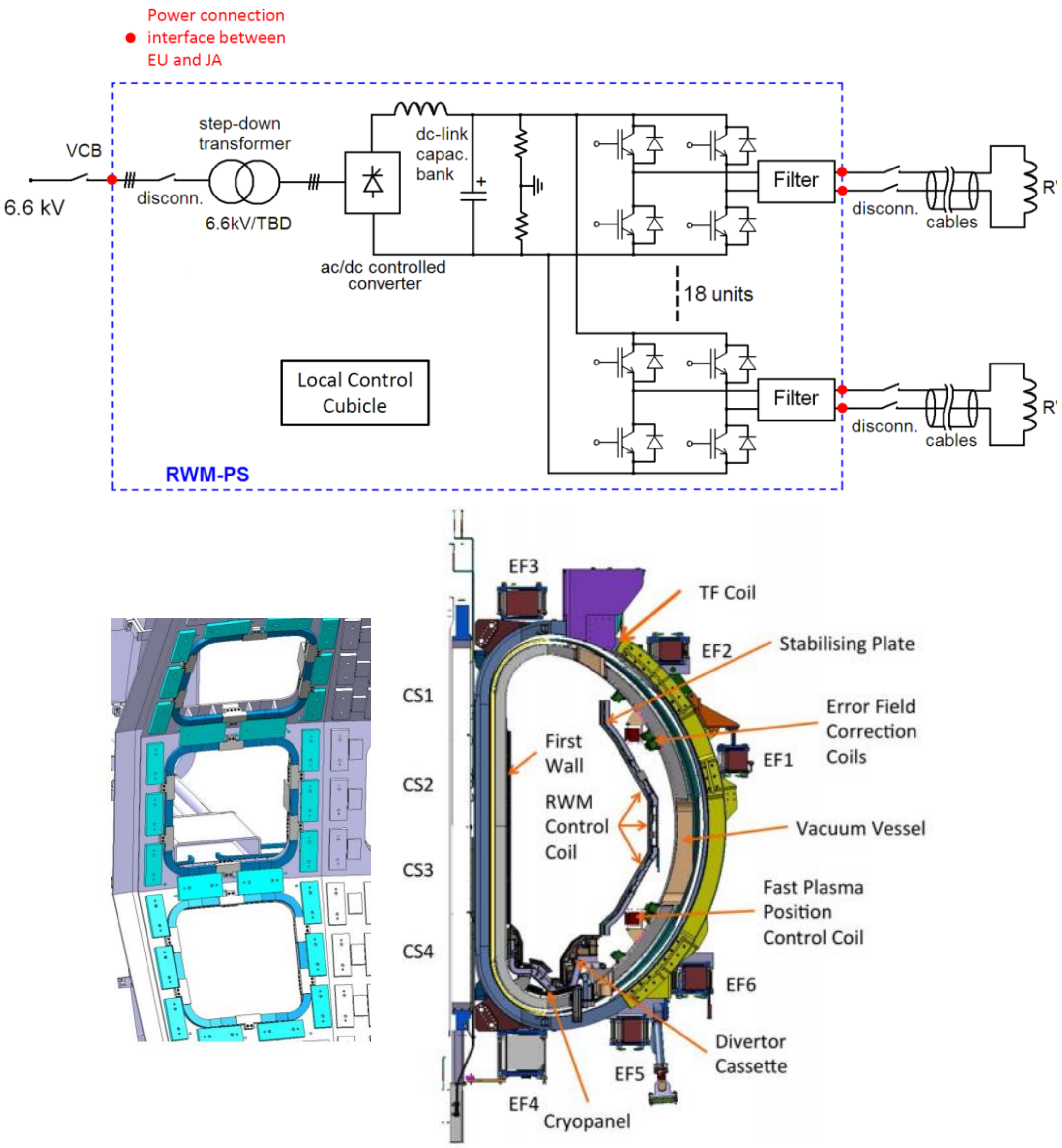


Fig. 4.2.1: Reference scheme of the RWM-PS and coil setup

specified dynamic performance with an H-bridge inverter topology with four main switches only. The manufacturing and acceptance tests were completed in 2014, proving a full compliance with the specification. The prototype was delivered to Consorzio RFX in December 2014 and installed in the Electric Workshop, where it is available for further analyses and tests. On the basis of this development, two papers have been written in 2015. One[66] was presented at the conference EPE'15 ECCE-Europe and describes the innovative characteristics of this inverter, both in terms of fast power section and full-digital control. The other[67] was presented at the 26th SOFE conference and reports on the advantages of using power switches based on SiC technology in power supplies for fast MHD modes control in fusion experiments.

Fig. 4.2.2: RWM-PS inverter prototype installed in the Electric Workshop of the Consorzio

Being proved the feasibility of the system, the Agreement of Collaboration and the Procurement Arrangement were prepared and signed in March and April 2015 respectively. An updated version of the Technical Specification (TS) for the Supplier was sent to F4E and JAEA on August 2015 and the last open points discussed. In particular, some interface issues were addressed (signals exchanged with JT-60SA circuit breaker and protection system, type and accuracy of measurements, type and features of Human Machine Interface etc.). A Design Review Meeting with F4E and JAEA was held on September 2015, to present and agree the TS also with JAEA magnet team and physicists. An issue is still present related to the voltage across the coils; the present requirement in terms of peak value

[66] A. Ferro, et al., "A 72 kVA very fast four-quadrant converter based on hybrid Si-SiC IGBTs", Power Electronics and Applications (EPE'15 ECCE-Europe), 17th European Conference on, 8-10 Sept. 2015, Geneva

[67] E. Gaio, et al., “Si-SiC Based Switching Power Amplifiers for MHD Modes Control in Fusion Experiments”, Proceedings of the 26th Symposium on Fusion Engineering, Austin (TX), 31 May - 04 Jun 2015, in press

can be met, while the compliance with that one in terms of voltage slope could compromise the dynamic performance necessary for an effective RWM control. The matter will be further studied during the detailed design development, to optimize the output filter such to limit the coil stresses, while preserving the desired promptness of response. Recently the documentation for the call for tender has been finalized and a call for interest launched on 19 Nov. 2015 to be closed by the end of January 2016, with the t signature of the contract in February 2016.

5. Socio Economic Studies and DEMO

5.1. *COE probability distribution of a DEMO-like power plant*

The viability of the fusion technology strongly depends on its economic sustainability. Studies on the possible future evolution of the Italian and global energy systems continued along with a review and a constant update of the tools for the economic assessment of a fusion power plant (FRESCO code) and for the energy scenarios development (COMESE code which performs stochastic analyses of the cost of electricity COE of future energy technologies). Stochastic analyses were performed with the FRESCO code for the assessment of the effects of uncertainties on specific technical and economic power plant parameters on the final cost of electricity. The results, presented at the SOFT2014 Conference, have been recently published[68]. The study showed that an economic analysis of a future fusion power plant is more reasonable when performed through a stochastic approach. In fact the large number of uncertainties that currently affect the fusion technology evolution make a deterministic approach less meaningful. The probability

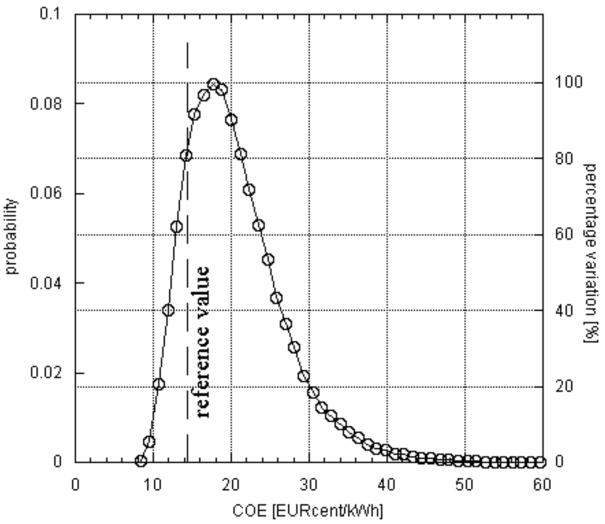


Fig. 5.1.1: COE probability distribution of a DEMO-like power plant assessed by randomly sampling the following stochastic variables: blanket and divertor lifetime, cost of the blanket materials, financial parameters, cost reduction

[68] [Bustreo,2015].

distribution of the Cost Of Electricity (COE) shown in Fig. 5.1.1 has a mode 20% higher than the value corresponding to reference assumptions recovered from the literature. The probability of such reference value is 20% lower than the mode and the same as that of a COE 50% higher. It is worth adding that such results are peculiar of most energy innovative technologies, thus a similar stochastic approach should be applied to all those competing with fusion in a future energy market, in order to correctly evaluate the cost of different energy mixes and more accurately assess the impact of Fusion. In line with this approach, the COMESE code is being translated in C++ language so as to improve the its flexibility. A comprehensive description of the code features along with the study of the short term Italian energy scenario has been submitted to the journal “Energy Policy”.

6. Industrial Collaborations

6.1. *Model for the electrostatic design a new VCB prototype*

At the end of the 2014 the “Agreement on a Development Order” has been signed between the Centro Ricerche Fusione (the University Padova Representative Entity of the Consorzio RFX) and Siemens Aktengetellschaft, Berlin. Purpose of the Agreement is the application of the Voltage Holding Predictive Model (VHPM), developed at RFX, to the design of the Siemens Vacuum Interrupter (VCB).

The electric current interruption in vacuum is considered by Siemens as a key technology for the development of the electric energy distribution systems (Smart Grids), where the switching components (circuit breakers) play a fundamental role in the reliability of the electric distribution service, and the VCBs are presently the best candidate.

For the optimization of the electrostatic design of the VCB, Siemens has deemed R&D effort necessary to realize a design tool capable to identify - with an index - the “quality” of the insulation strength of a VCB sample. Correspondingly, Consorzio RFX, in the R&D activities concerning the NBTF-MITICA Beam Source design, has gained a good expertise on the electrical insulation in vacuum and has also developed the VHPM based on the so-called clump theory and mixed with a probabilistic approach, that was very useful in designing the MITICA accelerator. Such a model corresponds substantially to the needs of Siemens and the Collaboration Agreement started first by assessing the applicability of the model to the VCB design, with the final objective to implement this technique in the design process of the VCBs.

During this first year, the activities carried out were devoted to analyze the statistical properties of the breakdown distribution of different samples of VCBs, subjected to Lightning Impulse Voltage Waveform (LIVW), as required by IEC standards. This analysis was necessary as the first step to assess whether the VHPM (developed for dc voltage application) is applicable also to pulsed voltage conditions. The analysis showed that the breakdown distribution, once the conditioning phase has been completed, follows the Weibull distribution, as required by the VHPM.

The VHPM has been then applied to several samples of VCB, to obtain a robust evaluation of the Weibull distribution parameters (scale and shape factors). Fig. 5.1.1 reports the Weibull plots of the calculated breakdown probability for a VCB sample, for contact gaps of 10 mm and 20 mm respectively. For the 10 mm gap case, the measured probability curves are also reported. The two curves (blue and red) are relevant to the inversion of polarity (positive and negative polarity, respectively).

For the 20 mm case, it was impossible to confirm the prediction, due to output voltage limitation of the pulse generator.

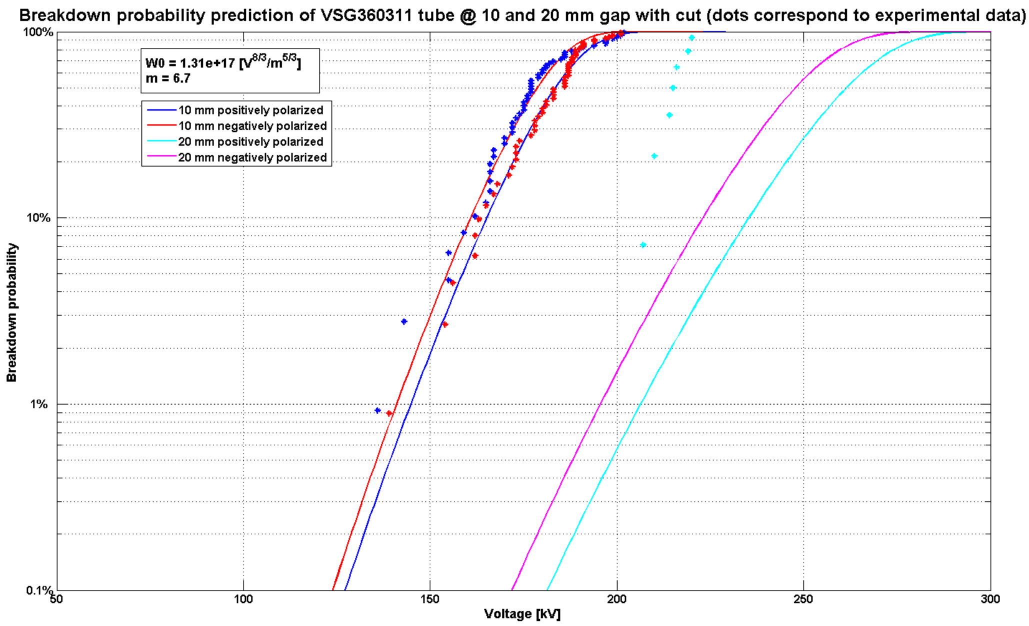


Fig. 6.1.1 Weibull plot of the calculated breakdown probability for a VCB sample

This year of activity showed that the VHPM can be applied to the VCB technology with sound results. Presently, tests are ongoing for the determination of the voltage breakdown probability of a VCB sample completely re-designed, and the comparison with the calculated probability (provided a good agreement is found) will give stronger confidence on the applicability of the model.

In case of extension of the Agreement (under evaluation by Siemens), the activity program will foresee the implementation of full 3D geometry in the VHPM. Moreover, it is planned an investigation on the effect of parameters α, β, γ of the kernel variable of the model (the triple product ${E_A}^{\alpha} \cdot {E_K}^{\beta} \cdot U^{\gamma}$, being the three variables the electric field at the anode, at the cathode and the voltage between the two electrodes) in its the prediction accuracy.

7. Education, training and information to the public

7.1. *International Doctorate in Fusion Science and Engineering*

In 2015 the Joint Research Doctorate in Fusion Science and Engineering (by Padua University, Lisbon Instituto Superior Tecnico and Naples University Federico II) and the European Interuniversity Doctoral Network in Fusion Science and Engineering (same Universities, plus the Munich Ludwig Maximilians University and the Tampere University of Technology) continued under the responsibility of the University of Padua and of Consorzio RFX. Also the correlated participation to the Erasmus Mundus International Doctoral College in Fusion Science and Engineering (Fusion DC), coordinated by Ghent University, continued fruitfully.

In particular, 5 new PhD students entered the Doctorate at the end of 2014 and started their research activity at RFX at the beginning of 2015: 4 directly admitted by our International Doctorate, and 1 by Fusion DC. At the same time, 5 PhD students completed their three years doctoral activity and passed the Final Examination, obtaining the Joint International Doctoral Diploma. Straight after, one of these five won a EuroFusion Engineering Grant and two have been engaged by RFX with a grant.

As usual, for the students of the Doctorate, during 2015, four courses were organized: two at RFX (Padua), one at IST (Lisbon) and one at IPP (Garching).

The two courses at RFX were: a Basic Course on Engineering, for the students starting the first year of the Doctorate, and an Engineering Advanced Course, for the students at the second year.

Programme and teachers of these Courses were

1. Engineering Basic Course (36 hrs)

- Fusion power plants (M. Dalla Palma, RFX)
- First wall, divertor, vacuum vessel (P.Agostinetti, RFX)

- Magnets (G. Chitarin, RFX and UniPD)
- Power systems for fusion experiments (E. Gaio, RFX)
- Feedback control theory with application to Tokamak (G. Manduchi, RFX)
- Basic data acquisition (G. Manduchi, RFX).

2. Engineering Advanced Course (50hrs)

Introduction*:*

- Presentation of the Course (P. Bettini, RFX and UniPD)
- Energy scenarios for the next century and the role of fusion. The Fusion reactor (D. Maisonnier, European Commission. Brussels),
- Fusion Plants studies, ITER and DEMO (D. Maisonnier, European Commission, Brussels),

Materials for fusion reactors:

- The role of materials in fusion devices and structural materials (S. Dudarev, CCFE Culham),
- Plasma facing components (E. Visca, ENEA Frascati)
- Liquid metal for first wall (G. Mazzitelli, ENEA Frascati),
- Superconducting magnets for fusion applications (P. Bruzzone, CRPP Lausanne),

Heating and current drive systems:

- Introduction: heating and current drive in fusion devices (T. Bolzonella, RFX),
- Plasma heating and current drive by NBI (C. Hopf, IPP Garching),
- ITER NBI (P. Sonato, RFX and UniPD),
- ECRH in fusion devices (G. Granucci, CNR Milano),
- ICRH and LHCD: electromagnetic issues and system integration (F. Mirizzi, ENEA Frascati),
- Antenna design for RF fusion systems (D. Milanesio, Politecnico Torino).

Fusion plant studies, management, modeling:

- Managing the design of a tokamak (JT60 SA) (G. Giruzzi, CEA Cadarache),
- Electromagnetic modeling of fusion machines (R. Albanese, UniNA),

- ITER vacuum vessel manufacturing preparation (P. Bonifazi, Walter Tosto SpA Chieti).

Teachers from RFX contributed also to the PhD courses held in Garching and Lisbon.

7.2. *Other education and training activities*

The other educational and training activities carried out at Consorzio RFX were:

tutorial activity for development of bachelor and master theses and organization of short (1-2 months) summer stages at Consorzio RFX of secondary school students.

Also the internal educational action dedicated to the RFX staff continued with the following courses:

- Electromagnetic compatibility EMI and EMC and radiation sources,
- Principles of electromagnetic shielding,
- CATIA.

Moreover the following 7 regular courses of Padua University were held by teachers from Consorzio RFX:

- Basic principles of Plasma Physics (6 ECTS, 1st Level Degree, Physics)
- Physics of Nuclear Fusion and Applications of Plasmas (6 ECTS, 2nd Level Degree, Physics)
- Fluid and Plasmas Physics (6 ECTS, 2nd Level Degree, Physics)
- Fission and Fusion Nuclear Plants (9 ECTS, 2nd Level Degree, Engineering)
- Energy Technology and Economics (9 ECTS, 2nd Level Degree, Engineering)
- Thermonuclear Fusion (6 ECTS, 2nd Level Degree, Engineering)
- Industrial Applications of Plasmas (6 ECTS, 2nd Level Degree, Engineering)

In conclusion, during 2015 the following educational activities were performed by RFX staff: management of the International Doctorate in Fusion Science and Engineering, tutoring of 18 PhD students preparing their PhD thesis, of 15 graduation students preparing their degree thesis and of a few secondary school students in summer stage and, apart from several lessons for the Doctorate, teaching of 7 regular courses at Padua University and of 3 internal courses at Consorzio RFX.

7.3. *Information to the public*

In 2015, the progress of the NBTF construction and the start of the installation of components strengthened the need of information and communication and led to a significant increase in both the outreach and public information activity.

Outreach and education

Great effort was dedicated to public talks and presentations given in a variety of formats: lectures, discussions, interviews, by scientists from Consorzio RFX for events and initiatives occurred in 2015:

- "L'atomo nel piatto" conference –Prof. Piero Martin – 11 March
- RAI television filming at Consorzio RFX for the "Nautilus" programme on air in March
- Partecipation with a booth at the scientific outreach event "L'era dell'atomo", organized by Museo delle Scienze Naturali in Venice in April
- RAI television filming at Consorzio RFX for the "Superquark" programme on air in August
- "Energia e vita" – round table event – Dr. Vanni Antoni, organized, in collaboration with CNR press office in Rome, at Orto botanico in Padova
- In September, Consorzio RFX participated to the European Night of Research event, by organizing 3 "open-nights" to the RFX-mod and NBTF plants with a wide support by the RFX researchers.
- In 10-11 December, the Broader Approach Steering Committee took place in Padova at Consorzio RFX. In those same days, the components for NBTF contributed by Japan were delivered and their installation could start soon after. The event was marked with a ceremony with the presence of national and international authorities, among them Dr. Bernard Bigot, ITER Director-General.

Information material (brochures, posters and images) was updated and elaborated for the events.

Socials: along the RFX website, a new facebook page of the Consorzio RFX was created; it is regularly kept updated.

Public information

Press notes were elaborated on the occasion for the best thesis in Fusion Science and Engineering Award 2015 and NBTF milestones .

Public speaking were given by researchers from Consorzio RFX to national and international stakeholders, local authorities and firms participating to NBTF call for tenders.

EUROfusion activity

In the frame of the outreach and communication activity foreseen in the Road Map in support of fusion energy research, Consorzio RFX participated in 2015 Social Economic and outreach Studies (SES).

In 2015, Consorzio RFX collaborated to the production of 3 videos on CNR-Diitet patents; the activity consisted in the elaboration of the script of the movies with acting instructions and scene directions and in the participation to the shooting and final video editing.

8. 2015 PUBLICATIONS

8.1. *International and national journals*

1. M. Spolaore, N. Vianello, I. Furno, D. Carralero, M. Agostini, J. A. Alonso, F. Avino, R. Cavazzana, G. De Masi, A. Fasoli, C. Hidalgo, E. Martines, B. Momo, A. Scaggion, P. Scarin, S. Spagnolo, G. Spizzo, C. Theiler and M. Zuin: "Electromagnetic turbulent structures: A ubiquitous feature of the edge region of toroidal plasma configurations" Phys. Plasmas **22**, 012310 (2015)

2. F J Casson, C Angioni, E A Belli, R Bilato, P Mantica, T Odstrcil, T Pütterich, M Valisa, L Garzotti, C Giroud, J Hobirk, C F Maggi, J Mlynar, M L Reinke: "Theoretical description of heavy impurity transport and its application to the modelling of tungsten in JET and ASDEX upgrade" Plasma Phys Contr F **57**, 014031 (2015)

3. J C Flanagan, M Sertoli, M Bacharis, G F Matthews, P C de Vries, A Widdowson, I H Coffey, G Arnoux, B Sieglin, S Brezinsek, J W Coenen, S Marsen, T Craciunescu, A Murari, D Harting, A Cackett, E Hodille: "Characterising dust in JET with the new ITER-like wall" Plasma Phys Contr F, **57**, 014037 (2015)

4. A Murari, E Peluso, M Gelfusa, I Lupelli, M Lungaroni and P Gaudio: "Symbolic regression via genetic programming for data driven derivation of confinement scaling laws without any assumption on their mathematical form" Plasma Phys Contr F, **57**, 014008 (2015)

5. N Vianello, C Rea, M Agostini, R Cavazzana, G Ciaccio, G De Masi, E Martines, A Mazzi, B Momo, G Spizzo, P Scarin, M Spolaore, P Zanca, M Zuin, L Carraro, P Innocente, L Marrelli, M E Puiatti, D Terranova: "Magnetic perturbations as a viable tool for edge turbulence modification" Plasma Phys Contr F, **57**, 014027 (2015)

6. Paul M. Bellan and Roberto Paccagnella: "Magnetic axis safety factor of finite β spheromaks and transition from spheromaks to toroidal magnetic bubbles" Phys. Plasmas **22**, 022513 ((2015)

7. T Barbui, L Carraro, P Franz, P Innocente, S Munaretto and G Spizzo: "Light impurity transport studies with solid pellet injections in the RFX-mod reversed-field pinch" Plasma Phys Contr F **57**, 025006 (2015)

8. V. D. Pustovitov and V. V. Yanovskiy: "Rotational stabilization of the resistive wall modes in tokamaks with a ferritic wall" Phys. Plasmas **22**, 032509 (2015)

9. A Damone, A Panarese, C M Coppola, J Jansky, C Coletti, L Chiodo, G Serianni, V Antoni and S Longo: "Theoretical determination of the microstructure of Cs covering of Mo in negative ion sources for Nucl Fusion applications" Plasma Phys Contr F **57**, 035005 (2015)

10. P. Bettini, T. Bolzonella, M.F. Palumbo, M. Furno, S. Matsrostefano, G. Matsunaga, R. Specogna, M. Takechi, F. Villone: "Advanced Computational Tools

for the Characterization of the Dynamic Response of MHD Control Systems in Large Fusion Devices” IEEE T Magnet, **51,** Issue 3, 7204105 (2015)

11. L Giudicotti and R Pasqualotto: “Rotational Raman scattering as a source of polarized radiation for the calibration of polarization-based Thomson scattering” Plasma Phys Contr F **57**, 035001 (2015)

12. Oreste Pezzi, Francesco Valentini and Pierluigi Veltri: “Nonlinear regime of electrostatic waves propagation in presence of electron-electron collision” Phys. Plasmas **22**, 042112 (2015)

13. T Koskela, M Romanelli, P Belo, O Asunta, S Sipilä, M O'Mullane, L Giacomelli, S Conroy, P Mantica, M Valisa, C Angioni, T Kurki-Suonio and JET-EFDA contributors: “Effect of tungsten off-axis accumulation on neutral beam deposition in JET rotating plasmas” Plasma Phys Contr F, **57**, 045001 (2015)

14. D Bonfiglio, M Veranda, S Cappello, D F Escande and L Chacón: “Helical self-organization in 3D MHD modelling of fusion plasmas” Plasma Phys Contr F, **57**, 044001 (2015

15. F. Auriemma, R. Lorenzini, M. Agostini, L. Carraro, G. De Masi, A. Fassina, M. Gobbin, E. Martines, P. Innocente, P. Scarin, W. Schneide[2] and M. Zuin: “Characterization of particle confinement properties in RFX-mod at a high plasma current” Nucl Fusion, **55**, 043010 (2015)

16. R. Lorenzini, M. Agostini, F. Auriemma, L. Carraro, G. De Masi, A. Fassina, P. Franz, M. Gobbin, P. Innocente, M.E. Puiatti, P. Scarin, B. Zaniol and M. Zuin: “The isotope effect in the RFX-mod experiment” Nucl Fusion, **55**, 043012 (2015)

17. G. Spizzo, G. Pucella, O. Tudisco, M. Zuin, M. Agostini, E. Alessi, F. Auriemma, W. Bin, P. Buratti, L. Carraro, R. Cavazzana, G. Ciaccio, G. De Masi, B. Esposito, C. Galperti, S. Garavaglia, G. Granucci, M. Marinucci, L. Marrelli, E. Martines, C. Mazzotta, D. Minelli, A. Moro, M.E. Puiatti, P. Scarin, C. Sozzi, M. Spolaore, O. Schmitz, N. Vianello and R.B. White: “Density limit studies in the tokamak and the reversed-field pinch” Nucl Fusion, **55**, 043007 (2015)

18. P. Zanca, R. Paccagnella, C. Finotti, A. Fassina, G. Manduchi, R. Cavazzana, P. Franz, C. Piron and L. Piron: “An active feedback recovery technique from disruption events induced by $m = 2$, $n = 1$ tearing modes in ohmically heated tokamak plasmas” Nucl Fusion, **55**, 043020 (2015)

19. G. Albani, G. Croci, C. Cazzaniga, M. Cavenago, G. Claps, A. Muraro, F. Murtas, R. Pasqualotto, E. Perelli Cippo, M. Rebai: “Neutron beam imaging with GEM detectors” J Inst, **10**, C0140040, April (2015)

20. Murari, E. Peluso, M. Gelfusa, M. Lungaroni, P. Gaudio: “How to Handle Error Bars in Symbolic Regression for Data Mining in Scientific Applications”, Statistical Learning and Data Sciences, Volume 9047 of the series Lecture Notes in Computer Science, 347-355 April (2015)

21. C. Angioni, F. J. Casson, P. Mantica, T. Pütterich, M. Valisa, E. A. Belli, R. Bilato, C. Giroud, P. Helander and JET Contributors: “The impact of poloidal asymmetries on tungsten transport in the core of JET H-mode plasmas” Phys. Plasmas **22**, 055902 (2015)
22. Italo Predebon and P. Xanthopoulos: “Ion temperature gradient turbulence in helical and axisymmetric RFP plasmas” Phys. Plasmas **22**, 052308 (2015)

23. E. Peluso, M. Gelfusa, A. Murari, I. Lupelli, P. Gaudio: “A Statistical Analysis of the Scaling Laws for the Confinement Time Distinguishing between Core and Edge” Physics Procedia, **62**, 113–117 (2015)

24. G. Croci, C. Cazzaniga, G. Albani, A. Muraro, G. Claps, M. Cavenago, G. Grosso, F. Murtas, R. Pasqualotto, E. Perelli Cippo, M. Rebai, M. Tardocchi, G. Gorini: “Performance of a Medium-Size Area nGEM Detector for Neutron Beam Diagnostics” Physics Procedia, 62,118-123 (2015)

25. M. Spolaore, M. Agostini, B. Momo, C. Rea, N. Vianello, M. Zuin, R. Cavazzana, G. De Masi, P. Innocente, L. Marrelli, E. Martines, A. Mazzi, M.E. Puiatti, S. Spagnolo, G. Spizzo, P. Scarin, D. Terranova and P. Zanca: “Turbulent electromagnetic filaments in actively modulated toroidal plasma edge” Nucl Fusion, **55**, 063041, (2015)

26. Murari A., J. Vega, D. Mazon, T. Courregelongu, ·JET-EFDA Contributors: “Preliminary numerical investigations of conformal predictors based on fuzzy logic classifiers” Ann Math Artif Intell, **74,** Issue 1-2, 155-180 June (2015)

27. Vega I., A. Murari, S. Dormido-Canto, T. Cruz: “Simulations of Nucl Fusion diagnostics based on projections with Venn predictors and context drift detection” Ann Math Artif Intell, **74,** 223–244 (2015)

28. G. Giruzzi, J.F. Artaud, M. Baruzzo, T. Bolzonella, E. Fable, L. Garzotti, I. Ivanova-Stanik, R. Kemp, D.B. King, M. Schneider, R. Stankiewicz, W. Stępniewski, P. Vincenzi, D. Ward and R. Zagórski: “Modelling of pulsed and steady-state DEMO scenarios” Nucl Fusion, **55**, 073002, (2015)

29. Murari A., E. Peluso, M. Gelfusa, I. Lupelli and P. Gaudio: “A new approach to the formulation and validation of scaling expressions for plasma confinement in tokamaks” Nucl Fusion, **55**, 073009 (2015)

30. Umberto Rosani, Elena Tarricone, Paola Venier , Paola Brun, Velika Deligianni, Matteo Zuin, Emilio Martines, Andrea Leonardi , Paola Brun: “Atmospheric-Pressure Cold Plasma Induces Transcriptional Changes in Ex Vivo Human Corneas” PLOS ONE, **10** Issue: 7 e0133173 JUL (2015)

31. V. Toigo, D. Boilson, T. Bonicelli, R. Piovan, M. Hanada, A. Chakraborty, G. Agarici, V. Antoni, U. Baruah, M. Bigi, G. Chitarin, S. Dal Bello, H. Decamps, J. Graceffa, M. Kashiwagi, R. Hemsworth, A. Luchetta, D. Marcuzzi, A. Masiello, F. Paolucci, R. Pasqualotto, H. Patel, N. Pomaro, C. Rotti, G. Serianni, M. Simon, M. Singh, N.P. Singh, L. Svensson, H. Tobari, K. Watanabe, P. Zaccaria, P.

Agostinetti, M. Agostini, R. Andreani, D. Aprile, M. Bandyopadhyay, M. Barbisan, M. Battistella, P. Bettini, P. Blatchford, M. Boldrin, F. Bonomo, E. Bragulat, M. Brombin, M. Cavenago, B. Chuilon, A. Coniglio, G. Croci, M. Dalla Palma, M. D'Arienzo, R. Dave, H. P. L De Esch, A. De Lorenzi, M. De Muri, R. Delogu, H. Dhola, U. Fantz, F. Fellin, L. Fellin, A. Ferro, A. Fiorentin, N. Fonnesu, P. Franzen, M. Fröschle, E. Gaio, G. Gambetta, G. Gomez, F. Gnesotto, G. Gorini, L. Grando, V. Gupta, D. Gutierrez, S. Hanke, C. Hardie, B. Heinemann, A. Kojima, W. Kraus, T. Maeshima, A. Maistrello, G. Manduchi, N. Marconato, G. Mico, J. F. Moreno, M. Moresco, A. Muraro, V. Muvvala, R. Nocentini, E. Ocello, S. Ochoa, D. Parmar, A. Patel, M. Pavei, S. Peruzzo, N. Pilan, V. Pilard, M. Recchia, R. Riedl, A. Rizzolo, G. Roopesh, G. Rostagni, S. Sandri, E. Sartori, P. Sonato, A. Sottocornola, S. Spagnolo, M. Spolaore, C. Taliercio, M. Tardocchi, A. Thakkar, N. Umeda, M. Valente, P. Veltri, A. Yadav, H. Yamanaka, A. Zamengo, B. Zaniol, L. Zanotto and M. Zaupa: "Progress in the realization of the PRIMA neutral beam test facility" Nucl Fusion, **55**, 083025, (2015)

32. G Rubino, D Borgogno, M Veranda, D Bonfiglio, S Cappello and D Grasso: "Detection of magnetic barriers in a chaotic domain: first application of finite time Lyapunov exponent method to a magnetic confinement configuration" Plasma Phys Contr F, **57** 085004 (2015)

33. B. Viola, V. Pericoli Ridolfini , N. Visona, G. Corrigan, D. Harting, G. Maddaluno, R. Zagórski: "Analysis of FAST snowflake divertor by EDGE2D/EIRENE" J Nucl Mater, **463**, 1205–1208, August (2015)

34. D A Ryan, Y Q Liu, A Kirk, W Suttrop, B Dudson, M Dunne, R Fischer, J C Fuchs, M Garcia-Munoz, B Kurzan, P Piovesan, M Reinke, M Willensdorfer, the ASDEX-Upgrade team and the EUROfusion MST1 team: "Toroidal modelling of resonant magnetic perturbations response in ASDEX-Upgrade: coupling between field pitch aligned response and kink amplification" Plasma Phys Contr F **57**, 095008 (2015)

35. H.P.L. de Esch, M. Kashiwagi, M. Taniguchi, T. Inoue, G. Serianni, P. Agostinetti, G. Chitarin, N. Marconato, E. Sartori, P. Sonato, P. Veltri, N. Pilan, D. Aprile, N. Fonnesu, V. Antoni, M.J. Singh, R.S. Hemsworth and M. Cavenago: "Physics design of the HNB accelerator for ITER" Nucl Fusion, **55**, 096001, (2015)

36. M Gobbin, P Franz, F Auriemma, R Lorenzini and L Marrelli: "Spontaneous versus induced hydrogen and deuterium helical shaped plasmas with electron internal transport barriers" *Plasma Phys. Control. Fusion* **57** 095004 (2015)

37. Simona Corrao, Elena Tarricone, Andrea Leonardi, Brun Paola, Matteo Zuin, Emilio Martines: "In vitro and in vivo effects of helium cold plasma on wound healing**"** Italian Journal of Anatomy and Embryology**, [S.l.], p. 136, Sep. (2015)**

38. Ondrej Kudlacek, Paolo Zanca, Claudio Finotti, Giuseppe Marchiori, Roberto Cavazzana and Lionello Marrelli: "Real time measurement of plasma macroscopic parameters on RFX-mod using a limited set of sensors" Phys. Plasmas **22**, 102503 (2015)

39. G. Ciaccio, O. Schmitz, G. Spizzo, S. S. Abdullaev, T. E. Evans, H. Frerichs and R. B. White: "Helical modulation of the electrostatic plasma potential due to edge magnetic islands induced by resonant magnetic perturbation fields at TEXTOR" Phys. Plasmas **22**, 102516 (2015)

40. H.W. Müller, M. Bernert, D. Carralero, A. Kallenbach, B. Kurzan, A. Scarabosio, B. Sieglin, Tophøj I., N. Vianello, E. Wolfrum, ASDEX Upgrade Team: "Far scrape-off layer particle and heat fluxes in high density – High power scenarios" J Nucl Mater, **463,** 739–743 (2015)

41. J.S. Sarff, A.F. Almagri, J.K. Anderson, M. Borchardt, W. Cappechi, D. Carmody, K. Caspary, B.E. Chapman, D.J. Den Hartog, J. Duff, S. Eilerman, A. Falkowski, C.B. Forest, M. Galante, J.A. Goetz, D.J. Holly, J. Koliner, S. Kumar, J.D. Lee, D. Liu, K.J. McCollam, M. McGarry, V.V. Mirnov, L. Morton, S. Munaretto, M.D. Nornberg, P.D. Nonn, S.P. Oliva, E. Parke, M.J. Pueschel, J.A. Reusch, J. Sauppe, A. Seltzman, C.R. Sovinec, D. Stone, D. Theucks, M. Thomas, J. Triana, P.W. Terry, J. Waksman, G.C. Whelan, D.L. Brower, W.X. Ding, L. Lin, D.R. Demers, P. Fimognari, J. Titus, F. Auriemma, S. Cappello, P. Franz, P. Innocente, R. Lorenzini, E. Martines, B. Momo, P. Piovesan, M. Puiatti, M. Spolaore, D. Terranova, P. Zanca, V.I. Davydenko, P. Deichuli, A.A. Ivanov, S. Polosatkin, N.V. Stupishin, D. Spong, D. Craig, H. Stephens, R.W. Harvey, M. Cianciosa, J.D. Hanson, B.N. Breizman, M. Li and L.J. Zheng: "Overview of results from the MST reversed field pinch experiment" Nucl Fusion, **55**, 104006, (2015)

42. P.W. Terry, D. Carmody, H. Doerk, W. Guttenfelder, D.R. Hatch, C.C. Hegna, A. Ishizawa, F. Jenko, W.M. Nevins, I. Predebon, M.J. Pueschel, J.S. Sarff and G.G. Whelan: "Overview of gyrokinetic studies of finite-β microturbulence" Nucl Fusion, 55, 104011, (2015)

43. M.E. Puiatti, S. Dal Bello, L. Marrelli, P. Martin, P. Agostinetti, M. Agostini, V. Antoni, F. Auriemma, M. Barbisan, T. Barbui, M. Baruzzo, M. Battistella, F. Belli, P. Bettini, M. Bigi, R. Bilel, M. Boldrin, T. Bolzonella, D. Bonfiglio, M. Brombin, A. Buffa, A. Canton, S. Cappello, L. Carraro, R. Cavazzana, D. Cester, L. Chacon, B.E. Chapman, G. Chitarin, G. Ciaccio, W.A. Cooper, M. Dalla Palma, S. Deambrosis, R. Delogu, A. De Lorenzi, G. De Masi, J.Q. Dong, D.F. Escande, B. Esposito, A. Fassina, F Fellin, A. Ferro, C. Finotti, P. Franz, L. Frassinetti, M. Furno Palumbo, E. Gaio, F. Ghezzi, L. Giudicotti, F. Gnesotto, M. Gobbin, W.A. Gonzales, L. Grando, S.C. Guo, J.D. Hanson, S.P. Hirshman, P. Innocente, J.L. Jackson, S. Kiyama, M. Komm, L. Laguardia, C. Li, S.F. Liu, Y.Q. Liu, R. Lorenzini, T.C. Luce, A. Luchetta, A. Maistrello, G. Manduchi, D.K. Mansfield, G. Marchiori, N. Marconato, D. Marocco, D. Marcuzzi, E. Martines, S. Martini, G. Matsunaga, G. Mazzitelli, E. Miorin, B. Momo, M. Moresco, M. Okabayashi, E. Olofsson, R. Paccagnella, N. Patel, M. Pavei, S. Peruzzo, N. Pilan, L. Pigatto, R. Piovan, P. Piovesan, C. Piron, L. Piron, I. Predebon, C. Rea, M. Recchia, V. Rigato, A. Rizzolo, A.L. Roquemore, G. Rostagni, C Ruset, A. Ruzzon, L. Sajò-Bohus, H. Sakakita, R. Sanchez, J.S. Sarff, E. Sartori, F. Sattin, A. Scaggion, P. Scarin, O. Schmitz, P. Sonato, E. Spada, S. Spagnolo, M. Spolaore, D.A. Spong, G. Spizzo, L. Stevanato, M. Takechi, C. Taliercio, D. Terranova, G.L. Trevisan, G. Urso, M. Valente, M. Valisa, M. Veranda, N. Vianello, G. Viesti, F. Villone, P. Vincenzi, N. Visona', Z.R. Wang, R.B. White, P. Xanthopoulos, X.Y. Xu, V. Yanovskiy, A. Zamengo, P. Zanca, B. Zaniol, L. Zanotto, E. Zilli and M. Zuin: "Overview of the

RFX-mod contribution to the international Fusion Science Program " Nucl Fusion, 55, 104012, (2015)

44. G. De Tommasi, G. Manduchi, D.G. Muir, S. Ide, O. Naito, H. Urano, S. Clement-Lorenzo, N. Nakajima, T. Ozeki, F. Sartori: "Current status of the European contribution to the Remote Data Access System of the ITER Remote Experimentation Centre" Fus Eng and Design **96-97**, 769–771, October (2015)

45. Fernanda G. Rimini, Diogo Alves, Gilles Arnoux, Matteo Baruzzo, Eva Belonohy, Ivo Carvalho, Robert Felton, Emmanuel Joffrin, Peter Lomas, Paul McCullen, Andre Neto, Isabel Nunes, Cedric Reux, Adam Stephen, Daniel Valcarcel, Sven Wiesen, JET EFDA contributors: "The development of safe high current operation in JET-ILW" Fus Eng and Design, **96-97**, 165–170, October (2015)

46. Muraro A., G. Croci, G. Albani, C. Cazzaniga, G. Claps, M. Cavenago, G. Grosso, M. Dalla Palma, M. Fincato, F. Murtas, R. Pasqualotto, E. Perelli Cippo, M. Rebai, M. Tollin, M. Tardocchi, G. Gorini: "Status of the CNESM diagnostic for SPIDER" Fus Eng and Design, **96-97**, 311-314, October (2015)

47. G. Manduchi, A. Luchetta, C. Taliercio, A. Neto, F. Sartori, G. De Tommasi: "Integration of Simulink, MARTe and MDSplus for rapid development of real-time applications" Fus Eng and Design, **96-97**, 645–648, October (2015)

48. N. Marconato , P. Agostinetti, G. Chitarin: "Magnetic and thermo-structural design optimization of the Plasma Grid for the MITICA neutral beam injector" Fus Eng and Design, **96-97**, 517-521, October (2015)

49. L. Pigatto, P. Bettini, T. Bolzonella, G. Marchiori, F. Villone: "Optimal strategies for real-time sparse actuator compensation in RFX-mod MHD control operations" Fus Eng and Design, **96-97**, 690–693, October (2015)

50. Pierluigi Zaccaria , Matteo Valente, Wladi Rigato, Samuele Dal Bello, Diego Marcuzzi, Fabio Degli Agostini, Federico Rossetto, Marco Tollin, Antonio Masiello, Giorgio Corniani, Matteo Badalocchi, Riccardo Bettero, Dario Rizzetto: "Manufacturing, assembly and tests of SPIDER Vacuum Vessel to develop and test a prototype of ITER neutral beam ion source" Fus Eng and Design, **96-97**, 383–387, October (2015)

51. Marco Boldrin , Luca Grando, Alberto Pesce, Mauro Recchia, Vanni Toigo, Daniel Gutierrez, Muriel Simon, Giovanni Faoro, Andrea Guion, Edoardo Maggiora, Diego Pedron, Anita Roman, Hans Decamps: "The 100 kV Faraday cage (High Voltage Deck) for the SPIDER experiment" Fus Eng and Design **96-97**, 411–415, October (2015)

52. Michela De Muri, Marco Cavenago, Gianluigi Serianni, Pierluigi Veltri, Marco Bigi, Roberto Pasqualotto, Marco Barbisan, Mauro Recchia, Barbara Zaniol, Timour Kulevoy, Sergey Petrenko, Lucio Baseggio, Vannino Cervaro, Fabio Degli Agostini, Luca Franchin, Bruno Laterza, Alessandro Minarello, Federico Rossetto,

Manuele Sattin, Simone Zucchetti: “Installation and first operation of the negative ion optimization experiment” Fus Eng and Design, **96-97**, 249–252, October (2015)

53. P. Agostinetti , M. Dalla Palma, F. Degli Agostini, D. Marcuzzi, A. Rizzolo, F. Rossetto, P. Sonato, P. Zaccaria: “Vacuum Tight Threaded Junctions (VTTJ): A new solution for reliable heterogeneous junctions in ITER” Fus Eng and Design, **96-97**, 48–55, October (2015)

54. S. Mastrostefano , P. Bettini, T. Bolzonella, M. Furno Palumbo, Y.Q. Liu, G. Matsunaga, R. Specogna, M. Takechi, F. Villone: “Three-dimensional analysis of JT-60SA conducting structures in view of RWM control” Fus Eng and Design, **96-97**, 659–663, October (2015)

55. Alberto Ferro, Elena Gaio, Luca Novello, Makoto Matsukawa, Katsuhiro Shimada, Yoichi Kawamata, Manabu Takechi: “Reference design of the power supply system for the resistive-wall-mode control in JT-60SA” Fus Eng and Design, **98–99**, 1053-1057, October (2015)

56. Marco Bigi , Luigi Rinaldi, Muriel Simon, Luca Sita, Giuseppe Taddia, Saverino Carrozza, Hans Decamps, Adriano Luchetta, Abdelraouf Meddour, Modesto Moressa, Cristiano Morri, Antonio Musile Tanzi, Mauro Recchia, Uwe Wagner, Andrea Zamengo, Vanni Toigo: “Design, manufacture and factory testing of the Ion Source and Extraction Power Supplies for the SPIDER experiment” Fus Eng and Design, **96-97**, 405–410, October (2015)

57. Adriano Luchetta , Gabriele Manduchi, Cesare Taliercio, Francesco Paolucci, Filippo Sartori, Lennart Svensson, Carmelo Vincenzo Labate, Mauro Breda, Roberto Capobianco, Federico Molon, Modesto Moressa, Paola Simionato, Enrico Zampiva, Paolo Barbato, Sandro Polato: “Control and data acquisition of the ITER full-scale ion source for the neutral beam test facility” Fus Eng and Design, **96-97**, 512–516, October (2015)

58. Francesco Fellin, Marco Boldrin, Pierluigi Zaccaria, Piero Agostinetti, Manuela Battistella, Marco Bigi, Samuele Dal Bello, Mauro Dalla Palma, Aldo Fiorentin, Adriano Luchetta, Alberto Maistrello, Diego Marcuzzi, Edoardo Ocello, Roberto Pasqualotto, Mauro Pavei, Nicola Pomaro, Andrea Rizzolo, Vanni Toigo, Matteo Valente, Loris Zanotto, Luca Calore, Federico Caon, Massimo Caon, Michele Fincato, Gabriele Lazzaro, Michele Visentin, Enrico Zampiva, Simone Zucchetti: “Plant integration of MITICA and SPIDER experiments with auxiliary plants and buildings on PRIMA site” Fus Eng and Design, **96-97**, 257–260, October (2015)

59. N. Pilan, D. Marcuzzi, A. Rizzolo, L. Grando, G. Gambetta, S. Dalla Rosa,V. Kraemer, T. Quirmbach, G. Chitarin, R. Gobbo, G. Pesavento, A. De Lorenzi, L. Lotto, R. Rizzieri, M. Fincatoa, L. Romanato, L. Trevisan, V. Cervaro, L. Franchin: “Electrical and structural R&D activities on high voltage dc solidinsulator in vacuum” Fus Eng and Design **96–97**, 563–567, (2015)

60. M. Dalla Palma, E. Sartori, P. Blatchford, B. Chuilon, J. Graceffa, S. Hanke, C. Hardie, A. Masiello, A. Muraro, S. Ochoa, D. Shah, P. Veltri, P. Zaccaria, M.

Zaupa: “Design and R&D for manufacturing the beamline components of MITICA and ITER HNBs” Fus Eng and Design, **96-97,** 557–562, , October (2015)

61. Paolo Bettini, Luca Grando, Giuseppe Marchiori: “Feasibility study of a local active correction system of magnetic field errors in RFX-mod” Fus Eng and Design, **96-97**, 649–653, October (2015)

62. Philippe Moreau, Pascal Spuig, Alain Le-luyer, Philippe Malard, Bruno Cantone, Patrick Pastor, François Saint-Laurent, George Vayakis, Dominique Delhom, Shakeib Arshad, Jonathan Lister, Matthieu Toussaint, Philippe Marmillod, Duccio Testa, Christian Schlatter, Simone Peruzzo: “Development of the ITER Continuous External Rogowski: From conceptual design to final design” Fus Eng and Design, **96-97**, 878–881, October (2015)

63. Paolo Bettini , Maurizio Furno Palumbo, Ruben Specogna: “A boundary element method for eddy-current problems in fusion devices” Fus Eng and Design, **96-97**, 620–623, October (2015)

64. Nicola Pomaro, Marco Boldrin, Gabriele Lazzaro: “The earthing system of the PRIMA Neutral Beam Test Facility based on the Mesh Common Bonding Network topology” Fus Eng and Design, **96-97**, 334–337, October (2015)

65. Chiara Bustreo, Tommaso Bolzonella, Giuseppe Zollino: “The Monte Carlo approach to the economics of a DEMO-like power plant” Fus Eng and Design, **98–99**, 2108–211, October (2015)

66. Luca Novello , Olivier Baulaigue, Alberto Coletti, Nicolas Dumas, Alberto Ferro, Elena Gaio, Alessandro Lampasi, Alberto Maistrello, Makoto Matsukawa, Katsuhiro Shimada, Kunihito Yamauchi, Pietro Zito: “Overview of the new Magnet Power Supply Systems of JT-60SA procured by EU” Fus Eng and Design, **98–99**, 1122-1126, October (2015)

67. C. Finotti, E. Gaio, I. Song, J. Tao and I. Benfatto. “Improvement of the dynamic response of the ITER Reactive Power Compensation system” Fus Eng and Design, **98–99**, 1058–1062, (2015)

68. C. Rea, N. Vianello, M. Agostini, R. Cavazzana, G. De Masi, E. Martines, B. Momo, P. Scarin, S. Spagnolo, G. Spizzo, M. Spolaore and M. Zuin: “Comparative studies of electrostatic turbulence induced transport in presence of resonant magnetic perturbations in RFX-mod” Nucl Fusion, **55**, 113021, (2015)

69. P. Vincenzi, F. Koechl, L. Garzotti, D. B. King, E. Tindale, T. Bolzonella, P. T. Lang, B. Pegourié, M. Romanelli and R. Wenninger: “Fuelling and density control for DEMO” Nucl Fusion, **55**, 113028 (2015)

70. F. Ghezzi, L. Laguardia, R. Caniello, A. Canton, S. Dal Bello, B. Rais, M. Anderle: “XPS, SIMS and FTIR-ATR characterization of boronized graphite from the thermonuclear plasma device RFX-mod” Appl Surf Sci, **354**, Part B, 1, 408–419, November (2015)

71. L Giudicotti and R Pasqualotto: “On the calibration of polarimetric Thomson scattering by Raman polarimetry” Plasma Phys Contr F **57**, 125015 (2015)

72. B Cannas, P C de Vries, A Fanni, A Murari, A Pau, G Sias and JET Contributors: “Automatic disruption classification in JET with the ITER-like wall” Plasma Phys Contr F, **57**, 125003 (2015)

73. E. Sartori, G. Serianni, S. Dal Bello: “Simulation of the gas density distribution in the large vacuum system of a fusion-relevant particle accelerator at different scales” Vacuum, **122**, Part B, 275–285, December (2015)

74. L. A. Poggi, A. Malizia, J. F. Ciparisse, M. Gelfusa, A. Murari, S. Pierdiluca, E. Lo Re, P. Gaudio: “First Experimental Campaign to Demonstrate STARDUST-Upgrade Facility Diagnostics Capability to Investigate LOVA Conditions” J Fusion Energ, **34**, Issue 6, 1320-1330 December (2015)

8.2. *Conference proceedings*

REHVA Annual Conference "Advanced HVAC and Natural Gas Technologies"
06-09 May 2015 / Riga / Latvia

Francesco Fellin, Vanni Antoni, Sergio Bobbo, Lorenzo Fellin, Cesare Pagura, Martina Spolaore, Abramo Pellizzon
“Energy Costs Division and Plant Modification in a Large Research Complex: the Experience of Padova National Research Council (CNR) Area”

IEEE 15th International Conference on Environment and Electrical Engineering (EEEIC), Rome, Italy 10-13 June 2015

Loris Zanotto, Claudio Finotti, Vanni Toigo
“Overview of the Toroidal Power Supply system of RFX-mod after ten years of operation”
Proceedings of 2015 EEEIC, Rome, Italy 10-13 June 2015, pages 926 - 931

42nd EPS Conference on Plasma Physics, June 22-26 2015, Lisbon, Portugal

P.Mantica, F.J.Casson, M.Valisa, C.Angioni, R.Bilato, E.Belonohy, C.Giroud, M.Goniche, N.Hawkes, E. Lerche and JET contributors
Progress in understanding W control using ICRH in the JET-ILW tokamak
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P1.101

D. Carralero, H. J. Sun, S. A. Artene, P. Manz, H. W. Müller, M. Groth, M. Komm, J. Adamek, L. Aho-Mantila, G. Birkenmeier, M. Brix, U. Stroth, N. Vianello, E. Viezzer, M. Wischmeier, E. Wolfrum, ASDEX Upgrade Team, COMPASS Team and JET Contributors
“Towards a general scaling of the Scrape-off Layer density width”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, O2.106

M. Spolaore1, K. Kovařík, J. Stöckel, J. Adamek, I. Ďuran, M. Komm, E. Martines, J. Seidl, N. Vianello and COMPASS Team
"ELM and inter-ELM electromagnetic filaments in the COMPASS Scrape Off Layer"
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.107

R. Wenninger, R. Kemp, F. Maviglia, H. Zohm, R. Albanese, R. Ambrosino, F. Arbeiter, J. Aubert, C. Bachmann, W. Biel, E. Fable, G. Federici, J. Garcia, A. Loarte, Y. Martin, T. Pütterich, C. Reux, B. Sieglin, P. Vincenzi
"DEMO Exhaust Challenges Beyond ITER"
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal P4.110

B. Esposito, D. Carnevale, J.R. Martin-Solis, L. Boncagni, Z. Popovic, F. Causa, M. Agostini, E. Alessi, G. Apruzzese, W. Bin, P. Buratti, C. Cianfarani, R. De Angelis1, S. Galeani, C. Galperti, S. Garavaglia, M. Gospodarczyk, A. Grosso, G. Granucci, G. Maddaluno, D. Marocco, C. Mazzotta, L. Panaccione, A. Pensa, V. Piergotti, S. Podda, G. Pucella, G. Ramogida, M. Riva, G. Rocchi, M. Sassano, A. Sibio, C. Sozzi, B. Tilia, O. Tudisco, M. Valisa, ECRH team and FTU team
"Runaway electron experiments in FTU"
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.113

C.Mazzotta, M.E.Puiatti, L.Gabellieri, G.Apruzzese, V.Dolci, L.Carraro, F.Causa, A.Romano and the FTU team
"Neon transport simulation for highly peaked density FTU plasma"
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.114

D Frigione, C Challis, J Garcia, J Hobirk, B Alper, G Artaserse, C Angioni, M Baruzzo, E Belonohy, R Bilato, A Brett, P Buratti, I Carvallho, F Casson, L Frassinetti, L Garzotti, E Giovannozzi, D Grist, NC Hawkes, E Lerche, J Mailloux, P Mantica, M Maslov, J Morris, G Pucella, E Rachlew, M Reich, F Rimini, ACC Sips, MF Stamp, P Tamain, M Tsalas, M Valisa, H Weisen and JET contributors"
"Overview of hybrid development in JET with ITER-Like Wall
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P2.116

P. Zanca, M. Okabayashi, R. Paccagnella, E.J. Strait, A.M. Garofalo, J.M. Hanson, Y. In, R.J. La Haye, L. Marrelli, P. Martin, P. Piovesan, C. Piron, L. Piron, D. Shiraki, F.A. Volpe, and the DIII-D and RFX-mod Teams
"Avoidance of m=2, n=1 tearing mode wall-locking by torque-balance control with magnetic feedback in DIII-D and RFX-mod"
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P5.118

F. Felici, C.J. Rapson, W. Treutterer, L. Giannone, E. Maljaars, H. van den Brand, M. Reich, O. Sauter, A. Teplukhina, D. Kim, P. Piovesan, C. Piron, L. Barrera, M. Willensdorfer, A. Bock, E. Fable, B. Geiger, G. Tardini
"Real-time plasma profile state reconstruction on ASDEX-Upgrade"
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, O4.127

R. Aledda, B. Cannas, A. Fanni, A Murari, A. Pau, G. Sias, the ASDEX Upgrade Team, the JET Contributors and the EUROfusion MST1 Team
"A comparative multivariate analysis of disruption classes between JET and AUG"
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P2.137

C. Piron, F. Felici, D. Kim, C.J. Rapson, M. Reich, O. Sauter, T. Goodman, W. Treutterer, H. van den Brand, I. Chapman, the ASDEX Upgrade Team, C. Finotti, G. Manduchi, G.Marchiori, L. Marrelli, O. Kudlacek, P. Piovesan, C. Taliercio, the RFX-mod Team and the EUROfusion MST1 Team
“Real-time simulation of internal profiles in the presence of sawteeth using the RAPTOR code and applications to ASDEX Upgrade and RFX-mod”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P1.145

S. Mastrostefano, P. Bettini, T. Bolzonella, V. Igochine, Y. Liu, F. Villone and D. Yadykin
“MHD modes analysis in high-beta ASDEX Upgrade configurations including a 3D model of conductors”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P1.149

P. Vincenzi, S. Murakami, M. Osakabe, R. Seki, M. Yokoyama, T. Bolzonella
“NBI modelling by upgraded TASK3D-a code in preparation of LHD deuterium campaigns”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P1.150

S. Costea, J.J. Rasmussen , N. Vianello , H.W. Müller, V. Naulin, R. Schrittwieser, A.H. Nielsen, J. Madsen, C. Ionita, M. Spolaore, D. Carralero, F. Mehlmann
“Investigation on radial transport of perpendicular momentum in the SOL of AUG during L-I-H transition”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P1.151

B. Zaniol, T. Bolzonella, R. Cavazzana, P. Innocente, P. Zanca and M. Zuin
“Studies on RFX-mod discharges with spontaneous rotation”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.153

O. Kudlacek, R. Cavazzana, C. Finotti, G. Marchiori, L. Marrelli, P.Piovesan, P. Zanca, M. Zuin
“H-mode accessibility in ohmic discharges on RFX-mod”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.154

F. Auriemma, F. Sattin, G. Urso, D. F. Escande
“Exploiting genetic algorithms in transport modelling in RFX-mod”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.157

M. Zuin, L. Stevanato, E. Martines, F. Auriemma, B. Momo, R. Cavazzana, G. De Masi, W. Gonzalez, R. Lorenzini, P. Scarin, S. Spagnolo, M. Spolaore, N. Vianello, W. Schneider, D. Cester, G. Nebbia, L. Sajo-Bohus, G. Viesti
“Characterization of Particle Dynamics and Magnetic Reconnection in the RFX-mod Plasmas”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.158

D. Abate, L. Barbato, C. Finotti, G. Marchiori, N. Marconato, S. Mastrostefano, F. Villone
“Analysis of Vertical Stability and Resistive Wall Modes in RFX-mod Tokamak Discharges Including 3D Effects”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.159

B. Liu, M. Spolaore, U. Losada, A. Alonso, M.A. Pedrosa, T. Estrada, B.Ph. van

Milligen, N. Vianello, C. Hidalgo and the TJ-II team
“Electromagnetic turbulence measurements during the L-H transition in the TJ-II stellarator”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P4.166

L.A. Poggi, A. Malizia, J.F. Ciparisse, M. Gelfusa, A. Murari, S. Pierdiluca, E. Lo Re, and P. Gaudio
“Experimental campaign to test the capability of STARDUST-Upgrade diagnostics to investigate LOVA and LOCA conditions”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P2.176

V.V. Yanovskiy and R. Paccagnella
“Plasma surface currents in the presence of a resistive wall and their connection to Halo currents during disruptions in tokamaks”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P1.181

Y. Zhang, F. Auriemma, A. Fassina, D. Lopez-Bruna, R. Lorenzini, E. Martines, B. Momo, F. Sattin and D. Terranova
“Multiple domain scheme for heat transport analysis in plasmas with magnetic islands: a first study”
42nd EPS Conference on Plasma Physics, June 2015 22-26 Lisbon, Portugal, P1.182

FISMAT 2015, Italian National Conference on Condensed Matter Physics, Palermo, Italy September 28 - October 2, 2015

T. Bolzonella
“Advanced active feedback schemes for MHD studies in hot magnetized plasmas”
FISMAT 2015- Book of abstracts, 029, 2015

P. Vincenzi, T. Bolzonella
“Energetic neutral particle beam interaction with thermonuclear plasmas: from present day experiments”
FISMAT 2015- Book of abstracts, P203, 2015

Predebon I., P. Xantopoulos
“Microturbulence in helical and axisymmetric reversed field pinch plasmas”
FISMAT 2015- Book of abstracts, P153, 2015

S. Cappello, M. Veranda, D. Bonfiglio, Chacon, D. Escande, P. Franz, M. Gobbin, M.E. Puiatti and RFX team
“Macroscopic dynamics, optimization and transport barrier formation in Reversed Field Pinch plasmas”
FISMAT 2015- Book of abstracts, 024, 2015

D. Grasso, D. Bonfiglio, D. Borgogno, S. Cappello , G. Rubino , M. Veranda
“Transport processes in chaotic magnetic field configuration: the Quasi-Single-Helicity states in RFX-mod”
FISMAT 2015- Book of abstracts, 264, 2015

Massimo Nocente, F. Bonomo, U. Fantz, B. Heinemann, W. Kraus, R. Pasqualotto, M. Tardocchi, D. Wünderlich, G. Gorini
“Neutron emission from beam-target reactions studied at the ELISE neutral beam test

facility"
FISMAT 2015- Book of abstracts, 095, 2015

Fourth International Symposium On Negative Ions, Beams And Sources (Nibs 2014) Garching, Germany 6–10 October 2014

V. Antoni, P. Agostinetti, M. Brombin, V. Cervaro, R. Delogu, M. De Muri, D. Fasolo, L. Franchin, R. Ghiraldelli, K. Ikeda, M. Kisaki, F. Molon, A. Muraro, H. Nakano, R. Pasqualotto, G. Serianni, Y. Takeiri, M. Tollin, K. Tsumori and P. Veltri
"Design, installation, commissioning and operation of a beamlet monitor in the negative ion beam test stand at NIFS "
(Nibs 2014) AIP Conf. Proc. 1655, 060005 (2015)

P. Veltri, M. Cavenago and C. Baltador
"Design of the new extraction grid for the NIO1 negative ion source"
(Nibs 2014) AIP Conf. Proc. 1655, 050009 (2015)

B. Zaniol, M. Barbisan, M. Cavenago, M. De Muri, A. Mimo, R. Pasqualotto and G. Serianni
"NIO1 diagnostics" (Nibs 2014)
AIP Conf. Proc. 1655, 060010 (2015)

N. Fonnesu, P. Agostinetti, G. Serianni, M. Kisaki and P. Veltri
"A multi-beamlet analysis of the MITICA accelerator"
(Nibs 2014) AIP Conf. Proc. 1655, 050008 (2015)

F. Bonomo, B. Ruf, M. Barbisan, S. Cristofaro, L. Schiesko, U. Fantz, P. Franzen, R. Pasqualotto, R. Riedl, G. Serianni, D. Wünderlich and the NNBI-Team
"BATMAN beam properties characterization by the beam emission spectroscopy diagnostic"
(Nibs 2014) AIP Conf. Proc. 1655, 060009 (2015)

P. Franzen, D. Wünderlich, R. Riedl, R. Nocentini, F. Bonomo, U. Fantz, M. Fröschle, B. Heinemann, C. Martens, W. Kraus, A. Pimazzoni, B. Ruf and NNBI Team
"Status of the ELISE test facility"
(Nibs 2014) AIP Conf. Proc. 1655, 060001 (2015)

G. Chitarin, P. Agostinetti, D. Aprile, N. Marconato and P. Veltri
"Improvements of the magnetic field design for SPIDER and MITICA negative ion beam sources"
(Nibs 2014) AIP Conf. Proc. 1655, 040008 (2015)

G. Serianni, F. Bonomo, M. Brombin, V. Cervaro, G. Chitarin, S. Cristofaro, R. Delogu, M. De Muri, D. Fasolo, N. Fonnesu, L. Franchin, P. Franzen, R. Ghiraldelli, F. Molon, A. Muraro, R. Pasqualotto, B. Ruf, L. Schiesko, M. Tollin and P. Veltri
"Negative ion beam characterisation in BATMAN by mini-STRIKE: Improved design and new measurements"
(Nibs 2014) AIP Conf. Proc. 1655, 060007 (2015)

R. Nocentini, F. Bonomo, A. Pimazzoni, U. Fantz, P. Franzen, M. Fröschle, B. Heinemann, R. Pasqualotto, R. Riedl, B. Ruf and D. Wünderlich
"Advanced ion beam calorimetry for the test facility ELISE"

(Nibs 2014) AIP Conf. Proc. 1655, 060006 (2015)

E. Sartori, P. Veltri, E. Dlougach, R. Hemsworth, G. Serianni and M. Singh
"Benchmark of numerical tools simulating beam propagation and secondary particles in ITER NBI"
(Nibs 2014) AIP Conf. Proc. 1655, 050006 (2015)

M. Cazzador, M. Cavenago, G. Serianni and P. Veltri
"Semi-analytical modeling of the NIO1 source"
(Nibs 2014) AIP Conf. Proc. 1655, 020014 (2015)

R. Pasqualotto, G. Serianni, I. Mario, P. Veltri, M. Zanini, V. Cervaro and D. Fasolo
"A wire calorimeter for the SPIDER beam: Experimental tests and feasibility study"
(Nibs 2014) AIP Conf. Proc. 1655, 060008 (2015)

P. Veltri, M. Cavenago, G. Chitarin, D. Marcuzzi, E. Sartori, G. Serianni and P. Sonato
"Electrostatic steering and beamlet aiming in large neutral beam injectors"
(Nibs 2014) AIP Conf. Proc. 1655, 050005 (2015)

***SPIE* 9643, Image and Signal Processing for Remote Sensing, October 15, 2015**

M. Gelfusa, A. Murar, A. Malizia, M. Lungaroni, E. Peluso, S. Parracino, S. Talebzadeh, J. Vega, P. Gaudio
"Advanced signal processing based on support vector regression for lidar applications"
Proc. SPIE 9643, Image and Signal Processing for Remote Sensing XXI, 96430E October 15, 2015 Conference Volume 9643

8.3. *Conference participation*

10th IAEA Technical Meeting on Control, Data Acquisition and Remote Participation for Fusion Research, Gujarat, India, 20-24 April 2015
Proceedings to be published in a special issue of Fusion Engineering and Design

G. Manduchi, T.W.Fredian, J. A. Stillerman, A. Neto, F. Sartori
"Fast development of real-time applications using MDSplus and MARTe frameworks"

G. Manduchi, A. Luchetta, C. Taliercio
"Integrating Supervision, Control and data Acquisition Ã¢Â□Â" The ITER Neutral Beam Test Facility experiment"

8.3.1.

26th IEEE Symposium on Fusion Engineering (SOFE) May 31-June 4, 2015, Austin, Texas USA

C. Finotti, E. Gaio, I. Benfatto, I. Song, J. Tao
"Continuous state space model of the ITER ac/dc converters for stability analysis of the Pulsed Power Electrical Network" SP12-46

E. Gaio, A. Ferro, L. Novello, M. Matsukawa

“Si-sic based switching power amplifier for MHD control in fusion experiments” SO13-5 **(invited)**

M. Brombin, R. Ghirardelli, F. Molon, N. Pomaro, G. Serianni, R. Pasqualotto
“Development of readout electronics for NIO1 thermocouples” SP2-2

A. Maistrello, E. Gaio, A. Ferro, F. Baldo, M. Perna, C. M. Panizza, S. D'Arrigo, M. Povolero, L. Novello, M. Matsukawa, K. Yamauchi:
“Installation, Commissioning and Acceptance Tests of the JT-60SA Quench Protection Circuit” SP12-45

S. Peruzzo, M. Brombin, M. Furno Palumbo, W. Gonzalez, N. Marconato, A. Rizzolo, S. Arshad, Y. Ma, G. Vayakis:
“ Progress in the design of the in-vessel magnetic pick-up coils for ITER” SP2-31

D. Marcuzzi, P. Agostinetti, M. Dalla Palma, M. De Muri, G. Chitarin, G. Gambetta, N. Marconato,R. Pasqualotto, M. Pavei, N. Pilan, A. Rizzolo, G. Serianni, V. Toigo, L. Trevisan, M. Visentin, P. Zaccaria, M. Zaupa, D. Boilson, J. Graceffa, R. S. Hemsworth, C. H. Choi, M. Marti, K. Roux, M. J. Singh, A. Masiello, M. Froeschle, B. Heinemann, R. Nocentini, R. Riedl, H. Tobari, H. P. L. de Esch,V. N. Muvvala:
“Final Design of the Beam Source for the MITICA Injector” SP13-60

O. Kudlacek, B. B. Carvalho, H. Figueiredo, H. Fernandes, G. Marchiori:
“Measurement of Plasma Centroid Position on ISTTOK Using Cleaned Magnetic Signals” SP2-21

J. Vega, A. Murari, S. Dormido-canto, R. Moreno, A. Pereira, G. A. Ratta, J. ET Contributors:
“Disruption Precursor Detection: Combining the Time and Frequency Domains” SO18-2 **(invited)**

H. Patel, C. Rotti, M. V. Nagaraju, A. Chakraborty, B. Schunke, J. Chareyre, D. Boilson, L. Svensson, M. Dalla Palma, P. Zaccaria, P. Roberto, E. Pfaff, J. Schafer, C. Eckardt:
“Manufacturing Experience of Beam Dump for Spider Facility” SO20-5

T. Franke, K. Avramidis, G. Granucci, J. Jelonnek, I. Jenkins, M. Kalsey, J. -M. Noterdaeme, A. Simonin, P. Sonato, M. Q. Tran:
“On the Present Status of the EU DEMO H&CD Systems, Technology, Functions and Mix” SP13-63

L. Novello, O. Baulaigue, A. Coletti, N. Dumas, A. Ferro, E. Gaio, A. Lampasi, A. Maistrello, M. Matsukawa, K. Shimada, K. Yamauchi, P. Zito:
“Advancement on the Procurement of Power Supply Systems for JT-60SA” SO13-7 **(invited)**

12th International Symposium on Fusion Nuclear Technology, Jeju Island, Korea, September 14-18, 2015
Proc. to be published on Fusion Engineering and Design, special issue (ISFNT-12)

M. Dalla Palma

“Hardening parameters for cyclic loadings of austenitic stainless steels 304L, 316L, 316L-N-04” P1.088,

N. Marconato, A. Rizzolo, M. Brombin, W. Gonzalez, S. Peruzzo, S. Arshad, Y. Ma and G. Vayakis
“Electro-mechanical connection system for ITER in-vessel magnetic sensors” -09, P1.184, 12th International Symposium on Fusion Nuclear Technology, Jeju Island, Korea, September 14-18, 2015,

E. Sartori, P. Veltri, M. Dalla Palma, P. Agostinetti, G. Serianni, R. Hemsworth, M. Singh
“Solutions to mitigate heat loads due to electrons on sensitive components of ITER HNB beamlines” -01, P2.015,

M. Dalla Palma, P. Blatchford, A. Muraro, E. Sartori, E. Delmas, J. Graceffa, R. Pasqualotto, L. Svensson, P. Zaccaria, G. Mico Montava
“Design of safety important feedthroughs for ITER HNB injectors” -06, P3.121,

M. Dalla Palma, R. Pasqualotto, N. Pomaro E. Delmas, L. Svensson, G. Mico Montava
“Design of thermocouple connectors for ITER HNB injectors”-06, P3.126,

Piero Agostinetti, G. Chitarin, Gambetta, D.
“Two key improvements to enhance the thermo-mechanic performances of accelerator grids for neutral beam injectors”-08, P3.156,

Nisarg Hasmukhbhai Patel, M. Dalla Palma, P. Sonato
“Vacuum boundary modifications of the RFX-mod machine”-06, P1.125,

ICIS 2015 - 16th International Conference on Ion Sources, August 23 - 28, 2015, New York
Proceedings will be published as a special issue of Rev Sci Instrum

Diego Marcuzzi, P. Agostinetti, M. Dalla Palma, M. De Muri, G. Chitarin, G. Gambetta, N. Marconato, R. Pasqualotto, M. Pavei, N. Pilan, A. Rizzolo, G. Serianni, V. Toigo, L. Trevisan, M. Visentin, P. Zaccaria, M. Zaupa, D. Boilson, J. Graceffa, R. S. Hemsworth, C. H. Choi, M. Marti, K. Roux, M. J. Singh, A. Masiello, M. Froeschle, B. Heinemann, R. Nocentini, R. Riedl, H. Tobari, H. P. L. de Esch, V. N. Muvvala: “Final Design of the Beam Source for the MITICA Injector”
Oral

P. Agostinetti, M. Giacomin, G. Serianni, P. Veltri, F. Bonomo and L. Schiesko
“Preliminary results concerning the simulation of beam profiles from extracted ion current distributions for mini-STRIKE”

E. Sartori, T. J. Maceina, P. Veltri, M. Cavenago and G. Serianni
“Simulation of space charge compensation in a multibeamlet negative ion beam”

P. Agostinetti, G. Serianni, P. Veltri
“Simulation of beam profiles from extracted ion current distributions for mini-STRIKE”

Rita S. Delogu, Carlo Poggi, Antonio Pimazzoni, G. Rossi, Gianluigi Serianni
“Analysis of diagnostic calorimeter data by the transfer function technique”

Simone Peruzzo, Vannino Cervaro, Mauro Dalla Palma, Rita Delogu, Michela De Muri, Daniele Fasolo, Luca Franchin, Roberto Pasqualotto, Antonio Pimazzoni, Andrea Rizzolo, Marco Tollin, and Gianluigi Serianni
“Castellated tiles as the beam-facing components for the diagnostic calorimeter of the negative ion source SPIDER”

E. Sartori, P. Veltri, M. Cavenago, G. Serianni
“Gas Flow and Density Profile in NIO1 Accelerator and Vessel”

E. Sartori, P. Veltri, M. Cavenago and G. Serianni
“Background gas density and beam losses in NIO1 beam source “

Gianluigi Serianni, Piero Agostinetti, Vanni Antoni, Carlo Baltador, Marco Cavenago, Giuseppe Chitarin, Nicolò Marconato, Roberto Pasqualotto, Emanuele Sartori, Vanni Toigo, Pierluigi Veltri
“Numerical Simulations of the First Operational Conditions of the Negative Ion Test Facility SPIDER”

C. Baltador, P.Veltri, P.Agostinetti, G. Chitarin, G.Serianni
“Multi-beamlet investigation of the deflection compensation methods of SPIDER beamlets”

Nicola Pilan, Vanni Antoni, Antonio De Lorenzi, Giuseppe Chitarin, Pierluigi Veltri and Emanuele Sartori
“Beam deflection applied to Neutral Beam Injection for a Fusion Devices reactor”

Silvia Spagnolo, Monica Spolaore, Mauro Dalla Palma, Roberto Pasqualotto, Emanuele
Sartori, Gianluigi Serianni, and Pierluigi Veltri
“Preliminary Design of Electrostatic Sensors for MITICA Beam Line Components”

P. Veltri, V. Antoni, P. Agostinett1, M. Brombi1, K. Iked2, M. Kisak2, H. Nakan2, E. Sartor1, G. Seriann1, Y. Takeir2 and K. Tsumor2
“Optics of the NIFS Negative ion source test stand by infrared calorimetry and numerical modeling”

M. Cavenago, G. Serianni, M. De Muri, P. Agostinetti, V. Antoni, C. Baltador, M. Barbisan, L. Baseggio, M. Bigi, V. Cervaro, F. Degli Agostini, E. Fagotti, T. Kulevoy, N. Ippolito, B. Laterza, A. Minarello, M. Maniero, R. Pasqualotto, S. Petrenko, M. Poggi, D. Ravarotto, M. Recchia, E. Sartori, M. Sattin, P. Sonato, F. Taccogna, V. Variale, P. Veltri, B. Zaniol, L. Zanotto and S. Zucchetti
“First experiments with the negative ion source NIO1”

M.Barbisan, C. Baltador, B. Zaniol, M. Cavenago, U. Fantz, R. Pasqualotto, G.Serianni, D.Wünderlich
“First hydrogen operation of NIO1: characterization of the source plasma by means of an optical emission spectroscopy diagnostic”

A. Fassina, F. Pretato, M. Barbisan,L. Giudicotti, R. Pasqualotto
“Feasibility Study of a NBI Photoneutralizer Based on Nonlinear Gating Laser Recirculation”

Michela De Muri, Mauro Pavei, Federico Rossetto, Diego Marcuzzi, Enrico Miorin, Silvia M. Deambrosis
“Design optimization of RF lines in vacuum environment for the MITICA experiment”

Giuseppe Chitarin, Piero Agostinetti, Daniele Aprile, Nicolò Marconato, Diego Marcuzzi, Gianluigi Serianni, Pierluigi Veltri, Pierluigi Zaccaria
“Off-normal and failure condition analysis of the MITICA negative-ion Accelerator”

E. Sartori, L.Brescaccin, G. Serianni
“Simulation of diatomic gas-wall interaction and accommodation coefficients for Negative Ion Sources and accelerators”

Mauro Pavei, Bernd Böswirth, Henri Greuner, Diego Marcuzzi, Andrea Rizzolo, Matteo Valente
“Development and tests of Molybdenum armed copper components for MITICA ion source”

Pierluigi Veltri and Emanuele Sartori
“Transmission of electrons inside the cryogenic pumps of ITER Neutral Beam Injector”

M. Zaupa, E. Sartori, M. Dalla Palma, F. Fellin, D. Marcuzzi, M. Pavei, A. Rizzolo
“Steady state thermal-hydraulic analysis of the MITICA experiment cooling Circuits”

Nicola Fonnesu, Marco Cavenago, Gianluigi Serianni and Pierluigi Veltri
“Particle Transport and Heat Loads in NIO1”

V. Variale, M. Cavenago, P. Agostinetti, P. Sonato and L. Zanotto
“Ion collector design for an energy recovery test proposal with the negative ion source NIO1”

LAPD2015 17th International Symposium on Laser-Aided Plasma Diagnostics, Sep 27- Oct 1 2015, Chateraise Gateaux Kingdom Sapporo, Hokkaido, JAPAN

L. Giudicotti, M. Bassan, F. P. Orsitto, R. Pasqualotto, M. Kempenaars
“Conceptual study of a polarimetric Thomson scattering diagnostic in ITER”
LAPD2015 17th International Symposium on Laser-Aided Plasma Diagnostics, 27th Sep.-1st Oct. 2015, Chateraise Gateaux Kingdom Sapporo, Hokkaido, JAPAN , proceedings will be published in the Journal of Instrumentation (JINST)

25th International Toki Conference (ITC-25), November 3-6, 2015, Ceratopia Toki, Toki-city, Gifu, JAPAN

P. Vincenzi, S. Murakami, M. Osakabe, R. Seki, M. Yokoyama, T. Bolzonella
“Analysis of LHD NBI-plasma interaction with upgraded FIT3D code of TASK3D-a analysis transport suite”
25th International Toki Conference (ITC-25), November 3-6, 2015, Ceratopia Toki, Toki-city, Gifu, JAPAN, Proceedings to be published in Plasma and Fusion Research

G. Serianni, P. Agostinetti, V. Antoni, D. Aprile, C. Baltador, M. Cavenago, G. Chitarin, N. Marconato, D. Marcuzzi, E. Sartori, P. Sonato, V. Toigo, P. Veltri, P. Zaccaria, “The full-size source and injector prototypes for ITER neutral beams” invited

25th International Toki Conference (ITC-25), November 3-6, 2015, Ceratopia Toki, Toki-city, Gifu, JAPAN, Proceedings to be published in Plasma and Fusion Research

8.4. *Communications to Workshops and Conferences*

Complex Plasma Phenomena in the Laboratory and in the Universe, Accademia Nazionale dei Lincei, Roma, Italy, January 19-20, 2015

V. Antoni and the NBI Team

“The R&D activities for the Neutral Beam Injector development at Consorzio RFX”

First EPS Conference on Plasma Diagnostics - 1st ECPD, 14-17 April 2015, Villa Mondragone, Frascati (Rome) Italy

R. Pasqualotto, M. Agostini, M. Barbisan, F. Bonomo, M. Brombin, G. Croci, M. Dalla Palma, R. S. Delogu, M. De Muri, N. Fonnesu, G. Gorini, A. Muraro, N. Pomaro, G. Serianni, S. Spagnolo, M. Spolaore, M. Tardocchi, B. Zaniol

“Overview of diagnostics on ITER neutral beam test facility”

First EPS Conference on Plasma Diagnostics - 1st ECPD 14-17 April 2015, Villa Mondragone, Frascati (Rome) Italy

J. Vega, R. Moreno, A. Pereira, S. Dormido-Canto, A. Murari, JET Contributors
“Advanced Disruption Predictor Based on the Locked Mode signal: Application to JET”
First EPS Conference on Plasma Diagnostics - 1st ECPD, 14-17 April 2015, Villa Mondragone, Frascati (Rome) Italy

Giornate Nazionali della saldatura 8, Genova, Italy 28-29 maggio 2015

Dalla Palma Mauro, Michele Lanza
“Progetto mitica: iniettore prototipo di particelle neutre per il progetto ITER. ASPETTI DI fabbricazione”

8th Festival de Théorie "Pathways to Relaxation", July 6–24 2015, Aix-en-Provence, France

Susanna Cappello
“Relaxation processes in the Reversed Field Pinch: results & open issues” **invited Tutorial + invited Lecture**

32nd ICPIG, July 26-31, 2015, Iaşi, Romania

A Damone, A Panarese, C M Coppola, J Jansky, C Coletti, L Chiodo, G Serianni, V Antoni and S Longo

“Ab initio modeling of Cs-Mo interfaces in negative ion sources”
32nd ICPIG, July 26-31, 2015, Iaşi, Romania

V. Antoni, P. Agostinetti, M. Cavenago, G. Chitarin, S. Longo, R. Pasqualotto, E. Sartori, G. Serianni, F. Taccogna, P. Veltri
"The status of negative ions R&D for Fusion Applications”
32nd ICPIG, July 26-31, 2015, Iaşi, Romania

597th Wilhelm and Else Heraeus Seminar “Stochasticity in Fusion Plasmas” September 10-12 2015, Physikzentrum Bad Honnef, Germany

Susanna Cappello “Chaos healing and transport barrier formation in reversed-field pinch plasmas, achievements and open issues” invited talk

European Fusion Theory Conference 2015, October 5-8 2015, Lisbon, Portugal.

Predebon Italo, Xanthopoulos

“ITG turbulence in finite-beta helical and axisymmetric reversed field pinch plasmas”

20th International Stellarator-Heliotron Workshop (ISHW) October 5 - 9 2015, Greifswald, Germany

Spolaore Monica M. Agostini, B. Momo, C. Rea, N. Vianello, M. Zuin,R. Cavazzana, G. De Masi, P. Innocente, L. Marrelli, E. Martines,M. E. Puiatti, S. Spagnolo, G. Spizzo, P. Scarin, P. Zanca
“3D active modulation of edge topology in toroidal devices: effects on turbulent EM filaments” oral presentation

Scarin Paolo, M. Agostini, G. Spizzo, M. Spolaore, N. Vianello
“3D anharmonic topology of RFX-mod edge”

Bonfiglio Daniele, S. Cappello, M. Veranda, L. Chacon and D. F. Escande
“3D MHD simulations of stellarator plasmas with SPECYL and PIXIE3D codes”

RFP Workshop 2015, 26-30 October 2015, Hefei, China

M.E. Puiatti for the RFX-mod team
“Overview of recent achievements and perspectives for RFX-mod”

L. Marrelli
“Tokamak experiments in RFX-mod”

Roberto Cavazzana, with the support of the whole RFX-Team
“Operational Scenarios in RFX-mod”

L. Zanotto for the RFX team
“Upgrades of Power Supplies for RFX-mod2”

P.Sonato On behalf of RFX-Team
“RFX-mod2: status of the design activities, a set of modifications to increase the experimental features”

M. Veranda, D. Bonfiglio, S. Cappello, L. Chacón[1], D.F. Escande, RFX Team
“MHD dynamics and magnetic transport barriers formation in the reversed-field pinch”

F. Auriemma, A. Fassina, D. Lopez Bruna, R. Lorenzini,E. Martines, B.Momo, D. Terranova, F. Sattin, Y. Zhang
“Transport analysis in plasmas with magnetic islands”

R. Lorenzini, F. Auriemma, A. Fassina, E. Martines, D. Terranova, F. Sattin
“Quasi Separatrix Layers and ITBs in RFX-mod”

M. Agostini, P.Scarin, L.Carraro, R.Cavazzana, G.Spizzo, M.Spolaore, N.Vianello
“Plasma edge deformation with 3D magnetic field”

R. Lorenzini, M. Agostini, F. Auriemma, L. Carraro, G. De Masi, A. Fassina, P. Franz, M. Gobbin, P. Innocente, M.E. Puiatti, P. Scarin, B. Zaniol, M. Zuin
“The isotope effect in RFX-mod”

A.Canton, L.Carraro, RFX-mod team
“W samples and tiles exposure in RFX-mod”

APS 57th Annual Meeting of the APS Division of Plasma Physics, November 16–20, 2015, Savannah, Georgia

Matteo Agostini, Paolo Scarin, Lorella Carraro, Gianluca Spizzo, Monica Spolaore, Nicola Vianello
“Poloidal structure of the plasma edge with 3D magnetic fields”
Bullettin of the American Physical Society, Volume 60, Number 19 PP12.00091

L.M. Reusch, P. Franz, M.E. Galante, J. Goetz, D.J. Den Hartog, M.B. Mcgarry, H.D. Stephens,
“Improvements in electron temperature measurements from soft x-rays in MST plasmas”
Bullettin of the American Physical Society, Volume 60, Number 19 CP12.00035

M.D. Nornberg, M.E. Galante, Nova, L.M. Reusch, D.J. Den Hartog, P. Franz, H.D. Stephens
“Combining impurity X-ray and impurity density measurements to determine *Z*eff”
Bullettin of the American Physical Society, Volume 60, Number 19 CP12.00036

Piero Martin, Marc Beurskens, Stefano Coda, Thomas Eich, Hendrik Meyer
“Overview of the EUROfusion Medium Size Tokamak program”
Bullettin of the American Physical Society, Volume 60, Number 19 GP12.00128

Michio Okabayashi, N. Logan, B. Tobias, Z. Wang, B. Budny, R. Nazikian, Pppl, E. Strait, R. La Haye, C.J. Paz-Soldan, N. Ferraro, Ga, D. Shiraki, Ornl, J. Hanson, P. Zanca, R. Paccagnella,
“Multi-layered mode structure of locked-tearing-modes after unlocking”
Bullettin of the American Physical Society, Volume 60, Number 19 JP12.00095