Annex 1

EUROfusion Engineering Grants 2019

List of positions

Contents

WP DIAGNOSTIC AND CONTROL

1. DEMO diagnostic development

Position ref. EEG-2019/01

Contact person: Wolfgang Biel w.biel@fz-juelich.de

Job Description

The properties of the DEMO plasma control system will strongly depend on the availability of accurate measurements related to all relevant properties to be controlled. While a large number of diagnostic methods have been successfully developed and applied on existing fusion devices, their application on DEMO is facing severe limitations: First, all diagnostic front-end components on DEMO will be subject to extremely adverse conditions (e.g. high neutron and gamma fluxes and fluences, high fluxes and fluences of CX neutrals, high temperatures), and second the space for diagnostic implementation will be quite limited, in order to maximise the tritium breeding rate and to preserve first wall integrity. As a consequence, DEMO control will have to rely on a limited number of diagnostic systems and channels, which are mounted in a retracted position and hence will provide only limited performance.

The training and work steps for this post should comprise a major part of the following points:

- Review and assessment of plasma diagnostic methods relevant to a DEMO fusion reactor, their technical realisation on existing fusion devices, and quantitative prediction of their expected performance properties (accuracy, time resolution, reliability) towards DEMO conditions
- Review, assessment and further detailing of the suite of foreseen measurements for DEMO plasma control, with regard to the completeness of covering all foreseeable plasma conditions, and to the reliability of control
- Assessment of possibilities and options for specific diagnostic implementation on DEMO, including assessment of the impact of the space consumption on tritium breeding rate and first wall integrity, and assessment of options for maintenance
- Specific conceptual studies on the design and engineering of a limited number of DEMO diagnostic systems, preferably with emphasis on optical diagnostics (e.g. spectroscopy, radiation measurements, interferometry) and/or magnetic (coil based) diagnostics
- Quantitative analysis of the degradation of diagnostic front-end components under DEMO conditions (diagnostic lifetime assessment, reliability analysis)

- Development and testing (demonstration experiments) of diagnostic prototype components under fusion relevant conditions

Candidates with knowledge in one or more of the following areas are encouraged to apply. The scope of the various areas are also briefly described below:

- **Mechanical or electrical or optical engineering**: To conduct conceptual studies, design and engineering analysis on the integration, installation and operation of the plasma diagnostic equipment and the corresponding interfaces, including the possible development and testing of prototypes;
- **Plasma diagnostics development and application**: To develop concepts for the layout of plasma diagnostic systems, conduct studies on expected diagnostic performance (experiments and modelling), and perform diagnostic calibration, measurements and data evaluation on fusion plasmas;

Eligibility: Scientists/Engineers holding a Master degree or PhD in Engineering or Physics.
Main Work Package: WPDC
Facilities to be used: To be defined as part of the proposal, as required e.g. to prototype testing or demonstration experiments.

WP REMOTE MAINTENANCE

2. Application of Condition Monitoring in DEMO Remote Maintenance System

Position ref. EEG-2019/02

***Contact person: Antony Loving* - antony.loving@ukaea.uk**

Job description

The optimal and safe operation of DEMO, will depend critically on timely and highly efficient in-vessel maintenance. In order that all such equipment operates safely, predictably and is highly performant, a robust and intelligent condition monitoring system is required. Such a system must have the capability to observe, diagnose and predict as many time-varying parameters and performance measures as possible. Trends that might be insignificant at one level or in isolation could indicate subtle underlying and possibly detrimental changes in current or future performance. The ability to prevent failures and the costly recovery processes is of paramount importance for the viability of the DEMO Remote Maintenance System.

UKAEA operates the Joint European Torus (JET), the world's largest operational fusion tokomak. The vessel is maintained by a suite of advanced robotics systems comprising articulated, motor-driven, booms on which are mounted sophisticated manipulators. These systems have existing remote diagnostic and data acquisition equipment fitted for the purposes of condition monitoring and would be an ideal test platform for this research. Furthermore, the JET ex-vessel remote maintenance system TARM, with its telescopic mast and articulated boom, will be available as a test-bed for research into dynamic control and will be instrumented for condition monitoring.

New research is required in the development of techniques that can reliably determine and predict the time-varying condition of a vast number of parameters of various systems.

The underlying technologies include; low bandwidth signal data sourced from software based control systems and high bandwidth signal data directly from robotic sensors. Both sources of signal data require the provision of descriptive metadata that should, as a minimum, cover; units, minima and maxima values. It is likely that streaming technologies;

"big data", NoSQL databases (e.g. time-series, graph etc.) and tools such as Apache Spark and Flink will be required for both contemporaneous and archival data processing.

Objectives of the task

A condition monitoring system will be researched and developed that processes quantities that includes; vibration, temperature, movement, response to commands, electrical values, strain and acceleration. Vision processing and LiDAR may also be used. For example, these data will represent; 3D location, velocity, joint torque values, gearbox backlash (hysteresis) and friction. All data and parameters require uncertainty models and the system should be able to detect and identify anomalies from sensor faults to imminent systematic failures.

The condition monitoring system will also analyse spatial and time series trends in carrying out fault and uncertainty classification using, for example; stochastic systems theory, state-estimation, machine learning, time-series, time-frequency, fuzzy inference, fuzzy rules, fuzzy templates, neural-networks, wavelets, cluster analysis and state vector machines. Fuzzy templates could be built from ontological models that encapsulate the relationships between sub-systems and degradation modes.

Investigations will be made into the overall maintenance strategy including benefits analysis of condition monitoring, and therefore predictive maintenance, as opposed to regular or reactive maintenance. Further investigations will be made into reliability and dependability of robotic devices within a fusion-like temperature and radiation environment, and systems which are tolerant to failure, with graceful degradation will be explored.

Short and long-term predictive maintenance software will be developed, based on machine learning, and it will be used to investigate, ontologies, probabilistic failure modes, non-linear (e.g. unscented KF, particle filtering etc.) and/or model-free prediction. Outputs will include failure likelihood, bounds on uncertainty, failure impact (severity) and preventative action. This work will also inform measurement placement studies and the trade-off between cost of measurements and the increased accuracy and robustness of the system. The project may explore radiation hard sensors and devices for condition monitoring.

This work interfaces with other WPRM EEGs, particularly the Physical Sensing and Control System tasks from 2016 and the Automated Remote Maintenance task from 2018. The WPRM Project Leader will hold progress meetings involving all EEG members to maximise integration of the work and endeavour to integrate the physical validation work in all the EEGs to produce a combined system to validate the new technologies required for DEMO remote maintenance. The work will also interface with current research and development at UKAEA into the Adaptive Position Control Systems for the JET, TARM, DEMO and DONES remote handling systems which will facilitate validation of the condition monitoring system developed under this EEG using real data.

The successful applicant will be expected to spend time at the JET facility in Culham, United Kingdom, to gain an in-depth understanding of state-of-the-art RM systems in fusion tokamaks. In addition, the candidate will have access to the RACE experimental robotics facilities at Culham to validate autonomous systems.

Main work package: WPRM

Facilities to be used: JET Remote Handling and RACE Robotic Facilities

WP TRITIUM FUELLING VACUUM

3. Hydrogen separation and pumping by superpermeation

Position ref. EEG-2019/03

Contact person: Christian Day – christian.day@kit.edu

Job Description

Tritium inventory minimisation has been recognized as key challenge and as main design driver of the DEMO fuel cycle which has resulted in a novel architecture. The foreseen concept (Direct Internal Recycling) separates most of the hydrogen isotopes directly from the exhaust gas mixture and routes it to the fuelling systems in a bypass thereby avoiding complete isotope separation. Consequentially, the amount of the gas mixture that has to be treated in the tritium plant can be reduced and the tritium inventory in the whole fuel cycle is minimised. This requires to add a new functionality to the fuel cycle, namely the separation of a stream of pure unburnt fuel at the typically low densities encountered close to the divertor. This important task will be done by a metal foil pump that relies on the effect of superpermeation. Although superpermeation is theoretically and experimentally known, it has never been implemented in an engineering design of a technical component such as a pump. Due to the enormous impact (mitigate the showstopper of excessive tritium inventory) and the high risk coming from the presently low technical readiness, the metal foil pump technology has been identified as one of the key design integration issues of DEMO to be addressed with a dedicated R&D programme.

This call aims to develop a first design of a metal foil pump. The work has to address two main aspects, namely (i) the simulation and experiments for the production of energetic (suprathermal) hydrogen by various technologies to generate a cold plasma, which is needed to enable superpermeation, and (ii) the characterisation of the gas-metal interaction and transport. The successful applicant will first familiarize with the previous work and can then focus on either of the two aspects above. The character of the work includes both the experimental side (in existing and new facilities dedicated to support the development of the metal foil pump technology) and the modelling side. As a result, the successful applicant will finally develop a first technical (mechanical, manufacturable) pump design that meets the full scope of DEMO requirements.

The successful applicant will be closely integrated in the TFV team located at KIT. Previous experience in either the simulation of low temperature plasma or the characterisation of hydrogen in metals, as well as experience in the field of vacuum technology are desired.

Main Work Package: WPTFV
Facilities to be used: HERMES Facilities (at KIT)

WP PLANT LEVEL SYSTEMS ENGINEERING, DESIGN INTEGRATION AND PHYSICS INTEGRATION

4. DEMO Cost Model

Position ref. EEG-2019/04

Contact person: Richard Kembleton – richard.kembleton@euro-fusion.org

Job Description

The DEMO reactor, which will follow ITER, will be a crucial step towards the production of electricity through fusion energy. EUROfusion pre-conceptual design activities began in 2014 and will end in 2020. The conceptual design should be finalized in 2027. Since the main aim of the Programme is to advance the design a DEMO fusion power plant with minimum technical feasibility risks and reasonable costs, a robust costing approach must be one of the criteria used for optimizing DEMO and selecting technologies for inclusion. Cost modelling and control is also a key project management task which will be required for successful development of the DEMO project.

The main objective of the task is the development of a robust costing framework for the main DEMO key-systems using (when possible) industry methodology; the collection of data from the EUROfusion projects to allow cost comparisons of different technologies; the identification of key risks arising from e.g. resource restrictions or supply chain bottlenecks; and the interrogation of the cost model using a Monte Carlo approach to assess significant uncertainties and cost sensitivities arising from design immaturity or technology options.

The corresponding activities are foreseen:

- Definition of a consistent costing approach, building on existing work, for the comparison of different system technologies, to take into account the possibility of industrialization of component manufacturing processes, global resource availability, and future implications for commercial fusion power. This approach should then be distributed to the EUROfusion projects for their own use in assessing technology options.
- Definition of a lifetime project costing framework for a fusion power plant, including component costs, land and buildings, maintenance and operations, financing, project management overheads, and decommissioning.
- Collation of costing data from the EUROfusion projects, RUs, and industrial sources
- Costing studies to develop DEMO costs with appropriate uncertainties based on technology maturity

This is necessarily a multi-disciplinary role and requires overview knowledge of a range of DEMO systems and technologies, a grasp of manufacturing techniques and statistical methods, and an interest in supply chain economics. The approach will include consultation with fusion experts from laboratories and high experienced people from industry and civil works.

Eligibility: Scientists/Engineers holding a university degree in Physics or Engineering, or similar.
Main Work Package: WPPMI. It is expected that the candidate will need to spend considerable time in the PMU Garching. Interaction with Project Leaders and visits to different RUs and industrial partners to gather information will also be required. Travelling costs will be covered by EUROfusion.
Facilities to be used: n/a

WP BREEDING BLANKET

5. Heat loads analysis and design of DEMO wall and divertor protections during plasma transients

Position ref. EEG-2019/05

Contact person/ coordinator: Francesco Maviglia - francesco.maviglia@euro-fusion.org

Project Leader: Lorenzo Virgilio Boccaccini – Lorenzo.boccaccini@kit.edu

Job Description

The present DEMO breeding blanked FW design heat load capability is limited to ≈1 MW/m^2 for steady state plasma loading, both for helium or water concepts, due to the specific requirements on high neutron irradiation capable materials, and high coolant temperature for efficient energy conversion. While this limit is achievable in nominal conditions in the present DEMO blanket concept designs, the greatest challenges arise from the occurrence of plasma transients, and in particular in the phases when the plasma is in contact with the first wall. To address this issue, ITER will use a high heat flux wall-limiter, designed with high thermal performance materials and with high alignment requirements, which increases the complexity and costs, and which is capable to withstand heat flux densities up to 4.6MW/m^2. Such solution provides a good risk mitigation and flexibility, given the uncertainty over wall loads, and this design can be accepted as there is no breeding or power conversion requirement in ITER. A DEMO wall-limiter is not thought to be viable due to the TBR impact, the need of materials capable to operate in a higher neutron irradiation environment, and high cost/complexity.

A solution which includes discrete protection limiters is being proposed and investigated instead, as one of the DEMO key design issues, with the aim to meet all the unique DEMO requirements. The DEMO IVC (In Vessel Components) must include dedicated wall modules which protect the wall/blanket during foreseen plasma transients, such as the initial plasma current ramp-up phase, before the plasma is controlled in diverted configurations, and unforeseen, such as perturbations and deviation from pre-programmed scenarios. An extreme case is off-normal accident conditions in which the plasma becomes limited during the flat-top phase, when it holds the full energy of the 1GJ of both thermal and magnetic energy. Such conditions are extremely damaging and so the wall protection concept is critical to demonstrate the overall feasibility of DEMO.

Two different transient events timescales and corresponding design are required to be considered:

- short, (microseconds to few milliseconds) transient events (like ELMs, REs, thermal quench), which are going to interfere with the surface of the PFC.
- slow, (milliseconds to seconds) transients events (such as H-L transition, VDEs, current quench), which, depending on the incident heat flux magnitude/deposition time, will involve the structural material and coolant.
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The candidate will work within the development of the DEMO first wall protection strategy, with particular focus on the plasma transients.

Candidates with knowledge in one or more of the following areas are encouraged to apply:

- A fair knowledge of the problematic relative to the plasma equilibrium codes, including a previous experience in interface or use of codes available in the fusion community, such as PROTEUS, MAXFEA, EFIT, CREATE-NL/L, or similar, with the capability to handle the plasma equilibria output for the further heat flux calculations.
- A fair knowledge of the problematic relative to the plasma-PFC interaction, focusing on the surface heat load density calculations for the resolution of the problems relative to charged particle calculations via 3D field-line tracing codes (*e.g.* PFCflux, and SMARDDA, which are the codes presently used in WPPMI), and radiation loads, using Monte Carlo simulations (*e.g*. CHERAB is the code presently used in WPPMI).
- A fair knowledge of thermo-hydraulic and thermo-mechanical FEM simulations, using as input surface (*e.g.* charged particles and radiation loads) and volumetric heat load maps, and including the capability to analyze and design different solutions (*e.g*. geometries, coolant parameters) of high heat flux components, to be used as protection during plasma transients.
- Knowledge on C++ language, as well as Paraview and VTK library, or other CAD software used also as interface between the heat flux calculation and the thermal FEM analysis, would be a great addition.

The selected candidate will receive a comprehensive knowledge, understanding and modelling expertise on the aspects related to the plasma wall interactions, and will work towards proposing new solutions and more advanced models. The candidate will also make himself/herself acquainted with the interface of the heat load types, from the previous point, with the power exhaust systems, and the related key issues in the design choices which determine their technological limitations.

Eligibility: Scientists/Engineers holding a university degree in Physics or Engineering, or similar.
Main Work Package: WPBB
Interlinks with other Work Packages: Main links are with WPPMI, WPDIV, WPMAT, WPADC.

Facilities to be used: n/a

WP PLANT LEVEL SYSTEMS ENGINEERING, DESIGN INTEGRATION AND PHYSICS INTEGRATION

6. Analysis of tritium inventory and permeation in DEMO plasma facing components

Position ref. EEG-2019/06

Contact person: Fabio Cismondi – Fabio.cismondi@euro-fusion.org

Job description

Accurate estimates of the long term accumulation of tritium on the surfaces and in the bulk of the materials of DEMO plasma facing components (e.g., first wall/ blanket, divertor, etc.) are required for determining the tritium supply requirements, for assessing the radiological hazards from routine operation and from potential accidents. The degree of tritium permeation to the coolant is also important for the design of the water detritiation system. A potential critical issue, which must be investigated, is the uptake of tritium implanted in the thin First wall of DEMO (1 mm W and 3-5 mm EUROFER separate the high pressure high temp coolant from the plasma) and its permeation to the coolant. The use of a dedicated tritium permeation barrier on the first wall to suppress/mitigate ion-driven permeation might be required albeit they will be subject to several design constraints based on the harsh environment and their physical, thermal and mechanical properties.

This call aims at the development of engineering skills and experience in the field of hydrogen retention and permeation in metals. The candidate will develop the skills necessary to provide an in-depth study of tritium retention and permeation in Plasma Facing Components under reactor-relevant conditions with the use of state-of–the-art modelling tools such as TMAP[1] or similar tools. To aid in this task, the candidate will conduct research on relevant permeation and retention behavior of RAFM steels and possible tritium permeation barrier candidates. Experiments will be performed with deuterium as a surrogate for tritium to determine necessary design parameters not listed in literature. Possible tools at the disposal of the candidate include experimental setups for deuterium

1 The Tritium Migration Analysis Program (TMAP) has been developed by the Fusion Safety Program of EG and G Idaho, Inc., at the Idaho National Engineering Laboratory (INEL) to analyze tritium loss from fusion systems during normal operation and under accident conditions. TMAP is a one-dimensional code that determines tritium movement and inventories in a system of interconnected enclosures and wall structures and treats multi-specie surface absorption and diffusion in composite materials with dislocation traps. In addition, the thermal response of structures is modeled to provide temperature information required for calculations of tritium movement.

ion / gas loading of samples, ion- or gas-driven permeation experiments and methods for quantification of the deuterium content in samples (e.g. NRA, TDS). Theoretical modelling tools shall be applied to model tritium retention, diffusion and permeation in DEMO PFCs. The final goal will be to predict the tritium inventory in the structure and first wall of DEMO, as well as relevant tritium losses to the surrounding systems.

Main Work Package: WPPMI
Interlinks with other Work Packages: WPPFC, WPMAT
Facilities to be used: Available plasma-material interaction, characterization and material-development facilities in European RUs

WP EARLY NEUTRON SOURCE

7. Liquid metal technology for IFMIF-DONES

Position ref. EEG-2019/07

Contact person: Angel Ibarra - angel.ibarra@ciemat.es

Job Description

The WPENS project in the framework of the EUROfusion activities is aimed to further progressing the engineering design of the IFMIF-DONES facility, an intense fusion-like neutron source with the objective of qualifying the structural materials to be used in a DEMO reactor. The work being developed is complementary to the activities carried out in the IFMIF/EVEDA Project. IFMIF-DONES is based on the interaction of a 40 MeV deuteron beam with a flowing liquid Li generating a flux of neutrons by stripping nuclear reactions. The required neutron dose rate, induce a very high current accelerator (125 mA –the highest in the world for this kind of machines-) and a very high power handling requirements in the Li flow (5 MW) becoming also the largest Li loop never built.

Due to these characteristics, the facility, based on advance accelerator technologies to be used for fusion applications in the materials research, is a multidisciplinary facility in which very different technologies are required.

This position is aimed for the development of the candidate's skills in relation with the IFMIF-DONES facility and represents a unique opportunity to work within a team developing the associated technologies. The work will be focused on different aspects of the Li technologies, with emphasis on a experimental workprogram, one of the key specific characteristics associated with the IFMIF-DONES but with a significant number of cross-cutting synergies with other Li application in fusion or with other liquid-metal technologies of great impact on other fusion-related components.

Different aspect of the Li technology will be considered in the development of the work including (experimental workprogram will be preferred):

- Li safety
- Li impurities monitoring and extraction, including H isotopes
- Li flow and radiation diagnostics

Eligibility: Scientists/Engineers holding an university degree in Physics or Engineering, or similar.
Main Work Package: WPENS
Interlinks with other Work Packages: WPBB (for liquid metal technologies), WPSAE (for safety related aspects

Facilities to be used: Available facilities in various RUs

WP SAFETY AND ENVIRONMENT

8. DEMO Nuclear Safety Analyses

Position ref. EEG-2019/08

Contact person: Sergio Ciattaglia – sergio.ciattaglia@euro-fusion.org

Job Description

In the current pre-conceptual design stage of the European DEMO project, safety studies are performed to ensure that the evolving design will satisfy safety requirements and that it is optimized for the safety of both personnel and the public, and has minimal impact on the environment. In this context, safety analyses are performed including the modelling of postulated accident sequences. These allow, using conservative assumptions, an evaluation of the potential impact of abnormal and fault conditions, and the sequence of events that can be conceived to follow.

In order to ensure that the postulated accident sequence being analysed are comprehensive, a formal methodology, Functional Failure Modes and Effects Analysis (FFMEA) has been employed to identify postulated initiating events (PIEs) that could start an accident sequence. The initiating events identified for the DEMO plant have been grouped into a set of 21 PIEs that are representative of the full range of the most challenging events that can be conceived to occur[2]. Each of these is to be the subject of analyses, using computer modelling, to evaluate the maximum potential impact on the plant, personnel, the public and the environment.

To date, accident analyses have focussed on initiating events affecting the cooling systems of the components inside the vacuum vessel (first wall, breeder blankets and divertors), in particular loss-of-coolant and loss-of-flow accidents (LOCA and LOFA). Now it is required to begin analyses of other events from the list of 21 PIEs. In this engineering grant, some of these analyses will be performed. The main activities are foreseen to be:

- Selection of events to be studied from the list of 21 PIEs (choosing only events that have not so far been the subject of analyses within WPSAE)
- Development of accident sequences based on the selected PIEs

[2] T. Pinna et.al., Identification of accident sequences for the DEMO plant, Fusion Engineering and Design, **124**, 1277-1280 (2017).

- Gathering of necessary input data such as outline design information, source terms, energies (e.g. decay heat) from previous WPSAE tasks and from other Work Packages in the DEMO project
- Setting up of computer models to simulate the accident sequences using appropriate computer codes
- Use of the computer models with a range of conservative assumptions to establish the maximum consequences of the accident sequences
- Evaluation of the potential impact in terms of radiological doses to personnel or members of the public, and of releases to the environment.
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The grantee will work with nuclear safety specialists in the Research Unit (RU) hosting the Engineering Grant. Periods working with specialists at other RUs participating in WPSAE, at associated universities, and/or at the DEMO Programme Management Unit in Garching may also be included in the work programme.

The candidate should have a knowledge of nuclear safety issues and be competent in scientific/engineering computing, with the capability of setting up complex computer models. In the course of the grant, the successful applicant will gain a good understanding of fusion systems and aspects of the DEMO design, will further deepen his/her knowledge of nuclear safety principles and their application to fusion, and gain good experience of setting up and using complex engineering computer models for safety analyses.

Interim and final reports on the work will be written by the grantee. The work may also be presented at international fusion conferences and papers published in their proceedings. Attendance a two/three such conferences in the course of the grant will also give the grantee valuable exposure to the broader world of scientific and engineering research for fusion power.

Eligibility: Scientists/Engineers holding an university degree in Physics or Engineering, or similar.
Main Work Package: WPSAE
Facilities to be used: Computer facilities at the hosting Research Unit.

WP MAGNETS

9. Wide-range studies on the insulation in DEMO magnets

Position ref. EEG-2019/09

Contact person: Valentina Corato - valentina.corato@enea.it

Job Description

The insulation represents a critical aspect in the manufacturing and in the operative phase of large high field superconducting magnets for fusion reactors. Due to fast changes in the current flowing in the magnet or unpredictable failures, the insulating material can be subject to very high voltages, voltage oscillations and non-linear distribution in the winding pack (WP). Anyway, the high voltage level sustainable by the insulating material, cannot be simply improved by increasing the thickness of the insulations, since it creates adherence difficulties to the WP during the manufacturing process. Moreover, the robustness and the life time of the insulating material under thermal cycles and mechanical loads occurring during operation is not well assessed. The effect of the neutron irradiation is also under study.

This call is aimed at the development of the know-how and of practical experience in the area of insulation for superconducting magnet R&D, considering a broad range of possible activities:

- Study of the bibliography on the insulating material properties and the industrial technique used during the coil manufacturing process.
- Study of the problem of high voltage, voltage oscillations and non-linear distribution in the WP in case of break-down, fast discharge and failures and proposal of new solutions.
- Design of mock –up for testing insulation in a small portion of WP under thermal cycles and mechanical loads (the mock-up could be manufactured and tested after 2020).
- Following the existing experimental activity on insulation carried out at ITER.
- Following the experimental activity on neutron irradiation of the insulating material.

The proposed activity would be very interdisciplinary and the candidate is required to interact with several Research Units

Eligibility: Scientists with an MSc or PhD in physics can also apply

Main Work Package: WPMAG

Interlinks with other Work Packages: WPPMI, WPMAT.

Facilities to be used: Available high voltage test and neutron irradiation facilities in various research units

WP HEATING AND CURRENT DRIVE SYSTEMS

10.Design and Development Ion Cyclotron Wave (ICW) system

Position ref. EEG-2019/10

Contact person: Minh Quang Tran - minhquang.tran@epfl.ch; (+41 79 248 30 79)

Job Description

The design of Heating and Current Drive Systems with improved efficiency and reliability is an important area of research priority for DEMO and future fusion power reactors. This call aims at the training of a high level engineer or scientist in the field of Ion Cyclotron wave (ICW) system. As physics and engineering are interrelated in these complex systems (ICW), candidates with either an engineering or physics background are encouraged to apply.

This call aims at the strengthening of good engineering skills in the RF analysis and development of an ICW antenna to be fully integrated in the DEMO design. The distributed Ion Cyclotron Heating antenna is a concept that relies on the advantages of ICRF (high plug to power efficiency, ion heating, well established technology for the generators and transmission lines) while avoiding some negative aspects (need to put the antenna in a port of limited size, high voltage and current, impurity production) to provide a reliable and sturdy overall system for DEMO.

The work will be focused on the design and integration of Ion cyclotron antennas into DEMO1. The antenna shall be placed in the mid plane and shall use the equatorial ports for assembly and supply to avoid interference with the Breeding Blanket. Regarding the feeding of the antenna, two concepts will be explored: a scheme where straps are fed separately or the Traveling Wave Antenna (TWA) one. The guidelines for the work will be given by the PL at the beginning of the grant period and information can be obtained by contacting the PL (see above) A good knowledge of RF theory and practice of RF power systems mainly concerning TWA systems and transmission line components and their RF modelling is a prerequisite. The candidate will use CAD codes (CATIA) and RF codes (COMSOL/Microwave studio/HFSS) in collaboration with the DEMO design team.

Interactions with several EU Research Institutions engaged in IC system design, development and operation is foreseen. It is also foreseen that the grantee will have extended missions to IPP Garching for integration work and interaction with PMU.

During the work, the Grantee could also be trained, if necessary, and work in the field of neutronics and remote maintenance with specialized groups within EUROfusion.

Main Work Package: WPHCD

Interlinks with other Work Packages: WPCD, WPPMI, WPBB, WPRM, EUROfusion PMU

Facilities to be used: ICW facilities existing in RUs, tokamaks and stellarators

WP HEATING AND CURRENT DRIVE SYSTEMS

11. Modelling of DEMO1 scenarios using Electron Cyclotron Wave system

Position ref. EEG-2019/11

Contact person: Mattia Siccinio – Mattia.siccinio@euro-fusion.org

Job Description

At present in DEMO1 (a pulsed machine), three heating systems are under consideration, using electron cyclotron waves (ECW) , ion cyclotron waves (ICW) and neutral beam injection (NBI). Physics scenarios are being developed based on various combinations of power from these three systems, exploring different solutions for each of the aspects involved.

Recently, the activities of the Work Package Heating and Current Drive (WPHCD) were reviewed by a Panel of External Experts under the chairmanship of Prof. F. Wagner. One of the recommendations of the Panel, is to devote a specific study considering the use of only ECW for all the functions required for the operation of DEMO1: plasma break-down, start-up (access to H mode), MHD control, control during the burning phase, control of the radiative instabilities and plasma ramp-down. The goal of the study is twofold:

- Determine whether ECW can fulfil all the requirements for DEMO1, being at the same time compatible with the available number of ports
- If not, what function(s) could not be insured by ECW and what other heating systems could fulfill best this (these) function(s).

The task could be performed by a young physicist or engineer with interest in modelling. After an introductory period where he/she will get familiar with the physics of the interaction of ECW, ICW and NBI with plasma and of the various requirements at each step of DEMO1 scenarios, he/she will elaborate scenarios using only ECW as heating system. The feasibility of the scenarios must be assessed on the technical point of view, through interaction with WPHCD experts. Gaps in the scenarios will then be identified, and the best alternatives from physics and technology be proposed.

The applicant should have a background in tokamak physics, and interest in modelling and in heating and current drive technology. The work will be closely with the physics part of PMI, and with WPHCD. Exchange with European laboratories with experience in such simulations could be foreseen.

Main Work Package: WPHCD and WPPMI

Interlinks with other Work Packages: EUROfusion PMU

WP DIVERTOR

12.Evaluation technology for divertor plasma facing components

Position ref. EEG-2019/12

Contact person: Jeong-Ha You - you@ipp.mpg.de

Job Description

Among all in-vessel plasma-facing components (PFCs) in a fusion power plant such as the demonstration reactor DEMO, the divertor targets are the most severely loaded components which will be exposed to intense bombardment of plasma particles, energetic neutrons and electromagnetic impact forces causing extreme heat fluxes, cyclic stresses, surface erosion and material damages. Such a harsh loading environment poses a particular challenge for the design and engineering development of the target PFCs with required heat exhaust capability, structural reliability and lifetime.

To this end, integrated and interdisciplinary R&D efforts have been carried out in the work package “Divertor” (WPDIV) to deliver preconceptual design concepts and technologies for the divertor targets of the European DEMO focusing on high-heat-flux (HHF) PFCs. Besides the fabrication technologies for the materials and components, the technologies to evaluate the production quality, HHF performance, structural integrity and durability of manufactured PFC mock-ups play a key role in the respective R&D chain of the individual PFC concepts. In this context, a technically sound, feasible, credible and integrated methodology to evaluate the quality and performance of PFCs is required for a rational qualification.

The primary objective of this EEG program is to train a young professional in the field of PFC evaluation technologies covering non-destructive inspection, calibration techniques, in-situ diagnostics, and metallographic examination of microscopic damages. The candidate is supposed to be fully integrated in the work package’s R&D program contributing to the scope addressed above in close collaboration with the other research groups involved. It is expected that the grantee will be working with a self-initiative and team-oriented attitude. The grantee shall have the opportunity of a short-term work stay in the labs of the cooperating research units where scientific supervision and technical supports shall be offered by the experts. Research programs to devise a holistic evaluation scheme for integrating multilateral testing techniques and analysis methods with an enhanced accuracy are highly welcome.

A successful candidate is expected to have postgraduate-level knowledge in mechanical metallurgy or materials engineering. Applicants should possess solid technical skills in both metallography and electron-microscopy. Experience in FEM simulations is considered an advantage. A good organizational and communication skill with a good command of English is required. Candidates who meet this qualification profile are encouraged to apply.

Eligibility: Scientists/Engineers holding a university degree (or PhD) in Materials, Nuclear or Mechanical Engineering

Main Work Package: WPDIV

Facilities to be used: SATIR (CEA), GLADIS (MPG), HELCZA (IPP.CR), HELIOS (MPG)

WP ASSESSMENT OF ALTERNATIVE DIVERTOR CONFIGURATIONS AND LIQUID METAL PFCs

13. Scenario and magnetic configuration control of the DTT divertor options

Position ref. EEG-2019/13

Contact person: Holger.reimerdes@epfl.ch

Job description:

The Divertor Tokamak Test (DTT) facility is being designed and will be built by a consortium of Italian research institutes to explore and qualify alternative plasma exhaust solutions for DEMO as indicated in the EUROfusion Roadmap. The activities in the engineering area of the WPDTT1-ADC project seek to maximise the compatibility of the DTT facility with the full range of alternative divertor configurations (ADCs) presently considered by EUROfusion for DEMO. DTT should offer sufficient flexibility to be able to accommodate the most promising candidate divertor concept including conventional, snowflake, X, super-X and double null configurations, which will be selected on the basis of the studies carried out in the present tokamaks involved in the PEX activities (around 2022-2023). The present strategy implies a severe effort on the design of DTT since the available space and the port locations must be compatible with all considered divertor options.

The main objective of the activity is the optimisation of the scenarios and the magnetic configuration control of the DTT divertor options. DTT addresses the challenge of investigating alternative magnetic configurations with plasma conditions similar to DEMO with the possibility to explore up-down symmetric solutions to alleviate the power load problem. The magnetic control of ADCs is a very challenging problem and it is still an open issue in the fusion community. To control the details of the magnetic configuration related to the power exhaust, such as strike point position and flux expansion, DTT will be equipped with a set of internal coils capable to locally modify the magnetic field in the vicinity of the divertor target. The presence of dedicated internal coils makes DTT one of the most promising devices for the development and test of innovative feedback control strategies for the power exhaust problem.

The main responsibilities of the candidate will include:

- The definition of the PF coil scenario in terms of Voltage/Currents for all DTT divertor options.
- An analysis of the compatibility of the scenario with current drive and additional heating systems.
- An analysis of the vertical stability of the DTT divertor options ranging from the evaluation of the best achievable performance to the design of a realistic VS controller.
- A sensitivity analysis and shape control of the configurations with emphasis on quantities related to power exhaust issues.

The candidate is required to have:

- A background in electromagnetic modelling and control.
- A good knowledge of the problems related to the 2D plasma equilibrium development, including a previous experience in the use of codes available in the fusion community, such as PROTEUS, MAXFEA, CREATE-NL/L, EFIT, or similar.
- A good knowledge of the problems related to the design of feedback control of the plasma including a previous experience in the use of closed loop simulation codes, such as MATLAB/SIMULINK or similar.

The selected candidate will get a comprehensive knowledge, understanding and modelling expertise on the aspects related to the plasma equilibrium and magnetic control, also based on experiments in present and future devices. The candidate will also make himself acquainted with the power exhaust systems and the related key issues in the design choices. Due to the highly integrated and international nature of the project, it is essential requirement for the candidate to possess good skills of organisation and communication. The candidate will be consulted and supported by the supervisor and the Project Leader with regard to scientific and administrative affairs, but high degree of self-initiative is also desired.

Main Work Package: WPDTT1-ADC

Interlinks with other Work Packages: WPPMI, WPDC

Facilities to be used: EAST, TCV

WP ASSESSMENT OF ALTERNATIVE DIVERTOR CONFIGURATIONS AND LIQUID METAL PFCs

14. Developments of diagnostics adaptable to all DTT divertor options

Position ref. EEG-2019/14

Contact person: Holger.reimerdes@epfl.ch

Job description:

The Divertor Tokamak Test (DTT) facility is being designed and will be built by a consortium of Italian research institutes to explore and qualify alternative plasma exhaust solutions for DEMO as indicated in the EUROfusion Roadmap. The activities in the engineering area of the WPDTT1-ADC project seek to maximise the compatibility of the DTT facility with the full range of alternative divertor configurations (ADCs) presently considered by EUROfusion for DEMO. DTT should offer sufficient flexibility to be able to accommodate the most promising candidate divertor concept including conventional, snowflake, X, super-X and double null configurations, which will be selected on the basis of the studies carried out in the present tokamaks involved in the PEX activities (around 2022-2023). The present strategy implies a severe effort on the design of DTT since the available space and the port locations must be compatible with all considered divertor options.

The main objective of the activity is the integration of the diagnostic systems into all DTT divertor options. Well assessed diagnostic methods have been successfully developed and applied in existing fusion devices. However, the diagnostic systems of DTT should take into account peculiar aspects of this machine. Firstly, DTT should be able to achieve alternative scenarios with dedicated divertor options in a machine where the available space is limited and the neutron load is significant. Secondly, DTT is a tokamak mainly devoted to test the solutions proposed the power and particle exhaust problem: The diagnostics should be used not only for post-pulse analysis but also for the real time control of the configuration and the plasma exhaust.

The candidate main responsibilities will include:

- Proposal of magnetic diagnostics hardware for the DTT device including flux loops, saddle loops, pick-up coils, Hall sensors, Rogowski coils, diamagnetic loops.

- Optimization of the number and position of in-vessel and out-vessel magnetic diagnostics for the DTT device.
- Analysis and integration of standard non-magnetic diagnostics for the DTT device including MSE, polarimetry, interferometry, bolometry, Thompson scattering.
- Analysis and integration of specific diagnostics to control and study plasma exhaust in the DTT device.

The candidate is required to have:

- Practical and theoretical background on basic magnetic diagnostics.
- Practical and theoretical background on basic non-magnetic diagnostics in a tokamak.
- Good knowledge of magnetic simulation tools.

The selected candidate will develop good skills and practical competences in the areas of fusion device diagnostics for both offline analysis and closed loop control of plasma configurations and power exhaust related quantities.

It is foreseen that this activity will be performed in close collaboration with the project partners within EUROfusion, possibly including external research groups. Due to the highly integrated and international nature of the project, it is essential requirement for the candidate to possess good skills of organisation and communication. The candidate will be consulted and supported by the supervisor and the Project Leader with regard to scientific and administrative affairs, but high degree of self-initiative is also desired.

Main Work Package: WPDTT1-ADC

Interlinks with other Work Packages: WPDC

Facilities to be used: EAST, TCV

WP ASSESSMENT OF ALTERNATIVE DIVERTOR CONFIGURATIONS AND LIQUID METAL PFCs

15. Remote handling studies for the replacement of the DTT divertor options

Position ref. EEG-2019/15

Contact person: Holger.reimerdes@epfl.ch

Job description:

The Divertor Tokamak Test (DTT) facility is being designed and will be built by a consortium of Italian research institutes to explore and qualify alternative plasma exhaust solutions for DEMO as indicated in the EUROfusion Roadmap. The activities in the engineering area of the WPDTT1-ADC project seek to maximise the compatibility of the DTT facility with the full range of alternative divertor configurations (ADCs) presently considered by EUROfusion for DEMO. DTT should offer sufficient flexibility to be able to accommodate the most promising candidate divertor concept including conventional, snowflake, X, super-X and double null configurations, which will be selected on the basis of the studies carried out in the present tokamaks involved in the PEX activities (around 2022-2023). The present strategy implies a severe effort on the design of DTT since the available space and the port locations must be compatible with all considered divertor options.

The main objectives of the activity are the definition of remote handling (RH) strategies for the replacement of the different DTT divertor options. DTT will operate in deuterium with expected 2.5MeV, neutron yield rate of $1.0 - 1.5 \cdot 10^{17} n/s$ and a total neutron production of $3 - 4 \cdot 10^{22}\, n$. The short/medium term activation is not negligible, making remote handling mandatory. This will have an impact on the divertor design and on the port locations and dimensions. Very reliable and robust remote handling techniques will be necessary to manipulate and exchange components weighing up to 4 tonnes.

After a starting period consisting in a preparatory phase to familiarise with the topic and issues, the candidate is supposed 1) to produce design schemes and fabrication plans of DTT alternative divertor target mock-ups on the basis of up-to-date technology, and 2) to develop RH strategies for the proposed divertor solutions.

The candidate is required to have:

- A background in 3D modelling and control, CATIA V5 (including DMU kinematics simulator and, optionally, plant layout), DELMIA.
- A background in static and dynamic structural analyses (FEA).

It is foreseen that this activity will be performed in close collaboration with the project partners within EUROfusion, possibly including external research groups. Due to the highly integrated and international nature of the project, it is essential requirement for the candidate to possess good skills of organisation and communication. The candidate will be consulted and supported by the supervisor and the Project Leader with regard to scientific and administrative affairs, but high degree of self-initiative is also desired.

Main Work Package: WPDTT1-ADC

Interlinks with other Work Packages: WPDIV, WPRM

Facilities to be used: --

WP HEATHING AND CURRENT DRIVE SYSTEMS

16. Caesium evaporation and dynamics in large Radio-Frequency driven negative ion sources for Neutral Beam Injection

Position ref. EEG-2019/16

Contact persons: Ursel Fantz ursel.fantz@ipp.mpg.de and Gianluigi Serianni gianluigi.serianni@igi.cnr.it

Job Description:

Neutral beam injection is one of the main heating and current drive mechanism for future fusion devices. On ITER two beamlines with large radio–frequency driven ion sources (1 × 2 m^2) will be installed, delivering a heating power of 16.7 MW each. Negative ions (H^-/D^-) are accelerated up to 1 MeV, neutralized and injected into the torus for 1 h. The production of negative ions inside the source is mainly achieved by surface conversion of atoms and ions on the plasma grid surface which is covered by a thin caesium layer in order to reduce the work function. The caesium is evaporated into the source by one or several ovens and redistributed inside the source during plasma operation. The goal is to assure a thin caesium layer (typically one monolayer), homogeneously deposited over the size of the plasma grid and stable throughout the pulse time of 1 h.

The successful applicant for this project will participate in the operation of the test facilities for the ITER NBI placed in Garching, Germany (ELISE and BATMAN) and in Padua, Italy (SPIDER). The activity will focus on the investigation of caesium distribution and dynamics and on the optimization of the effectiveness of caesium in generating negative ions. Applicant's contributions are expected to the optimization of the evaporation cycles and of caesium consumption as well as to improved oven and distribution concepts. Different source diagnostics (the implementation of which is not part of the Grantee's task) are available to measure the caesium evaporation rate from the oven (surface ionization detector) and the caesium distribution inside the source during the vacuum phase (laser absorption spectroscopy) as well as during the plasma phase (optical emission spectroscopy). The negative ion density in front of the plasma grid can be measured by cavity ring-down spectroscopy. These source parameters shall be correlated with the accelerated beam profile measurements for further optimization of the caesium management. In particular, the vertical uniformity of plasma and beam profiles should be addressed for the large ion sources ELISE and SPIDER. Principle investigations on the effectiveness and optimisation of caesium in generating negative ions will be performed at the test stands CATS and ACCESS. Furthermore the measurements shall be used to benchmark a caesium distribution code which is developed and used at IPP; the code will be applied to interpret the measurements in the ion sources and in the test stands and to identify further effects, like the role of back-streaming positive ions releasing caesium from the source back plate.

The candidate will be introduced to the available diagnostics and will work in a team of skilled physicists, engineers and technicians. The results gained should help to improve the source caesium management, one of the key technologies for powerful and reliable negative ion beams.

Eligibility: Scientists with an MSc or PhD in Physics or Engineering; preferences will be given to experimentalists with experiences in caesium handling and caesium diagnostics (e.g. spectroscopy).

EUROfusion Work Packages: WP Heating and Current Drive

Facilities to be used: Experimental time roughly equally shared among the test facilities at IPP, Germany (BATMAN and ELISE - Garching; ACCESS - Augsburg) and the test facilities in Padua, Italy (SPIDER, CATS).

WP HEATING AND CURRENT DRIVE SYSTEMS

17. Advanced assessment of density distribution and voltage holding around large Radio-Frequency driven negative ion sources for Neutral Beam Injection

Position Ref. EEG-2019/17

Contact persons: Piergiorgio Sonato piergiorgio.sonato@igi.cnr.it and Giuseppe Chitarin giuseppe.chitarin@igi.cnr.it

Job Description:

Neutral beam injection is one of the main heating and current drive mechanism for future fusion devices. For the ITER experimental reactor, two beamlines are foreseen, each delivering a heating power of 16.7 MW into the Tokamak plasma torus for a duration of about 1 hour. In each injector, negative ions (H^- or D^-) are produced in a radiofrequency driven plasma source (1 ×2 m^2), accelerated up to 1 MeV, neutralized and injected into the Tokamak plasma.

The production of negative ions in the source is based on the generation of a low-temperature plasma inside small chambers, named RF drivers, where H or D gas is injected and ionized by radiofrequency current flowing in a coil wound on the outside of each driver. The RF circuit voltage usually reaches values of some kV, which requires suitable level of insulation around the RF driver coils. However, according to the ITER HNB/MITICA design, the vacuum pressure on the back of the plasma source (where the driver coils are located) strongly depends on the gas conductance from the plasma source chamber to the back of the plasma source and from here to the vacuum pumps. The presence of obstacles to the gas flow (such as the electrostatic shields which are foreseen for -1 MV DC voltage holding to ground) could possibly produce an unfavourable gas pressure distribution, in the back of the ion source near the RF conductors. In this case, the Paschen curve could be approached from the low-pressure side , thus causing breakdowns discharges in the RF circuit.

The successful applicant for this project will contribute to the experimental and theoretical analysis of these voltage holding phenomena in presently operating experiments and to the prediction of their occurrences in the future ones.

The applicant will have the opportunity to participate in the operation of the test facilities for the ITER NBI placed in Garching, Germany (ELISE) and in Padua, Italy (SPIDER and

MITICA). The activity will focus on the investigation of gas pressure distribution around drivers in RF-driven NBI experiments and on developing possible solutions to mitigate the associated issues and risks, in particular in relation to the effect of an additional intermediate electrostatic shield (-400 or – 600 kV), which is being considered for the improvements of the -1 MV DC voltage holding capability.

The candidate will be introduced to the existing devices and the ongoing design/procurements and will work in a team of skilled physicists, engineers and technicians. The results gained should help to improve the knowledge and management of pressure distribution against voltage holding (both RF and DC fields) around the ion source, one of the critical issues for powerful and reliable negative ion beams.

Eligibility: Scientists with an MSc or PhD in Physics or Engineering; preferences will be given to applicants with experiences in numerical simulation of neutral particle distribution in different regimes. Experience in HV holding will also be an asset.

EUROfusion Work Packages: WP Heating and Current Drive

Facilities to be used: Experimental time dedicated mainly to the test facilities in Padua, Italy (SPIDER and MITICA), with reference also at IPP-Garching, Germany (ELISE). Additional information from experiments at QST-Naka will be available thank to the existing collaboration between Consorzio RFX and QST.