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NETWORK OF SMALL AND MEDIUM SIZE MAGNETIC CONFINEMENT FUSION DEVICES FOR FUSION RESEARCH

Report of the First Research Coordination Meeting

IAEA Headquarters, Vienna, Austria

8–11 October 2018

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FOREWORD

The first Research Coordination Meeting (RCM) of the Coordinated Research Project (CRP) on "Network of Small and Medium Size Magnetic Confinement Fusion Devices for Fusion Research" was held 8–11 October 2018 at IAEA Headquarters in Vienna with 22 participants from 18 Member States: Bulgaria, Canada, China, Costa Rica, Czech Republic, Islamic Republic of Iran, Lebanon, Malaysia, Mexico, Pakistan, Portugal, Russian Federation, Singapore, Slovenia, Spain, Thailand, Ukraine and United Kingdom.

This CRP is based on a previous project, "Utilization of the Network of Small Magnetic Confinement Fusion Devices for Mainstream Fusion Research," organized and conducted by the IAEA in 2011–2016, which focused solely on the network of small magnetic devices. This new CRP, planned to last four years, is specifically geared toward networking laboratories that use small and medium size magnetic confinement devices.

Given the arduous technical challenges involved in fusion research, the work is necessarily collaborative. Around 50 IAEA Member States are involved in plasma physics and fusion research, and together they are equipped with over 50 toroidal magnetic confinement devices—but around 40 additional small and medium size machines are also operational across 15 Member States.

Researchers working with small and medium size devices are making significant contributions toward achieving controlled fusion energy. The potential impact of closer collaborations among them are even more significant.

With the next generation of large-scale fusion devices, such as ITER in France, preparing for operation, laboratories with small and medium size devices have great potential to help push the research agenda forward. By establishing and sustaining a network of laboratories that will perform joint and comparative experiments, train personnel across institutions and Member States, and educate a new generation of fusion scientists in cutting edge theories and techniques, this CRP aims to advance fusion research by building strong ties between research groups and training future fusion experts.

The IAEA Scientific Secretary of the meeting was Sehila M. Gonzalez de Vicente of the Division of Physical and Chemical Sciences.

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1. BACKGROUND

The beginning of construction of the ITER reactor is accompanied by an apparent increase in fusion research activities all over the world. Many countries have or would like to have a national fusion programme and experimental fusion facilities. Without such facilities it is difficult to develop the required expertise in fusion science and technology in order to be able to take advantage from the progress leading to the use of fusion power in the future. Today, more than 50 magnetic confinement fusion devices (tokamaks, stellarators and others) are operational, under construction or being upgraded, of which more than 40 are compact fusion devices. About 50 IAEA Member States are involved in plasma physics and fusion research.

Small and medium size magnetic confinement fusion devices have played and continue to play an important role in fusion research. Thanks to their compactness, flexibility, low operational costs and the high skill of their personnel, they contribute to a better understanding of phenomena in a wide range of fields such as plasma confinement and energy transport, plasma stability in different magnetic configurations, plasma turbulence and its impact on local and global plasma parameters, processes at the plasma edge and plasma–wall interaction, scenarios with additional heating and non-inductive current drive. Research on small and medium size fusion devices has created the scientific basis for scaling up to larger facilities. In addition, these devices offer the attractive possibility for developing and testing new diagnostics, materials and technologies in the most efficient manner in terms of time and cost. Moreover, the experimental work is very appropriate for educating students, conducting scientific activities for postgraduate students and training personnel for larger fusion devices. Previous IAEA efforts in this area strived to establish a framework for cooperation of small magnetic fusion devices with the aim to coordinate research through the exchange of information and equipment, scientific visits and joint experiments. This concept has clearly demonstrated its value and potential for enhanced international collaborations and increased the impact of the small fusion devices. The purpose of the previous CRP on “Utilisation of a Network of Small Magnetic Confinement Fusion Devices for Mainstream Fusion Research”, organized and conducted by the IAEA in 2011–2016, was to continue the promotion of coordinated research activities with small magnetic confinement fusion devices with the view to streamline their contribution to the next generation of fusion facilities.

This new CRP “Network of Small and Medium Size Magnetic Confinement Fusion Devices for Fusion Research” follows the recommendation given by experts to broaden the framework established through the previous CRPs to increase the contribution of magnetic confinement fusion devices for successful fusion energy development. Hence, the proposed CRP seeks to maintain and broaden the network of magnetic confinement fusion devices that have been used to perform joint and comparative experiments in support of plasma physics research, technology development, modelling analysis and development of simulation and software tools. This will provide opportunities for more Member States to join the research efforts and contribute to the success of magnetic confinement fusion. The objectives of the CRP are:

- To study turbulence and transport, including the role of electric field and possible mechanisms of turbulence self-regulation;
- To investigate edge and core plasma physics, including the coupling between them;
- To study the features and the mechanisms of the isotope effect and their relevance to plasma transport;
- To investigate magnetohydrodynamic (MHD) activity and related fast particle physics;

- To test materials and technologies for liquid metal, high temperature superconductors, functional materials, advanced fuelling, modular vacuum vessels and complex geometry coil manufacture;
- To optimize the startup phase and plasma breakdown;
- To improve the coupling of energy transfer by the auxiliary heating systems;
- To develop new computational techniques for modelling plasma processes, in particular for real time analysis requiring high data volume processing;
- To develop and model new advanced diagnostics;
- To establish a program on education and training among the participants in the CRP encouraging the contribution of developing countries.

The objectives of this first RCM were to present the research activities of each project, classify each research topic, identify joint research interests and establish a working plan for the CRP.

At this meeting, CRP participants presented their current and future research plans and discussed activities to continue the promotion of coordinated research on small and medium size magnetic confinement fusion devices to streamline their contribution to next step fusion facilities. This has allowed the identification of common objectives and similar work among the participants, fostering the development of future synergies.

2. PROPOSED RESEARCH ACTIVITIES

Each chief scientific investigator presented a description of their proposed CRP related research activities as well as ongoing activities. A summary of these research proposals is given below. The proposed activities were organized under the following topics:

- Startup/New/Upgrade Device
- Research
- Diagnostics and Technology Developments
- Training/Education
- Joint Experiments

2.1. STARTUP/NEW/UPGRADE DEVICE

2.1.1. Characterization and Optimization of Plasma Produced Inside the SCR-1 Stellarator, *Iván Vargas-Blanco, TEC, Costa Rica*

Main research activities proposed

- To design and implement a bolometer as a magnetic diagnostics device capable of measuring the total amount of electromagnetic radiation derived from plasma produced inside the SCR-1 stellarator.
- To design and implement the following magnetic diagnostic instrumentation: (1) diamagnetic loop, (2) Rogowski coils and (3) Mirnov coils capable of measuring magnetic flux variation and energy contained in plasma produced inside the SCR-1 stellarator.
- To simulate the interaction between plasma produced by the SCR-1 stellarator and electromagnetic waves derived from an electron cyclotron resonance heating (ECRH) system based on the geometry and materials that comprise the SCR-1 vacuum chamber.
- To design an antenna or mirror systems for the ECRH system that allows the optimization of energy deposition in plasma produced by the SCR-1 stellarator.

Objective of the research

To characterize plasma produced inside the SCR-1 stellarator with the assistance of IPF-FDMC full wave simulation codes and a magnetic diagnostics system capable of measuring electromagnetic radiation, magnetic flux variations and energy contained in plasma.

2.1.2. Plasma Turbulence and Transport Characteristics of Discharges with Different Plasma Species, *Abd. Halim bin Baijan, MNA, Malaysia*

Main research activities proposed

The main research activities proposed are to extend the usefulness of the MNA plasma focus device for applications. It is important to better understand the fundamental processes in hot dense plasmas, as well as to optimize the plasma focus device for specific application. Various gas species and their mixtures will be used and studied.

Objective of the research

To apply the plasma focus device for material testing.

2.1.3. Plasma Startup Studies with a Spherical Tokamak, *Shahid Hussain, NTFP, Pakistan*

Main research activities proposed

In the framework of the present CRP, a small metallic spherical tokamak of the same size as that of GLAST-II (R = 15 cm, a = 10 cm and B_T = 0.1 T) will be commissioned. The main focus on this tokamak will be on plasma current startup studies. In order to reduce the requirements of the loop voltage, multiple pre-ionization sources will be used, e.g. RF sources of 2.45 GHz (1 kW and 3 kW), heated filaments and electron injector. A lithium coating technique will be implemented to reduce the impurity influx and improve the plasma conditions. An additional further high temperature superconductor (HTS) can be a good replacement of low temperature superconductor (LTS) in large devices. A study will be performed on low-cost HTS coil fabrication. Some important diagnostics will also be developed.

Objective of the research

An operational small spherical Tokamak with minimum flux consumption during the plasma breakdown and startup phases.

2.1.4. Plasma Scenarios and Physics Investigations for Development and Installation of the Thailand Tokamak I Programme, *Boonyarit Chatthong, PSU, Thailand*

Main research activities proposed

- To investigate and develop plasma scenarios (both for L mode and H-mode) for the future Thailand Tokamak I (TT-1) using three integrated predictive modelling codes: BALDUR, CRONOS, and TASK codes;
- To investigate the necessary criteria for L–H transition in TT-1;
- To investigate the possibility of optimized operation in order to form an internal transport barrier and further increase plasma performance in TT-1;
- To investigate and model impurity transport and accumulation in TT-1;
- To use the results as a basis for development and installation of TT-1;
- To develop human resources, knowledge and research on plasma fusion in Thailand;
- To gain a fundamental understanding of the dynamics of the scrape-off layer (SOL) of plasma by developing the one-dimensional and two-dimensional models based on fluid description that also take into account of the intermittent transport in the SOL;
- To investigate the time-dependent magnetic fields topology of TT-1 using for the input of the three integrated predictive modelling codes;
- To understand intermittency in plasmas;
- To study the role of nonlinear terms in the set of MHD equations.

Objective of the research

To prepare Thai researchers for the first Thailand tokamak programme. It involves using integrated predictive modelling codes to investigate and develop plasma scenarios for the new tokamak. Three predictive codes, i.e. BALDUR and CRONOS in collaboration with the French Alternative Energies and Atomic Energy Commission (CEA) and TASK in collaboration with Prof. Fukuyama, Japan, are available for study. Each code will be individually run using the same setup and scenarios, then the results will be benchmarked for comparison and assessment for their predictive capabilities. Optimized plasmas scenarios are expected to be the final results of these simulation study. The results then will be compiled and presented to the committee for operational recommendation of TT-I.

2.1.5. Research and Training in Thermonuclear Fusion Using the Lebanese Linear Plasma Device, *Ghassan Antar, AUB, Lebanon*

Main research activities proposed

To investigate plasma properties as a function of the main control parameters such as neutral pressure and magnetic field. Instabilities and the consequent dynamics of turbulence, which arise from the various gradients generated by the confinement of the plasma, will follow. Also, to address the question of instabilities and turbulence in confined plasmas, as turbulence is the main source of confinement degradation in toroidal fusion devices. These topics are still highly relevant for ITER. Our setup allows us to test new ideas on diagnostics, which could be beneficial for ITER. For example, developing fast Langmuir probe measurements with each probe tip having the capability to operate independently of the others, fast visible and ultraviolet imaging. Controlling turbulence using a set of electrodes biased with respect to each other is our proposal to control turbulence. We will spread information about thermonuclear fusion in Lebanon and the Middle East by recruiting students from our region, opening our facility to external scientists and publishing our work in international peered review journals.

Objective of the research

With this project, we are embarking on an exciting journey into plasma physics and the thermonuclear fusion world, where the fields of physics, electrical and mechanical engineering complement each other in a highly challenging environment. This proposal thus combines three different areas of expertise in an enriching experiment that is on the forefront of science and technology. Thermonuclear fusion energy is one of the most promising routes for energy production for the future. Particularly magnetic confinement of hot and dense plasma is attractive, as reflected in a recent agreement to build ITER in France.

2.1.6. ST40 Experimental Studies, *Mikhail Gryaznevich, TE, United Kingdom*

Main research activities proposed

This project has five main research lines, where the following activities are foreseen:

- Experimental studies on the ST40 tokamak;
- Development of merging–compression plasma formation on the ST40;
- Investigation of plasma performance under neutral beam heating;
- Investigation of divertor performance and tests of Li divertor;
- Investigation of plasma vertical stability with optimised passive plates;
- Experiments exploring advanced core fuelling concepts.

Objective of the research

To demonstrate operations of the high field ST as a prototype of an ST based compact fusion reactor.

2.1.7. MHD Behaviour during Plasma Startup, Current Ramp-Up and Ramp-Down in a Spherical Tokamak, *Gao Zhe, Tsinghua University, China*

Main research activities proposed

- Development of advanced diagnostics with high spatial and temporal resolutions;
- To study the MHD behaviours in the SUNIST spherical tokamak, including kink/tearing instabilities during the current ramp-up and IREs/TAEs during ramp-down;
- To explore an effective way to reduce the effects of the fierce MHD activity during the current rise, so as to find a practical scenario for efficient current startup for spherical tokamaks;
- To explore a safer current ramp-down scenario, in which the energy and percentage of runaway electrons can be decreased, and the resilience of the plasma is increased.

Objective of the research

To investigate and understand major MHD activities during the current ramp-up and ramp-down of plasma current and to explore an effective way to control these activities.

2.2. RESEARCH

2.2.1. Development of New Advanced Diagnostics in the IR-T1 Tokamak, *Sakineh Meshkani, IAU, Islamic Republic of Iran*

Main research activities proposed

- Design and fabrication of a runaway electron probe for study of energetic flow of runaway electrons in the plasma edge. This probe can detect high energy radiation of plasma such as gamma and beta rays in IR-T1 tokamak. Also, we are going to control plasma energy loss by applying external electric and magnetic fields. For this goal, different techniques such as biased voltage and resonant magnetic perturbation (RMP) will be utilized. The technical characteristics of the biasing system and RMP in the IR-T1 lab are as follows.
  i. The power supply: high voltage and high current; capacitor bank: AC power, bias voltage: $-380\text{ V} < V < +380\text{ V}$; bias current: $-40\text{ A} < I < +40\text{ A}$; and finally, a biased limiter that can move a maximum of 1.25 cm inside the plasma.
  ii. The RMP in IR-T1 is created by two sets of local helical fields that are installed outside the vacuum vessel. The minor radii of these helical windings are 22 cm ($L = 2$; $m = 2$, $n = 1$) and 23 cm ($L = 3$; $m = 3$, $n = 1$).
- SXR tomography system: Our plan for the second and third years is design and fabrication of two 32 channel SXR detectors (LD-35 photodiode) distributed around a poloidal plasma cross-section. The cameras will be separated by an angle of 90° and positioned close to the plasma edge. A filter made of Al with two different thicknesses will be installed on the photodiodes. The title of this research is “Study of Saw-Tooth Oscillations and Measurement of Electron and Density of Plasma.” Also, for first time we can investigate plasma shape and position by SXR tomography and control.
- Design and construction of a gas puffing system: There are usually three main fuelling methods, pellet injection, gas puffing and supersonic molecular beam injection. Condensed hydrogen pellets can deeply penetrate the core plasma with a high injection velocity, but it is more expensive and needs more complex equipment than the other two methods. Gas puffing does not require many complex techniques and does not cost so much. We will design and fabricate a gas puffing system with a high accuracy of 1 ms. This system will be

able to puff different gases (H, Ar, He) into the chamber during plasma operation to improve plasma confinement.

Objective of the research

The main research activity proposed in this contract is the development of new advanced diagnostics for the IR-T1 tokamak, such as a runaway electron probe and soft X-ray (SXR) tomography system. For this purpose, we are going to design and fabricate some useful diagnostics.

2.2.2. Langmuir Probe Diagnostics of the SOL and Tokamak Edge Plasma, *Tsviatko Popov, St Kliment Ohridski University of Sofia, Bulgaria*

Main research activities proposed

- Development and testing of advanced instrumentations and techniques for tokamak edge plasma diagnostics by large Langmuir probes, new electronic probe circuits, the first derivative probe technique, the triple probe technique for magnetized plasma, etc.
- Precise evaluation of the radial distribution of the plasma potential and electron energy distribution function (EEDF) in tokamak edge plasma at different poloidal locations, including the divertor region. Measurements will be performed at different discharge conditions by Ohmic and NBI heating with different fuelling gases such as deuterium and helium.
- Calculation using the results for the EEDF obtained of the parallel power flux densities in the midplane and divertor region for attached plasmas and during impurity seeding experiments for obtaining the detached regime. This should optimize the specification of plasma facing materials.
- Testing validity of the results from a new advanced first derivative probe technique (FDPT) by comparing experimental results with parallel kinetic particle-in-cell (PIC) simulations in order better to understand the role of atomic physics processes occurring in tokamak SOL plasmas.

Objective of the research

It is known that ITER will operate with strong impurity seeding at the edge, and we believe that a better understanding of the role of atomic physics processes occurring in tokamak SOL plasmas will have a strong impact not only on the plasma–wall interaction community but on the whole fusion community also and should be thoroughly assessed. It will be done by developing novel plasma diagnostics and obtaining by them new information for main plasma parameters in different regimes of fusion devises. All of this will enhance education of Master’s and PhD students and increase the skills of personnel.

2.2.3. Fuelling and Confinement Studies on the STOR-M Tokamak, *Chijin Xiao, University of Saskatchewan, Canada*

Main research activities proposed

The proposed project will focus on research and training using the STOR-M tokamak and the University of Saskatchewan Compact Torus Injector (USCTI) to investigate the viability of direct central fuelling of tokamak and sustained momentum injection by repetitive compact torus injection. Improved confinement triggering will be studied using various techniques combined with chamber wall treatment with lithium coating. In addition, the mechanism of RMP induced modification of plasma flow will be investigated.

Objective of the research

To clarify the mechanism of Ohmic H-mode triggered by various means and maintain by repetitive, alternate and simultaneous triggering techniques such as multiple electrode biasing pulses using a programmable power supply, compact torus injection and RMP. Another goal is to clarify the mechanism of toroidal velocity modification induced by tangential compact torus injection and RMP and the associated momentum transport mechanism.

2.2.4. Edge Plasma Studies on the COMPASS Tokamak, *Jan Stockel, IPP Prague, Czech Republic*

Main research activities proposed

- Liquid metals: Install into the divertor a test target based on a capillary porous system filled with liquid lithium/tin. This single target will be inclined toroidally in order to be exposed to an ITER relevant surface heat flux (30 MW/m^2). Significant lithium vaporization is expected. The scientific programme will focus on operational issues (redeposition of the evaporated metal, ejection of droplets, etc.) as well as effects on the plasma physics (improvement of plasma confinement, L-H power threshold, Zeff, etc.).
- Divertor biasing: Develop two techniques of broadening of the power flux deposition footprint during the edge localized mode. The divertor tiles are not biased by power sources, but each odd tile in a single toroidal angle is insulated from the vessel, while each even tile grounded to the vessel at fixed potential. Since the local floating potential is often different from the grounded zero, this creates flux tubes connected to individual tiles at different plasma potentials. The difference in potentials in the flux tubes then creates a radial electric field, which leads to poloidal E × B drift, pushing the plasma away from the strike points.

Alternatively, a localized gas puff of impurities (Ne, N_2) close to the strike point in the divertor along a magnetic field line will cool the corresponding flux tube and consequently reduce the local heat flux to the strike point.

Objective of the research

To contribute to understanding of plasma–wall interactions for next generation fusion facilities.

2.2.5. Training Centre to Study Core and Edge Plasma Turbulence, Plasma–Surface Interaction and Plasma Facing Materials, *Valery Kurnaev, National Research Nuclear University MEPhI, Russian Federation*

Main research activities proposed

- Combined studies of the core and edge plasma turbulence, plasma–wall interaction and plasma facing materials for magnetic fusion devices to provide extensive and comprehensive research in the area edge plasma physics relevant for ITER and DEMO;
- Modelling of the edge and divertor plasma processes by SOLPS code;
- Study of hydrogen isotope co-deposition with Li in laboratory devices and tokamaks;
- Study of Li transport in the SOL by tokamak experiments and modelling in SOLPS;
- Study of plasma interaction with tungsten samples;

- Development and tests of novel methods of plasma–surface interaction (PSI) diagnostics;
- Preparation and organizing of CRP joint experiments.

Objective of the research

Through experiments, diagnostic development and validated modelling contribute to fundamental understanding of electrostatic turbulence, the effects of electric fields on electrostatic turbulence and the complex interaction of high flux plasmas and plasma facing materials (erosion, H/D retention, surface modification, etc.), which are key milestones for the start of ITER operation.

2.2.6. Effects of the Radial Electric Field on Transport in the TJ-II Stellarator and T-10 Tokamak, *Cesar Romeo Gutierrez Tapia, ININ, Mexico*

Main research activities proposed

- Analysis of differences between E_r values obtained from experimental results and those obtained from neoclassical (NC) models in the TJ-II stellarator and T-10 tokamak with ECRH, NBI and Ohmic heating;
- Study of formation of electron internal transport barriers related with the electron temperature gradient in the TJ-II stellarator;
- Study of improved confinement regimes induced by the E_r in the TJ-II stellarator subjected to an external biasing voltage induced by an external electrode;
- Study of the turbulent particle flux in the core plasmas as measured by heavy ion beam probe (HIBP), statistical characteristics and moments.

Objective of the research

- Set limits to the applicability of the NC approach to model the electrostatic potential in the TJ-II stellarator and T-10 tokamak measured by HIBP diagnostics;
- Provide possible explanations for the contributions not accounted for by NC theory to reproduce profiles, such as suprathermal particles, in the discharges of the T-10 tokamak and TJ-II stellarator;
- Complete a systematic study of biasing schemes to modify plasma confinement in stellarators.

2.2.7. Microwave Preionization in Tokamaks, *Nikolai Timofeev, Saint Petersburg State University, Russian Federation*

Main research activities proposed

Detailed study of processes during the preionization phase during microwave breakdown in the GUTTA tokamak, including non-resonance ionization and implementation of preionization regimes in the new T-15 tokamak at the Kurchatov Institute, Russian Federation.

2.2.8. Development of Heavy Ion Beam Probe Diagnostics for Small and Medium Size Fusion Devices, *Alexander Melnikov, NRCKI, Russian Federation*

Main research activities proposed

The main idea of the project is to create an interest in the community of small and medium size fusion devices to study plasma confinement with links to plasma electric potential and turbulence and at most to organize this multi-machine study.

The following specific tasks are proposed:

- Calculation of HIBP probing beam trajectories and sample volume locations for multi-slit energy analyzers of the medium size fusion devices T-l0 and GLOBUS-M2 tokamaks and TJ-II and Heliotron-J stellarators;
- Calculation of ion trajectories inside the electrostatic energy analyzers for the mentioned devices;
- Design of a multichannel beam detector;
- Design of a steerable support system for the beam detector;
- Design of a high bandwidth, low noise multichannel preamplifier compatible to high vacuum conditions;
- In-situ testing of a designed preamplifier;
- Study of the geodesic acoustic modes (GAMs), Alfvén eigenmodes and broadband plasma turbulence in the T-10 tokamak and the TJ-II stellarator with new beam detectors.

Objective of the research

To increase the HIBP diagnostic capabilities and reliability of HIBP operation, aiming to make HIBP a routine diagnostic for small and medium size fusion devices.

2.2.9. Fusion Physics and Technology Studies at the TJ-II Stellarator, *Kieran Joseph McCarthy, Laboratorio Nacional de Fusión, CIEMAT, Spain*

Main research activities proposed

The main research activities proposed are experimental and theoretical studies of plasma fuelling by pellet injection in stellarators.

Objective of the research

To enhance international collaborations in the areas noted above and contribute to achieving a better understanding of pellet ablation (cryogenic and TESPEL), drift and diffusion, and deposition.

2.2.10. Kinetic Approach to Modelling and Measurements in the SOL of Tokamaks, *Jernej Kovačič, Jožef Stefan Institute (JSI), Slovenia*

Main research activities proposed

- Development of a kinetic SOL model using PIC simulations, focusing on source and sink modelling and collisional processes. The bulk of this work will be done using the BIT1/2 code suite and compared to, or with an input from, advanced probe technique results obtained from devices collaborating in this project.

- Support in radial measurements of precise evaluation of EEDF and plasma potential in the SOL of tokamaks at different poloidal positions in different operational regimes and with different fuelling gases. Measurements of turbulent plasma properties using electric probes, correlation of the obtained results to bulk parameters, e.g. parallel heat and total energy flows and generation of improved boundary conditions.
- Research and development of advanced diagnostic techniques using electrostatic probes, e.g. first derivative probe technique (FDPT), tunnel probe and triple probe technique.

Objective of the research

Using the proposed experiments and modelling we intend to improve our understanding of the SOL physics of current tokamaks, which could in future be extrapolated to ITER. One of the main issues of energetic fusion feasibility lies in the exhaust of fusion reactors. The SOL, which constitutes the exhaust of tokamaks, contains a complex plasma that is mostly not in thermodynamic equilibrium. Many non-elastic collisions, strong electric fields and different transport processes lead to a very non-linear behaviour of plasma. Therefore, it is very difficult to predict important quantities such as heat fluxes with enough precision. With advanced probe measurements and fully kinetic numerical modelling we hope to gain further insight into the subject.

2.2.11. Investigation of Behaviour of RF Produced Plasma in Stellarators Uragan-2M and Uragan-3M, *Igor Garkusha, IPP-NSC KIPT, Ukraine*

Main research activities proposed

This proposal focuses on the following most critical issues important for plasma confinement in magnetic fusion devices, both tokamak and stellarator types:

- Development of novel advanced diagnostics, and in particular a prototype test of the method of non-homogeneous plasma study based on refraction of microwaves;
- Development and installation of multichannel optical systems for observation of different kind plasma fluctuations in U-2M and U-3M;
- Development and application of novel diagnostics for monitoring of wall conditioning by RF plasma in stellarator U-2M;
- Analysis of plasma MHD activity. Measurements of MHD activity will be performed in U-3M plasma using the set of magnetic probes poloidally distributed in one cross-section of U-3M;
- Measurement of plasma turbulence and transport characteristics in RF discharges with a mixture of gases;
- Study of divertor physics, including analysis of divertor flows in U-3M. Using the multi-lamellar electric probes, the flows at the regions where the divertor streams enter the walls of the helical winding casings will be studied;
- Application of HIBPs in U-2M for measuring fluctuations in plasma volume; comparison with data obtained with electric probes;
- Development of cleaning scenarios of vacuum chamber walls with RF produced plasma;
- Application of alkaline metal (Li or Na) atom beams for measuring fluctuation activity at the plasma periphery;
- Study of plasma response to biasing of B_4C limiter in U-2M;
- Operation of U-2M stellarator with a massive B_4C movable limiter for controlling the size of SOL thickness during working discharges.

Objective of the research

The proposed studies will contribute to collaborative investigations of CRP teams for several important aspects of plasma confinement in magnetic fusion devices, development of diagnostics for fusion devices, creation of effective wall conditioning scenarios and studies of RF plasma heating in tokamaks and stellarators. This will promote coordinated activity in mentioned areas within the network of different magnetic confinement fusion devices for mainstream fusion research.

Collaboration with other scientific teams within this CRP allows performing joint and comparative experiments in available experimental facilities. It will also allow training and education of young scientists in working at small fusion devices worldwide, with a variety of different diagnostics and participation in scientific schools for young scientists organized by CRP members.

2.2.12. Fast Particle and Thermal Energy Confinement in Spherical Tokamak Globus-M2, *Mikhail Patrov, Ioffe Institute, Russian Federation*

Main research activities proposed

On the basis of the spherical tokamak Globus-M2 infrastructure, we plan to focus on the following activities:

- To measure the characteristics of MHD activities in a wide frequency range and control their behaviour by RMP and other means;
- To measure plasma turbulence and transport characteristics of discharges with different plasma species (hydrogen, deuterium) and make a comparative analysis with other machines;
- To measure the MHD instabilities and in particular, characterise the Alfvén eigenmodes excited by the interaction of fast particles (NBI induced fast ions) and the thermal plasma component;
- To measure the magnetic and electrostatic turbulence, including GAMs, and rotation and transport characteristics in regimes with various heating scenarios such as Ohmic heating, microwave heating and NBI in tokamaks by a set of advanced diagnostics.

Objective of the research

The project involves experimental study of MHD instabilities, Alfvén eigenmode and GAM impacts on thermal energy and NBI induced fast ion confinement in the compact tokamak Globus-M2. The experiments will be carried out in Ohmic and neutral beam heated plasmas with different plasma and beam species (hydrogen or deuterium).

2.2.13. Plasma Focus Device and Diagnostics for Plasma and Fusion-Relevant Education, Training and Research, *Rajdeep Singh Rawat, NIE-NTU, Singapore*

Main research activities proposed

Several research groups in developing countries are keen to initiate plasma fusion research using small and medium sized alternative magnetic confinement devices. They need avenues and resource to get training on relevant devices and diagnostics. Our project aims to provide fusion-relevant experimental education and expertise development in developing countries through hands-on training and research on a dense plasma focus device using an array of plasma and nuclear diagnostics and material characterization techniques.

In the light of above-mentioned scope, we will focus on the following activities:

- Develop a few specialized training and research programmes/modules (T&R modules):
  i. T&R Module 1 - Theoretical, simulation (Lee Code) and experimental training on DPF device.
  ii. T&R Module 2 - Soft and HXR diagnostics training and research.
  iii. T&R Module 3 - Deuteron and neutron diagnostics training and research.
  iv. T&R Module 4 – Optical diagnostics training and research.
  v. T&R Module 5 - Material irradiation, synthesis and characterization training and research.
- Organize training programmes/modules specially designed for effective training and research on a plasma focus device for individuals or small groups and for larger groups at colleges.

Objective of the research

Develop well-structured training and research modules on (i) fundamentals; (ii) Lee code simulation; (iii) electrical, magnetic, X-ray, neutron, optical diagnostics; and (iv) application in material synthesis and processing of DPF devices. We aim to share technology and advanced research experiments on DPF devices under the aegis of the IAEA.

2.2.14. Scientific and Education Activities on the GOLEM Tokamak in the Framework of the IAEA CRP*, Vojtech Svoboda, FJFI, Czech Technical University, Czech Republic*

Main research activities proposed

The scientific activities focus on the field of plasma edge studies using advanced probe techniques and developing diagnostics for runaway studies. In the CRP context there are two planned education activities: GOMTRAIC, a week of hands-on experiments at the GOLEM tokamak, and a set of remote participation training courses.

NOTE: Research proposals under this topic also include some of the proposals described in Section 2.1, namely:

- Characterization and Optimization of Plasma Produced Inside the SCR-1 Stellarator, *Iván Vargas-Blanco, TEC, Costa Rica;*
- Plasma Turbulence and Transport Characteristics of Discharges with Different Plasma Species, *Abd. Halim bin Baijan, MNA, Malaysia;*
- Plasma Scenarios and Physics Investigations for Development and Installation of the Thailand Tokamak I Programme, *Boonyarit Chatthong, PSU, Thailand;*
- ST40 Experimental Studies, *Mikhail Gryaznevich, TE, United Kingdom*;
- MHD Behaviours during Plasma Startup, Current Ramp-Up and Ramp-Down in a Spherical Tokamak, *Gao Zhe, Tsinghua University, China.*

2.3. DIAGNOSTISCS AND TECHNOLOGY DEVELOPMENT

Research proposals under this topic include some of the proposals described in Section 2.1–2.2, namely:

- Characterization and Optimization of Plasma Produced Inside the SCR-1 Stellarator, *Iván Vargas-Blanco, TEC, Costa Rica;*
- Plasma Startup Studies on a Spherical Tokamak, *NTFP, Pakistan*
- MHD Behaviours during Plasma Startup, Current Ramp-Up and Ramp-Down in a Spherical Tokamak, *Gao Zhe, Tsinghua University, China;*
- Development of New Advanced Diagnostics in IR-T1 Tokamak, *Sakineh Meshkani, IAU, Islamic Republic of Iran*;
- Development of Heavy Ion Beam Probe Diagnostics for Small and Medium Size Fusion Devices, *Alexander Melnikov, NRCKI, Russian Federation;*
- Investigation of Behaviour of RF Produced Plasma in Stellarators Uragan-2M and Uragan-3M, *Igor Garkusha, IPP-NSC KIPT, Ukraine;*
- Scientific and Education Activities on the GOLEM Tokamak in the Framework of the IAEA CRP, *Vojtech Svoboda, FJFI, Czech Technical University, Czech Republic.*

2.4. TRAINING/EDUCATION

2.4.1. Course on Tokamak Engineering, Diagnostics and Operation, *Horacio Joao Matos Fernandes, IST Lisbon, Portugal*

Main research activities proposed

The proposed research activity is oriented to develop experimental skills in tokamak engineering and operation for the appointed trainees. It is based on live training actions and courses. During the planned lessons, the trainees will become acquainted with most diagnostics and techniques for tokamak operation and control algorithms for assisted tokamak discharges. Those lessons are complemented with practical sessions on the Instituto Superior Técnico Tokamak (ISTTOK) for discharge planning and plasma performance evaluation.

The course focus on engineering aspects, namely on the actuators such as the power supplies, gas inlet systems, vacuum grading and technical diagnostics. A general introduction to some popular diagnostics systems will be addressed both theoretically and practical, covering magnetic probes, Langmuir probes, spectroscopy, tomography, bolometry, interferometry and RGA technics.

The trainees have full accesses to ISTTOK data and will learn common productive software based on a numerical computing environment (Python) to analyse the data. By the end of the activity trainees will be grouped into teams whose purpose is to elaborate a research paper to be published in a conference or journal.

Objective of the research

To elaborate a research paper to be published in a conference or journal.

NOTE: Research proposals under this topic also include some of the proposals described in Section 2.1, namely:

- Characterization and Optimization of Plasma Produced Inside the SCR-1 Stellarator, *Iván Vargas-Blanco, TEC, Costa Rica*
- Scientific and Education Activities on the GOLEM Tokamak in the Framework of the IAEA CRP, *Vojtech Svoboda, FJFI, Czech Technical University, Czech Republic*

- Investigation of Behaviour of RF Produced Plasma in Stellarators Uragan-2M and Uragan-3M, *Igor Garkusha, IPP-NSC KIPT, Ukraine*
- Training Centre to Study Core and Edge Plasma Turbulence, Plasma–Surface Interaction and Plasma Facing Materials, *Valery Kurnaev, MEPhI, Russian Federation*
- Plasma Focus Device and Diagnostics for Plasma and Fusion-Relevant Education, Training and Research, *Rajdeep Singh Rawat, NIE-NTU, Singapore*

2.5. JOINT EXPERIMENTS

The joint experiment is one of the activities accomplished in the framework of the IAEA CRP on "Network of Small and Medium Size Magnetic Confinement Fusion Devices for Fusion Research," gathering contributors among the interested members of the CRP. The experimental research topics are selected according to each device peculiarities. In the past, most of such experiments were conducted on tokamaks, the most recent taking place in COMPASS (Czech Republic), STOR-M (Canada) and ISTTOK (Portugal). It is proposed to extend research to stellarators and other plasma devices.

Taking into consideration that such activities rely on a well-established laboratory to serve as a reference and is equipped with suitable diagnostics and data acquisition infrastructure, it is proposed to have joint experiments in middle size devices such as Uragan and TJ-II to take advantage of complementary studies on both machines. Both laboratories have already links and projects with most members of the CRP. To be effective in the experimental campaigns on these midsize devices, it is desirable to extend the duration of the experiment for 10 consecutive days.

Moreover, extending the joint experiments to fusion materials and plasma–wall interaction studies that can be performed on plasma focus and linear devices is suggested. These activities can be performed in a more concise and effective way with the possibility to be integrated into the coordination meeting with the participants present.

3. COORDINATED RESEARCH PLANS

Most of studies performed to date under CRPs on small fusion devices and joint experiments were dedicated to detailed studies of relatively low temperature plasmas, e.g. at the plasma edge or in the core of low temperature tokamaks and other devices. The result was an impressive number of publications, but better coordination is needed. Understanding the plasma periphery is now advancing, making this research much more meaningful for mainstream fusion research.

As it is understood, the edge plasma can be described in three ways: by fluid dynamics, thermodynamics and gyrodynamics. Apparently, all these mechanisms play a role in edge plasma transport. However, to separate the roles of these effects in large scale fusion experiments is not easy. For example, fluid dynamics is strongly affected by plasma density, which in tokamaks and stellarators is often determined by the plasma–wall interaction and pedestal parameters, both difficult to control or fit such experiments in busy experimental schedules. However, in small fusion devices both effects can be either controlled (i.e. by Li or other wall conditioning and by gas puffing) or affected without compromising the required high performance. For example, there is no problem to scan the density in a linear device.

Thermodynamic effects relate to the temperature of the peripheral plasma and the energy distribution function. It was shown that the probability distribution function is often non-Maxwellian; however, to study this, specific advanced diagnostics are needed, which are often absent on big devices and present on small ones. Also, it is easier to affect the edge temperature (i.e. by biasing, which changes the effect of turbulence) in smaller devices.

Gyro-orbit effects can be tested by varying the magnetic field, but this is quite restricted on large scale devices due to dependence on the performance of the toroidal field (e.g. in spherical tokamaks) and stability constraints. Such scans are much easier to perform on small devices.

Dedicated studies that can help to distinguish the roles of these different mechanisms can be performed in a scope of CRP activities and may be suggested as goals of joint experiments. The results of such studies can be used to verify different computational models with direct application to predicting plasma edge and divertor performance in future next generation devices.

The activities are organized under the following topics.

- Startup/New/Upgrade Device
- Research
- Diagnostics and Technology Developments
- Training/Education
- Joint Experiments

3.1. STARTUP/NEW/UPGRADE DEVICE

First year		
Tasks	**Deliverables**	**Inputs Needed / Remarks**
Activity 1: Commissioning of structures and support systems		
Procurement of vacuum chamber extension and its installation (*MNA, Malaysia*)	Various gases Many species gases for experiment	
Testing of the extended vacuum chamber and attachment of new chamber to the existing plasma chamber (*MNA, Malaysia*)	Vacuum connection Check vacuum tightness	
Installation of vacuum/gas systems, magnetic coil systems and diagnostics (*NTFP, Pakistan*)	Assembled tokamak device ready for testing and optimization	
Vacuum system operation and leak testing with helium leak detector and RGA (*NTFP, Pakistan*)	Chamber with vacuum $\sim 10^{-7}$ mbar	
Design and fabrication of HTS coils (*NTFP, Pakistan*)	Two vertical field coils for R&D studies	ST40 and other relevant CRP members
Design and development of Li coating system (*NTFP, Pakistan*)	Experimental setup for R&D on Li coating	ST40 and other relevant CRP members
Installation/ testing of power supply system and measurements of vacuum currents (*NTFP, Pakistan*)	Electrical power system ready for operation	
Upgrades and automatization of the LLPD (*AUB, Lebanon*)	Writing of the LabVIEW code to control the various components and installation and connection of the different equipment to the control unit	
Activity 2: Commissioning of diagnostics		
Magnetic field optimization for vertical null generation. Differential loops and magnetic probes will be used. (*NTFP, Pakistan*)	Device with minimum vertical field region to help plasma current startup process	
Testing and calibration of spectrometers, triple Langmuir probe and high-speed camera (*NTFP, Pakistan*)	Tokamak device ready for experimental studies	
Experimental setup of the plasma focus device with other equipment	Gases for experiment Plasma focus stability	

Preparation for experiment and gas connection (*MNA, Malaysia*)		
Plasma generation using different antennas designs (*AUB, Lebanon*)	Antenna design and manufacturing, followed by radiation pattern and electric and magnetic field profiles and plasma average properties using a Langmuir probe	
Activity 3: Machine performance		
Heating/baking and RF glow discharge cleaning and analysis with gas analyser (*NTFP, Pakistan*)	Vessel with reduced outgassing rate	
RF assisted pre-ionization studies and its dependence on power and polarization (*NTFP, Pakistan*)	Publishable results for optimized RF assisted pre-ionization	Interaction with GLOBUS-M and relevant CRP members
Resistively heated filament assisted pre-ionization (*NTFP, Pakistan*)		Interaction with COMPASS, GOLEM
Second year		
Activity 1: Commissioning of structures and support systems		
Cooling system for HTS coils (*NTFP, Pakistan*)		ST40 and other relevant CRP members
Activity 2: Commissioning of diagnostics		
Design bolometer diagnostic with control and data acquisition systems. Design and install three magnetic diagnostics devices with control and data acquisition systems in SCR-1. (*TEC, Costa Rica*)	Prepare report on tasks Prepare conference papers and journal papers	Information about components, control and data acquisition systems from other devices
Plasma generation using different antennas designs (*AUB, Lebanon*)	Antenna design and manufacturing, followed by radiation pattern and electric and magnetic field profiles and plasma average properties using a Langmuir probe	
Assessment of antenna coupling with the plasma and its properties (*AUB, Lebanon*)	Obtain the plasma properties for this antenna as we compare it to others Effects of the magnetic field and resonance on plasma generation	
Developing a multi-tip Langmuir probe for fluctuations measurement (Costa Rica)	The construction and test of a multi-tip Langmuir probe to	

	measure the plasma fluctuations	
Activity 3: Machine Performance		
Plasma current initiation using Ohmic startup (*NTFP, Pakistan*)	Research publication	SUNIST and other relevant members of CRP
External sources (RF, filament etc.) assisted plasma current initiation (*NTFP, Pakistan*)	Publication and data for comparison with GLAST	Interaction with GLOBUS-M and support for high power RF sources from relevant CRP members
Third and fourth year		
Activity 1: Commissioning of structures and support systems		
Design development of high field HTS coils (*NTFP, Pakistan*)		Interaction with ST40 and relevant CRP members
Activity 2: Commissioning of diagnostics		
Define, design and mount bolometer system for inside the SCR-1 and obtain estimates. Design, assemble and install 3 complete magnetic diagnostics systems for SCR-1. Assemble and mount bolometer to obtain estimates of EM radiation from SCR-1 plasma. (*TEC, Costa Rica*)	Prepare report on tasks Prepare conference papers and journal papers Report on plasma characterization Mechanical device to enable precise positioning of microwave beam	
Design and simulate a new bolometer for radiation measurements (*AUB, Lebanon*)	Feasibility of a new bolometer design	
Fabrication and test of a new bolometer (*AUB, Lebanon*)	A new bolometer that can withstand harsh environment	
Activity 3: Machine performance		
Long pulse plasma discharge operation (modification in power supply, coil system and impurity control) (*NTFP, Pakistan*)	Research publication	SUNIST and other relevant CRP members
Testing and installation of HTS coils (*NTFP, Pakistan*)	Vertical field coils for testing on the tokamak	Interaction with ST40 and relevant CRP members

3.2. RESEARCH

First year		
Tasks	**Deliverables**	**Inputs needed / Remarks**
Activity 1: Experiments on plasma focus and linear devices		
Experimental set-up of the plasma focus device with other equipment. Preparation for experiment and gas connection (*MNA, Malaysia*)	Gases for experiment Plasma focus stability	
Effects of the axial magnetic field and the role of the reflected power (*AUB, Lebanon*)	Investigate the role of the main magnetic field on the plasma properties for the four different antennas as well as that of the reflected power.	
Hydrogen isotope co-deposition with Li in laboratory devices (*MEPhI, Russian Federation*)	Results of measurements at MD-2 device with in-situ TDS analysis. Calibrated sample production for possible joint experiments.	
Theoretical, Simulation, and Experimental Research on DPF (*NIE-NTU-Singapore*)	Detailed characterization of ZnO thin films using XRD, SEM, EDX, Raman and XPS spectroscopy Publications	Two participants from Pakistan are undertaking these activities
Activity 2: Plasma Startup Studies		
Magnetic field optimization for poloidal field null generation (*NTFP, Pakistan*)	Configuration with minimum poloidal field region to help plasma current startup process	
RF assisted pre-ionization studies and its dependence on power and polarization (*NTFP, Pakistan*)	Publishable results for optimized RF assisted pre-ionization	Interaction with GLOBUS-M and relevant CRP members
Resistively heated filament assisted pre-ionization (*NTFP, Pakistan*)		Interaction with COMPASS, GOLEM
First plasma operations on ST40 (*TE, United Kingdom*)	First experimental campaign has been successfully completed with 800+ plasma pulses	
Optimisation of merging-compression startup on ST40 (*TE, United Kingdom*)	M/c formation has been demonstrated w/o use of the central solenoid. Expected parameters for Phase 0 achieved during operations in January–June 2018	

Achievement of keV range of plasma temperatures during plasma formation on ST40 (*TE, United Kingdom*)	1–2 keV ion temps have been achieved and measured with Doppler spectroscopy	
Carrying out experiments on GUTTA tokamak to study processes during preionization phase at microwave breakdown (*Saint Petersburg State University, Russian Federation*)		
Preparation of the experiment on the T-15 tokamak (*Saint Petersburg State University, Russian Federation*)	Definition of the experiment conditions for the T-15 tokamak	In collaboration with Kurchatov Institute, T-15 tokamak
Activity 3: Simulations and modelling		
BALDUR, CRONOS and TASK codes are used to simulate and investigate plasma scenarios for TT-1 in L mode (*PSU, Thailand*)	Predictions of temperatures, densities and rotation profiles	With our simulation capabilities, we are enthusiastic to compare our simulations results with experimental results from other machines
The simulation results are benchmarked for comparison and evaluation among the codes (*PSU, Thailand*)	Comparison of results	Experimental measurements of temperatures, densities and rotations
The time-dependent simulations of toroidal and poloidal fields power supply showing the relation between the charging voltage and current waveform of magnetic coils (*PSU, Thailand*)	The relation of the charging voltage of magnetic power supply and output current waveform of magnetic coils	
To develop the model to describe dynamics of SOL plasma (*PSU, Thailand*)	Modelling code for studying SOL plasma	Experimental results from other machines for comparison, especially for plasma profiles in the SOL and divertors or limiters
To run MHD simulations in multiple scenarios (*PSU, Thailand*)	The comparison of intermittency in multiple scenarios	
To compare the strength of nonlinear terms in multiple scenarios (*PSU, Thailand*)	The understanding of how nonlinear terms give rise to the intermittency	
Two-fluid simulation code using finite volume (*AUB, Lebanon*)	First version of a MHD one-fluid code using finite volume	

A more accurate plasma current profile reconstruction method for the radial probe array operation on SUNIST (*Tsinghua University, China*)	Experimental data; conference reports and published journal papers on experimental results	
Simulation of absorbed energy of each crystal by 3D Mont Carlo GEANT4 (*IAU, Iran*)	Interpretation of the achieved experimental results by numerical simulations	
Modelling of plasma edge and divertor processes with SOLPS code (*MEPhI, Russian Federation*)	Study influence of divertor plasma opacity on the transition to the detached divertor regime.	Transition to detached divertor regime studied for the cases of completely opaque and opaque to the Lyman–alpha plasmas Results of measurements at MD-2 device with in-situ TDS analysis
Compare NC approach to model transport and E_r for tokamak and stellarator using the TJ-II and T-10 devices (*ININ-Mexico*)	Set limits to the applicability of the neoclassical approach to model the electrostatic potential in TJ-II and T-10	HIBP data from both TJ-II and T-10 devices. ASTRA and DKES codes
Development of a 1d3v model of a single flux-tube in a SOL of a tokamak (*JSI, Slovenia*)	A fully kinetic model of a SOL tokamak for BIT1 code	In collaboration with NIS (Bulgaria) and COMPASS team
Enhancement of classic model approach with an improved source and sink (*JSI, Slovenia*)	Enhanced model with a turbulent source and anomalous diffusion sink	
The isotopic effect of Alfvén modes on the fast particle losses (toroidal magnetic field 0.4 T) (*Ioffe Institute, Russian Federation*)	The theoretical analysis of the experiments on TAE excitation by means of NBI in the Globus-M spherical tokamak	
Confinement time scaling (*Ioffe Institute, Russian Federation*)	The expansion of the energy confinement time dependence on the line average electron density using ASTRA code and diamagnetic measurements. ($\tau_E \sim B^X$)	
Development of the Globus-M2 calculation model (*Ioffe Institute, Russian Federation*)	The effect of sawtooth oscillations and internal reconnections on stored energy and energetic particles	

Activity 4: Experiments on stellarators		
Analyze the similarity of the potential evolution for TJ-II and T-10, to check the possibilities/limits of the NC approach (*ININ, Mexico*)	Set limits to the applicability of the neoclassical approach to model the electrostatic potential in TJ-II and T-10	
Characterization of divertor plasma flows with set of electric probes in U-3M (*IPP-NSC KIPT, Ukraine*)	Vertical asymmetry of divertor flows will be studied. Main driving factors will be clarified	
Determination of the position of the regions where the divertor streams hit the walls of the helical winding casings by the use of the multi-lamellar electric probes in U-3M (*IPP-NSC KIPT, Ukraine*)	Sources of impurities due to the charge exchange atoms will be identified	
Activity 5: Experiments on tokamaks		
To study impurity behaviour in L-mode plasma of TT-1 (*PSU, Thailand*)	Predictive results for impurity transport in TT-1	Experimental results for impurity profiles from other machines for code validation
Study of energetic flow of runaway electrons in plasma edge (*IAU, Iran*)	Energy spectra of runaway electrons in different plasma positions.	Materials and equipment will be provided by PPRC.
Investigation of high-energy radiations of plasma such as gamma and beta rays in IR-T1 tokamak (*IAU, Iran*)	Time evolution of beta and gamma rays	
Investigation of external electric field effect on high-energy radiations of beta and gamma (*IAU, Iran*)	Energy spectra of runaway electrons in plasma edge and SOL region, time evolution of beta and gamma rays	
Investigation of RMP effect on high energy radiations of beta and gamma (*IAU, Iran*)	Energy spectra of runaway electrons in plasma edge and SOL region, time evolution of beta and gamma rays	
Use pre-programmable power supply to bias the electrode with different voltage pulse waveforms (*Univ. Saskatchewan, Canada*)	Sustainability of H-mode induced by multi-pulse electrode biasing	Compare with results from other small tokamaks
Effects of lithium coating on nominal STOR-M discharge (*Univ. Saskatchewan, Canada*)	Characterization of improved plasma parameters expected	Compare with results from other tokamaks with plans for (or results of) wall conditioning with Li
Increase repetitive CT operation rate (*Univ. Saskatchewan, Canada*)	30 Hz bursting CT operation	

To study the MHD behaviours in the SUNIST spherical tokamak, including kink/tearing instabilities during the current ramp-up and IREs/TAEs during ramp down. Density profile reconstruction methods. (*Tsinghua Univ., China*)	Experimental data; conference reports and published journal papers on experimental results	
Radiation profile reconstruction methods on SUNIST (*Tsinghua Univ., China*)	Experimental data; conference reports and published journal papers on experimental results	
Hydrogen co-deposition with lithium in tokamaks (*MEPhI, Russian Federation*)	Analysis of hydrogen co-deposition with Li in T-11M	
Measuring micro and macroscopic quantities in SOL of COMPASS during seeding experiments (*JSI, Slovenia*)	Obtaining plasma parameters (EEDFs, n, T, V_{fl}, Φ_{pl})	In collaboration with NIS (Bulgaria) and COMPASS team
Improving the triple-probe technique for use in tokamak SOL (*JSI, Slovenia*)	Measurements with TPT and comparison with other methods	In collaboration with NIS (Bulgaria), COMPASS team and GOLEM team
Edge plasma studies on the GOLEM tokamak (*FJFI, Czech Republic*)	Characterization of the influence of plasma species mass and edge biasing on edge plasma parameters and turbulence	Remote/on site participation
Runaway studies on the GOLEM tokamak (*FJFI, Czech Republic*)	Experimental test of new various runaway detection techniques RE generation and behaviour studies	
Preionization–Microwave and UV with the GOLEM tokamak (*FJFI, Czech Republic*)		
Liquid metal divertors tests with the GOLEM tokamak (*FJFI, Czech Republic*)		
Second year		
Activity 1: Experiments on plasma focus and linear devices		
Experiments with argon, deuterium, neon and other gases (*MNA, Malaysia*)	Analysis of the experimental results	
The plasma properties generated by the new antenna (*AUB, Lebanon*)	Obtain the plasma properties for this antenna and compare it to others Effects of the magnetic field and the resonance on plasma generation	

Fluctuations measurements (*AUB, Lebanon*)	Perform the first fluctuations measurements and identify the type of instabilities present in our device	
Soft and HXR training and research (*NIE-NTU, Singapore*)	Measurement of nuclear tracks to estimate flux and anisotropy measurements Recording of plasma dynamics in DPF and study of plasma instabilities in DPF device Understanding deposition and processing dynamics Publications	Invite researchers and students Collaboration request: Help in (i) low temp. plasma diagnostics using Langmuir probe, (ii) Energy and thermal flux measurements in DPF devices (iii) Optical emission spectroscopy
Deuteron and neutron diagnostics training and research (*NIE-NTU, Singapore*)	Estimation of neutron yield	
Activity 2: Plasma Startup Studies		
Plasma current initiation using Ohmic startup (*NTFP, Pakistan*)	Research publication	SUNIST and other relevant members of CRP
External sources (RF, filament, etc.) assisted plasma current initiation (*NTFP, Pakistan*)	Publication and data for comparison with GLAST	Interaction with GLOBUS-M and support for high power RF sources from relevant CRP members
Optimization of flux consumption (*NTFP, Pakistan*)	Publication and parameters for future reference	SUNIST and other relevant members of CRP
Investigations of plasma breakdown and startup phase in U-2M (*IPP-NSC KIPT, Ukraine*)	Plasma breakdown and startup phase in U-2M will be investigated	
Experiments with plasma gun preionization & helicity injection on SUNIST (*Tsinghua Univ., China*)	Conference reports and published journal papers on experimental results	
Continuation of experiments on the tokamak GUTTA. Detailed study of processes during microwave breakdown in tokamaks. (*Saint Petersburg State University, Russian Federation*)	Optimization of the preionization regimes.	

Modernization of the preionization system of tokamak T-15 and the study of preionization regimes (*Saint Petersburg State University, Russian Federation*)		
Activity 3: Simulations and modelling		
BALDUR, CRONOS and TASK codes are used to simulate and investigate the criteria for L–H transition in TT-1 (*PSU, Thailand*)	Conditions and scenarios necessary to obtain H-mode	Suggestions of parameter lists that are important for L–H transition
BALDUR, CRONOS and TASK codes are used to simulate and investigate plasma scenarios for TT-1 in H-mode (*PSU, Thailand*)	Predictions for temperatures, densities and rotations in H-mode	We can also predict H-mode for other machines and compare the results
BALDUR, CRONOS and TASK codes are used to simulate and investigate heating system to improve plasma performance for TT-1 (*PSU, Thailand*)	Predictions for temperatures, densities and rotations during ICRF, ECRF, NBI heating and pellet injection	We are looking to design the heating systems based on current technology which best optimize small tokamak
The development of two-fluid code for the linear plasma device (*AUB, Lebanon*)	Transform the one-fluid to a two-fluid code and perform our first simulations of the plasma with an axial magnetic field	
Analyze data or perform simulations on influence of density gradients, fast electrons and radial electric field after pellet injection in TJ-II (*CIEMAT, Spain*)	Report on studies performed Prepare conference papers and journal papers	HIBP data & analysis (Kurchatov Institute & MEPhI Moscow, & NSC KIPT Kharkov) ASTRA Code (NINM)
Kinetic simulation of tokamak SOL with proper collisional module (*JSI, Slovenia*)	Completed study of effects of non-elastic collisions on SOL profiles	In collaboration with NIS (Bulgaria) and COMPASS team
Estimation of the parallel heat flux density in SOL during NBI (*JSI, Slovenia*)	Improved model for calculation of the heat flux density in SOL	In collaboration with NIS (Bulgaria) and COMPASS team
The isotopic effect of Alfvén modes on the fast particle losses (*Ioffe Institute, Russian Federation*)	The theoretical analysis of the experiments on TAE excitation by means of NBI in the Globus-M/-M2 spherical tokamak in wide range of B_T	
Confinement time scaling (*Ioffe Institute, Russian Federation*)	The expansion of the energy confinement time dependence on the line average electron density using ASTRA code	

	and diamagnetic measurements. ($\tau_E \sim B^X$) in wide range of B_T	
Development of the Globus-M2 calculation model (*Ioffe Institute, Russian Federation*)	The effect of sawtooth oscillations and internal reconnections on stored energy and energetic particles in wide range of B_T	
Simulation of hydrogen isotopes retention/reflection from Li covered plasma faced materials as function of thickness layer, ion energy and angle of incidence (*MEPhI, Russian Federation*)	Results of computer simulations for comparison with experimental data on hydrogen retention in deposited Li layers	
Activity 4: Experiments on stellarators		
Analyze the influence of plasma profiles to E_r profiles and to the $E \times B$ shearing in TJ-II. (*ININ, Mexico*)	Show the effect of density and temperature gradients on the L–H transition in both the NC and turbulent approaches.	HIBP data from TJ-II. ASTRA and DKES codes
Perform studies on influence of density gradients, fast electrons and radial electric field after pellet injection in TJ-II as programmed in timetable (*CIEMAT, Spain*)	Perform experiments and data analysis on TJ-II Report on studies performed Prepare conference papers and journal papers	HIBP data & analysis (Kurchatov Institute & MEPhI Moscow, & NSC KIPT Kharkov) ASTRA Code (NINM)
Testing the new antenna and studying different regimes of its operation (*IPP-NSC KIPT, Ukraine*)	Interim report	
Experimental studies of plasma fluctuations in U-2M and U-3M (*IPP-NSC KIPT, Ukraine*)	Comprehensive analysis of plasma fluctuations in Uragan-2M stellarator	
Activity 5: Experiments on tokamaks		
Apply the knowledge of intermittency in tokamak (*PSU, Thailand*)	A suitable quantity to measure intermittency in a tokamak	
Find the relationship between intermittency and the processes in a tokamak (*PSU, Thailand*)	The level intermittency in a tokamak when operated at several scenarios	
Measurement of SXR of plasma in IR-T1 Tokamak (*IAU, Iran*)	Time evolution of SXR of plasma, study of sawtooth oscillations and MHD instabilities	Materials and equipment will be provided by PPRC
Study of electron temperature and density of plasma (*IAU, Iran*)	Time evolution and radial profiles of electron temperature and density	Materials and equipment will be provided by PPRC

Experimental investigations of the EEDF in the divertor region of the COMPASS tokamak during neutral beam injection heating (*Univ. Sofia, Bulgaria*)	Experimental results for the poloidal distribution of the plasma potential, electron temperatures and densities	In collaboration with the tokamak COMPASS team.
Estimation of the parallel power flux density in the divertor region (*Univ. Sofia, Bulgaria*)	Poloidal distribution of the parallel power flux density in the divertor region of the tokamak COMPASS	In collaboration with the tokamak COMPASS and Slovenian teams
Experiments with deuterium and helium tokamak plasma (*Univ. Sofia, Bulgaria*)	Clarify the origin of the bi-Maxwellian EEDF in the vicinity of the LCFS and divertor region of the tokamaks	In collaboration with tokamak COMPASS, GOLEM and TG-II stellarator, etc
Commissioning and operations of ST40 with advanced capabilities (*TE, United Kingdom*)	Commissioning and operations of ST40 with advanced capabilities, upgraded PSUs, central solenoid, NBI, upgraded diagnostics	
Sustainment of hot plasma using combination of inductive (solenoid) and non-inductive (NBI) CD schemes (*TE, United Kingdom*)	Development of a plasma discharge scenario supported by NBI	NBI supplied by RFX, Italy
Lithium coating + biasing experiments (*Univ. Saskatchewan, Canada*)	Easy transition conditions and better H-mode parameters	
RMP+ biasing (*Univ. Saskatchewan, Canada*)	Effects on electric and magnetic or electromagnetic fluctuations	
Experimental study of plasma RMP + single CT injection (*Univ. Saskatchewan, Canada*)	Synergetic effects on flow velocity modifications	
Operation with EBW heating on SUNIST (*Tsinghua Univ., China*)	Conference reports and published journal papers on experimental results	
Testing of liquid metal test divertor on COMPASS (*IPP Prague, Czech Republic*)	Recovery during steady state heat loads ELM transient heat shocks Influence of the Li vapor on diagnostics & windows Exchange Li with tin → less vapor, more radiation Impact on L-H transition	
Perform preliminary experiments with liquid metals as the first wall		

material on the COMPASS tokamak (*IPP Prague, Czech Republic*)		
Perform preliminary experiments with the localized gas puff along a magnetic field line in proximity of the strike point (*IPP Prague, Czech Republic*)		
Tests with high heat loads of different PFM coatings (*MEPhI, Russian Federation*)	High heat load tests of plasma facing materials and components	Collaborative work with capillary porous system for COMPASS
Study of Li transport in SOL (tokamak experiments and modelling) (*MEPhI, Russian Federation*)	High heat load tests Evaluation of Li transport in tokamak with Li limiter	
Study of plasma interaction with tungsten samples (*MEPhI, Russian Federation*)	High heat load tests Regularities in surface morphology changes under He/H plasma irradiation Data on influence of He on hydrogen isotope retention	
Experimental observation of NTM effect on confinement (*Ioffe Institute, Russian Federation*)	NTM behaviour in highly magnetised ST plasma	
Third and fourth year		
Activity 1: Experiments on plasma focus and linear devices		
Experiments with gases mixtures (manual or automatic mixing) (*MNA, Malaysia*)	Experiments with gases mixtures and data analysis	
Experiments for material testing (Setup for material testing and sample holder in plasma focus chamber) (*MNA, Malaysia*)	Experiments with materials and analysis for doping, material modification, microstructure, etc	
Characterization of the plasma instabilities (*AUB, Lebanon*)	Link the plasma average properties with the onset of instabilities	
Non-linear saturation (*AUB, Lebanon*)	Characterize the nonlinear saturation using Langmuir probes and fast imaging	
Instability in the linear device: Comparison of the results from the simulation code with the experiment (*AUB, Lebanon*)	Understanding of the onset of instabilities by combining simulation to experiment	
Seeking turbulence in the LLPD (*AUB, Lebanon*)	Identify the parameters where turbulence is reached and characterize it	
Activity 2: Plasma Startup Studies		

Measurement of electric field, EEDF and plasma rotation by spectroscopic techniques (*NTFP*, *Pakistan*)	Research publication	SUNIST and other relevant CRP members
Measurement of the radial profile of electric field fluctuations and plasma parameters using "Rake" probe (*NTFP*, *Pakistan*)	Research publication	COMPASS and other relevant CRP members
Long pulse plasma discharge operation (modification in power supply, coil system and impurity control) (*NTFP*, *Pakistan*)	Research publication	SUNIST and other relevant CRP members
Measurement of plasma turbulence (including ZFs), rotation and transport characteristics during various heating scenarios (*NTFP*, *Pakistan*)	Research publication	Interaction with SUNIST, COMPASS and relevant CRP members
Measurement of the characteristics of MHD activities in the wide frequency range and to control their behaviour by RMP and other means (*NTFP*, *Pakistan*)	Research publication	Interaction with SUNIST, COMPASS and relevant CRP members
Testing diverse scenarios for minimized flux consumption during plasma breakdown and startup phase (*NTFP*, *Pakistan*)	Research publication	Interaction with SUNIST and relevant CRP members
Solenoid-less startup (*NTFP*, *Pakistan*)	Research publication	Interaction with relevant CRP members
Activity 3: Simulations and modelling		
Simulate radiation from SCR-1 plasmas Analyse electric field variations for different plasma scenario (*TEC*, *Costa Rica*)	Prepare report on tasks Prepare conference papers and journal papers	Computer codes to simulate radiation emissions to provide output on electric field variations in different plasma cross sections
To combine SOL and core transport codes to improve predictive capabilities of simulation codes (*PSU*, *Thailand*)	Transport modelling code that integrates calculation of core and SOL plasmas	Experimental results from other machines for comparison, especially for plasma profiles in the SOL and divertors or limiters.
To develop 3D model for SOL region of the plasma (*PSU*, *Thailand*)	3D model code for studying plasma transport in SOL	Experimental results for plasma profiles from other machines.

To develop a lattice Boltzmann code for simulating plasma to compare with plasma in the tokamak (*PSU, Thailand*)	Qualitative comparison of plasma behaviour	
To synchronize the time-dependent magnetic field with three integrated predictive modelling codes for showing the plasma parameters (*PSU, Thailand*)	Time-dependent plasma parameters of the TT-1	
To develop and use program to analyse HXR from TT-1 (*PSU, Thailand*)	Local emissivity profile of HXR and LH energy deposition	
To summarize and write recommended scenarios for operation of TT-1 tokamak (*PSU, Thailand*)	Recommendation report for operational scenarios of TT-1	
Finalizing the two-fluid code (*AUB, Lebanon*)	A two-fluid code benchmarked to the experiment and other codes	
Testing validity of the results from new advanced FDPT by comparing experimental results with parallel kinetic PIC simulations in order better to understand the role of atomic physics processes occurring in tokamak SOL plasmas (*Univ. Sofia, Bulgaria*)	Results for the influence of the collisionality on the EEDF in SOL	In collaboration with Slovenian colleagues
Working with data base of Langmuir probe measurements in the tokamak SOL plasmas (*Univ. Sofia, Bulgaria*)	Results for the plasma potential, EEDF (respectively electron temperatures and densities) and parallel power flux density.	In collaboration with the tokamak COMPASS team and other tokamaks.
Analyze enhanced particle confinement and turbulence reduction due to E × B shear by applying an external radial electric field to the edge plasma. Analyze the interaction between density fluctuations, E × B shear flows, and zonal flows like events (*ININ, Mexico*)	Characterization of the improved confinement regimes due to the effects of sheared E × B fluxes in turbulence	HIBP data from both TJ-II and T-10 devices. ASTRA and DKES codes
Study of statistical characteristics and moments of the particle fluxes. Analysis of the contribution of energetic particles to NC electric fields and turbulent transport (*ININ, Mexico*)	Organized database of experimental core particle fluxes with statistical characterization. Calculations of energetic ion distributions from NBI and comparison of plasma potentials with experimental data.	HIBP data from both TJ-II and T-10 devices. EIRENE and FAFNER2 codes.

Modelling of turbulent transport (*JSI, Slovenia*)	"Integral" boundary conditions for "bloby" SOL	In collaboration with NIS (Bulgaria) and COMPASS team
Modelling of the SOL plasma based on the database of measurements (*JSI, Slovenia*)	Improved "integral" model of SOL in connection to database results	Access to database. Collaboration with other members of the collaboration.
Comparative analysis of the results obtained on Globus-M2 with other machines (*Ioffe Institute, Russian Federation*)	Cross-machine scaling	
Theoretical analysis of the effect of instabilities (sawtooth, NTM, AEs) of EP losses (*Ioffe Institute, Russian Federation*)	The sufficiently improve our physics understanding of energy and particle confinement in ST plasma	
Activity 4: Experiments on stellarators		
Characterize and simulate SCR-1 plasma based on EM radiation. Analyse electric field variations in SCR-1 (*TEC, Costa Rica*)	Report on plasma characterization Prepare conference papers and journal papers	
Study of the GAMs, Alfvén eigenmodes and broadband plasma turbulence in the TJ-II stellarator. (*NRCKI, Moscow*)	Spatial structure, frequency ranges and wavelength of the GAMs, Alfvén eigenmodes and broadband plasma turbulence in the TJ-II stellarator	
Perform studies on influence of density gradients, fast electrons and radial electric field after pellet injection in TJ-II as programmed in timetable (*CIEMAT, Spain*)	Perform experiments and data analysis on TJ-II Report on studies performed Prepare conference papers and journal papers	HIBP data & analysis (Kurchatov Institute & MEPhI Moscow, & NSC KIPT Kharkov) ASTRA Code (NINM)
Measurements of MHD activity of plasma in U-3M using the set of magnetic probes poloidally distributed in one cross section of U-3M (*IPP-NSC KIPT, Ukraine*)	MHD plasma activity in Uragan stellarator will be studied	
Cleaning of vacuum chamber walls with RF produced plasma (U-2M) (*IPP-NSC KIPT, Ukraine*)	Prospective scenarios of wall conditioning will be proposed	Contribution from Belgium and German colleagues on the modelling of wall conditioning
Optimization of wall conditioning procedure with the use of RF produced plasma (*IPP-NSC KIPT, Ukraine*)	Effectiveness of wall conditioning will be increased	Information/material to be provided by another lab

Study of plasma response to biasing of the B4C limiter in U-2M (*IPP-NSC KIPT, Ukraine*)	Plasma response to limiter biasing	
Operation of U-2M device with a massive B_4C movable limiter for control the size of the SOL thickness during working discharges (*IPP-NSC KIPT, Ukraine*)	Analysis of SOL during working discharges with use of limiter	
Activity 5: Experiments on tokamaks		
To study time-response of the toroidal and poloidal coils (*PSU, Thailand*)	Time-dependent of the toroidal, poloidal and TT-1 magnetic field	
Investigate the additional role of turbulence in tokamak (*PSU, Thailand*)	A new role of turbulence in a tokamak	
Characterize plasma structures in a tokamak (*PSU, Thailand*)	A plasma structures with their roles in a tokamak	
Investigation of plasma shape and position in IR-T1 tokamak (*IAU, Iran*)	Time evolution of plasma shape and plasma position	
The control of plasma–wall interaction by applying external field (*IAU, Iran*)	Plasma confinement improvement and reduction of energy loss	
Puff different gases (H, Ar, He) into vacuum chamber during plasma operation with high accuracy (1 ms) (*IAU, Iran*)	Study of gas puffing effect on plasma parameters such as electron temperature and density, soft and HXR, plasma impurities, plasma shape and position	
Langmuir probe measurements in tokamak SOL plasma (*Univ. Sofia, Bulgaria*)	Estimation of the EEDF in the SOL plasma	Access to database. Collaboration with members of the network. All activities will be in the frame of local network created between research groups from Sofia Univ., IPP Prague, and JSI.
Operations at full performance, 3 T/ 2 MA with a second range, flat-top of the plasma discharge (*TE, United Kingdom*)	Operations at full performance, 3 T/ 2 MA with a second-range flat-top of the plasma discharge.	
Demonstration of the high ion temperature mode supported by NB heating in DND configuration (*TE, United Kingdom*)	Demonstration of plasma parameters satisfying burning conditions in DD	

Tests of advanced divertor concepts, i.e. Li divertor (*TE, United Kingdom*)	Development of low recycling regimes with Li conditioning and Li divertors	
Achievement of plasma parameters satisfying burning conditions (*TE, United Kingdom*)	Demonstration of the burning plasma (alpha heating) conditions and performing tests of alpha confinement and heating in DT	
Repetitive CT operation on STOR-M (*Univ. Saskatchewan, Canada*)	100 Hz CT operation	
Multiple CT injection into single STOR-M discharge (*Univ. Saskatchewan, Canada*)	Accumulative effects on momentum transfer	Theoretical modelling of plasma flow and momentum transport
Lithium coating + CT injection, STOR-M (*Univ. Saskatchewan, Canada*)	Reduced gas recycling on momentum transport	Open to collaborations for experiments on STOR-M and data analyses of STOR-M data. Sharing data via MDSPlus (currently for internal network only).
Multiple CT injection into single STOR-M discharge (*Univ. Saskatchewan, Canada*)	Accumulative effects on momentum transfer	Theoretical modelling of plasma flow and momentum transport
To investigate the MHD behaviour during the current rise under different conditions, including pure Ohmic, EBW heating, plasma gun pre-ionization, and hybrid scenarios, and find a proper way to minimize the MHD activity during the current ramp-up (*Tsinghua Univ., China*)	Conference reports and publish journal papers on experimental results	Comparative/joint Experiments
Experimental study of the IREs/TAEs during the current ramp down. To understand their incentives and explore a safer current ramp-down scenario (*Tsinghua Univ., China*)	Conference reports and published journal papers on experimental results	Comparative/joint Experiments
Extreme tests of LMD on COMPASS: Runaway electron beams - splashing liquid lithium Melting the CPS mesh		

Downwards VDE → strong LMD heat shock (*IPP Prague, Czech Republic*)		
Continue with liquid metals and divertor biasing experiments on Compass (*IPP Prague, Czech Republic*)		
Measure properties of the edge plasma turbulence and transport at different working gases (H, D, He) to investigate isotope effects (*IPP Prague, Czech Republic*)		

Extrapolation to future COMPASS upgrade and EU DEMO (*IPP Prague, Czech Republic*)	Achieved results will be presented at several international conferences (IAEA FEC, EPS on plasma physics, plasma surface interaction, …) and published in refereed journals Collaboration within CRP on selected research activities will be strengthened	The research will be performed in broad int'l cooperation: GOLEM tokamak – Liquid metals, edge plasma studies, diagnostic development. Sofia Univ. - measurement of the EEDF. Consozio RFX, ltaly – measurements of current filaments in SOL of COMPASS. IST Lisbon – Liquid metals, joint experiments on COMPASS and ISTTOK tokamak on edge reflectometry. MEPhI – Liquid metals, edge plasma turbulence studies KFKI Research Institute for Particle and Nuclear Fusion – edge density profiles with Li - beam diagnostic. CIEMAT - collaboration on liquid metals as first wall element. Further collabo-ration could be established in the frame of this CRP
Analyse the influence of the geometry of the tokamak magnetic field on the magnitude of the turbulent transport coefficients of plasma in diverting region of the tokamak (*MEPhI, Russian Federation*)	Research publication	
Analysis of turbulence and transport, the role of electric field and possible mechanisms of turbulence self-regulation in the edge plasma (*MEPhI, Russian Federation*)	Research Publication	

Study of the GAMs, Alfvén eigenmodes and broadband plasma turbulence in the T-10 tokamak (*NRCKI, Moscow*)	Spatial structure, frequency ranges and wavelength of the GAMs, Alfvén eigenmodes and broadband plasma turbulence in the T-10 tokamak	Study of the GAMs, Alfvén eigenmodes and broadband plasma turbulence in the T-10 tokamak and the TJ-II stellarator.
Measurements of turbulent transport properties in SOL (*JSI, Slovenia*)	Poloidal profile of turbulent transport properties	In collaboration with NIS (Bulgaria) and COMPASS team

3.3. DIAGNOSTICS AND TECHNOLOGY DEVELOPMENTS

First year		
Tasks	**Deliverables**	**Inputs needed / Remarks**
Development of sweep Langmuir probe and necessary electronics (*NTFP, Pakistan*)	Probe with temporal resolution of 1ms	COMPASS and other relevant members of CRP Collaboration Pakistan–Bulgaria is foreseen
Design studies of "Rake" probe (*NTFP, Pakistan*)	Optimum design parameters	Interaction with relevant groups – Bulgaria, Czech Republic, MEPhI
Design and fabrication of HTS coils (*NTFP, Pakistan*)	Two vertical field coils for R&D studies	ST40 and other relevant CRP members
Design and development of Li coating system (*NTFP, Pakistan*)	Experimental setup for R&D on Li coating	Collaboration Pakistan–Czech Republic is foreseen If MEPhI is willing to collaborate?
Liquid metal divertors tests (*FJFI, Czech Republic*)		
Design of the improved probe constructions and electronic circuits for Langmuir probe measurements (*Univ. Sofia, Bulgaria*)	Prototype of new probes and electronic circuits for EEDF measurements in tokamak and stellarators	In collaboration with COMPASS and GOLEM teams
Triple probe technique for diagnostics of fusion plasma (*Univ. Sofia, Bulgaria*)	Test measurements and improvement of the equations of the triple probe technique for diagnostics of fusion plasma	In collaboration with Slovenian colleagues and COMPASS and GOLEM teams Collaboration Pakistan–Bulgaria is foreseen
5 channel 105 GHz microwave interferometer based on single sideband modulation, and corresponding data analysis methods	Experimental system development; conference reports and published journal papers on system development	

(*Tsinghua Univ., China*)		
Density profile reconstruction methods (*Tsinghua Univ., China*)	experimental data; conference reports and published journal papers on experimental results	
Development of multichannel SXR diagnostic system and corresponding data analysis methods (*Tsinghua Univ., China*)	Experimental system development. Conference reports and published journal papers on system development.	collaboration
Radiation profile reconstruction methods (*Tsinghua Univ., China*)	experimental data; conference reports and published journal papers on experimental results	
Development of a new set of magnetic diagnostic system with high spatial resolution and high frequency response (*Tsinghua Univ., China*)	Experimental system development; conference reports and published journal papers on system development	
A more accurate plasma current profile reconstruction method for the radial probe array operation (*Tsinghua Univ., China*)	experimental data; conference reports and published journal papers on experimental results	
Calculation of HIBP probing beam trajectories and sample volume locations for T-10 (*NRCKI*, *Russian Federation*)	Results of the calculations allowing the retrieval of the poloidal turbulence rotation for T-10.	
Design study of the multichannel beam detector, compatible with multichannel preamplifier (*NRCKI, Russian Federation*)	Design of the multichannel beam detector, compatible with multichannel preamplifier. Capability of the assessment of the toroidal beam size is foreseen	
Development of new diagnostics of non- homogenous plasma based on refraction of microwave (*KIPT*, *Ukraine*)	Method of non-homogeneous plasma study in stellarators by using diagnostics based on refraction of microwaves will be developed	
Experimental testing of developed diagnostic (*KIPT*, *Ukraine*)	New diagnostic will be tested on the test stand	
Second year		
Installation and testing of sweep Langmuir probe (*NTFP*, *Pakistan*)	Probe ready for operation	

Development of “Rake” probe (*NTFP, Pakistan*)	Set of six triple probes and associated electronics	COMPASS and other relevant members of CRP
Design studies of prototype NBI system (*NTFP, Pakistan*)	Parameters for development of low power NBI system	Interaction with relevant CRP members
Cooling system for HTS coils (*NTFP, Pakistan*)		ST40 and other relevant CRP members
Development and tests of novel methods of PSI diagnostics (*MEPhI, Russian Federation*)	Apparatus development for laser induced desorption	Test samples with coatings Various grades of W based materials can be tested if provided
Calculation of HIBP probing beam trajectories and sample volume locations for TJ-II (*NRCKI, Russian Federation*)	Results of the calculations allowing the retrieval of the radial distribution of poloidal turbulence rotation for TJ-II and to compare low field size and high field size of a plasma column	
Design study of the steerable support system for the multichannel beam detector (*NRCKI, Russian Federation*)	Design of the steerable support system for the multichannel beam detector. Capability of the 3D adjustment of the beam detector is foreseen.	
Development and installation of multichannel optical systems for observation of different kind plasma fluctuations in stellarators U-2M and U-3M (*KIPT, Ukraine*)	Multichannel optical systems for observation of different kind plasma fluctuation will be developed and tested	
Manufacturing and installation of a new RF antenna aiming for wall conditioning (*KIPT, Ukraine*)	Antenna installed in Uragan-2M. Interim report	
Testing the new antenna and studying different regimes of its operation (*KIPT, Ukraine*)	Interim report	
Third year		
Testing and installation of HTS coils (*NTFP, Pakistan*)	Vertical field coils for testing on the Tokamak	Interaction with ST40 and relevant CRP members
Design studies on electron injector (*NTFP, Pakistan*)	Optimum design parameters	Interaction with relevant CRP members
R&D for fabrication of prototype NBI system	Parameters for fabrication	Interaction with relevant CRP members

(*NTFP*, *Pakistan*)		
1. Development and tests of novel methods of PSI diagnostics (LIBS, MEIS, novel probes) 2. Benchmarking of different methods of in situ PSI diagnostics (LIBS, MEIS, novel probes) (*MEPhI*, *Russian Federation*)	Research publications, Results of benchmarking of different methods of in situ PSI diagnostics	Project proposal for using LIBS, MEIS and novel probes for T-15MD tokamak
Calculation of HIBP probing beam trajectories and sample volume locations for Globus-2M (*NRCKI*, *Russian Federation*)	Results of the calculations allowing the measurement of the radial distribution of plasma potential profiles for spherical tokamak Globus-2M.	Drawings of the Globus-2M tokamak.
Design study of the multichannel preamplifier (*NRCKI*, *Russian Federation*)	Design of the high gain, low noise vacuum compatible multichannel preamplifier.	
Integration of the beam detector, steerable support system and preamplifier in the assembly – detector unit. Test of the detector unit. (*NRCKI*, *Russian Federation*)	Integrated detector unit and the test results: gain functions for each channel	
Development and application of novel diagnostics for monitoring of wall conditioning by RF plasma in stellarator U-2M (*KIPT*, *Ukraine*)	New diagnostic for analysis of wall conditioning	
Fourth year		
Development of prototype NBI system (*NTFP*, *Pakistan*)	Low power NBI system	Interaction with relevant CRP members
Design studies of HIBP (*NTFP*, *Pakistan*)	Design parameters	Kurchatov Institute
Development of electron injector (*NTFP*, *Pakistan*)	Pulsed prototype system for pre-ionization	Interaction with SUNIST and GOLEM
Design and development of high field HTS coils (*NTFP*, *Pakistan*)		Interaction with ST40 and relevant CRP members
Calculation of HIBP probing beam trajectories and sample volume locations for Heliotron-J stellarator (*NRCKI*, *Russian Federation*)	Results of the calculations allowing the measurement of the radial distribution of plasma potential profiles for Heliotron-J stellarator.	Drawings of the Heliotron-J stellarator

Application of HIBP diagnostics at U-2M for measuring fluctuations in plasma volume; compare with data obtained with electric probes (*KIPT, Ukraine*)	First results from HIBP diagnostics in Uragan stellarator.	Input from Dr. Melnikov on the interpretation and analysis of the measurements results

3.3.1. Common topics

Topics	participants	Remarks
Probes	Shahid Hussain, Pakistan Tsviatko K. Popov, Univ Sofia, Bulgaria	COMPASS could join if interested, MEPhI is interested in collaboration
HIBP	Alexander Melnikov, NRCKI, Moscow, Shahid Hussain, Pakistan Igor Garkusha KIPT	Collaboration on the research area is foreseen: *HIBP - Probes measurement of plasma potential by Tsviatko Popov, Bulgaria *Neoclassical modelling of electric potential by Cesar Gutierres, Mexico
HTSC	Shahid Hussain, Pakistan M. Gryaznevich, Tokamak Energy, United Kingdom	
Li coating systems, including liquid metal	Shahid Hussain, Pakistan Vojtech Svoboda, Czech Republic	MEPhI is interested in collaboration

3.4. TRAINING/EDUCATION

First year		
Tasks	**Deliverables**	**Inputs needed / Remarks**
Activity 1: Short courses		
1.Theoretical, Simulation, and Experimental Training and Research on DPF (T&R Module 1) 2. Training and Research on material deposition and characterization using DPF device (T&R Module 5) (*NIE-NTU, Singapore*)	D1 – Learn to assemble DPF device and related safety D2 – Deposition and synthesis category manual D3 – Thin films of ZnO D4 – Detailed characterization of ZnO thin films using XRD, SEM, EDX, Raman and XPS spectroscopy D5 – Publications	Two participants from Pakistan will be subjected to these activities
GOLEM on-site GOLEM training course GOMTRAIC in March (*FJFI, Czech Republic*)	Onsite training of graduate (and postgraduate students) for ~15 students, Feb.–Apr.	The event advertisement

GOLEM remote (*FJFI, Czech Republic*)	Remote training courses of graduate (and postgraduate students)	Experienced tutor on the remote side.
Course on Tokamak Engineering, Diagnostics and Operation (*IST, Portugal*)	Lessons, and practical sessions/experimental work at ISTTOK	Complete 2018, 12 participants
Training courses for students and young scientist on COMPASS (*IPP Prague, Czech Republic*)	SUMTRAIC	2 weeks/year
Training courses for students and young scientist on COMPASS (*IPP Prague, Czech Republic*)	EMTRAIC	2 weeks/year
Summer school on physics of plasma surface interactions (*MEPhI, Russian Federation*)	Lectures by leading scientists	1 week in July 2018 (Completed)
Training course for young scientists in MEPhI laboratory on diagnostics of plasma wall interaction (*MEPhI, Russian Federation*)	Report on training due joint agreement between MEPhI and foreign University	2 weeks/year
Activity 2: Practical campaigns		
Training for development and data analysis of diagnostics for SCR-1 stellarator (bolometers, magnetic coils, etc) (*TEC, Costa Rica*)	Report on training, diagnostics, and simulations for diagnostic development in SCR-1 Stellarator. Timetable, work plan & participants.	Information about bolometers in other fusion devices Bolometer data from other devices for researcher training
Activity 3: PhD qualification		
Training and education of young scientists. Joint and comparative experiments in available experimental facilities (*IPP-NSC KIPT, Ukraine*)	PhD student from IPP KIPT will take part in joint experiment	Schedule and programme of experimental session from host laboratory, list of diagnostics involved
Activity 4: Educational contents		
Deploy of a Wiki content management site for ISTTOK (*IST, Portugal*)	Wiki install and customization	Complete by 30/6
Wiki organization (*IST, Portugal*)	Wiki well-structured and ToC	Completed
Populate ISTTOK wiki with relevant contents (*IST, Portugal*)	Publication of ISTTOK description and diagnostics specifications	In progress

Second year		
Activity 1: Short courses		
1.Soft and HXR training and research (T&R Module 2) 2.Deuteron and neutron diagnostics training and research (T&R Module 3) 3.Optical diagnostics training and research (T&R Module 4) (*NIE-NTU, Singapore*)	D1 – Lecture notes on each T&R module D2 – Manual of Plasma focus design development strategies using Lee code D3 – Trigger circuit, electric and magnetic probes and their usage manual D4 – Diode X-ray spectrometer and SXR pinhole imaging system design and usage manual to determine SXR yield, T_e and spatial SXR information D5 – Scintillator-photomultiplier detection system and its usage manual for time resolved HXR and neutron emission information D6 – Measurement of nuclear tracks to estimate flux and anisotropy measurements D7 – Estimation of neutron yield D8 – Recording of plasma dynamics in DPF and study of plasma instabilities in DPF device D9 – Understanding deposition and processing dynamics D10 - Publications	Invite researchers and students **Collaboration request**: Help in (i) low temp. plasma diagnostics using Langmuir probe, (ii) Energy and thermal flux measurements in DPF devices (iii) Optical emission spectroscopy
GOLEM on-site GOLEM training course GOMTRAIC in March (*FJFI, Czech Republic*)	Onsite Training of graduate (and post-graduate students) for ~15 students, Feb.–Apr.	The event advertisement
GOLEM remote (*FJFI, Czech Republic*)	Remote training courses of graduate (and post-graduate students)	Experienced tutor on the remote side.
Course on tokamak engineering, diagnostics and operation (*IST, Portugal*)	Lessons, and practical sessions/experimental work at ISTTOK	3weeks/July 2019

Training courses for students and young scientist on COMPASS (*IPP Prague*, *Czech Republic*)	SUMTRAIC	2 weeks/year
Training courses for students and young scientist on COMPASS (*IPP Prague*, *Czech Republic*)	EMTRAIC	2 weeks/year
Summer school on physics of plasma surface interactions (*MEPhI, Russian Federation*)	Lectures of leading scientists and practice in the labs	2 weeks/year
Third and fourth year		
Activity 1: Short courses		
1.Soft and HXR training and research (T&R Module 2) 2.Deuteron and neutron diagnostics training and research (T&R Module 3) 3.Optical diagnostics training and research (T&R Module 4) (*NIE-NTU*, *Singapore*)	D1 – Lecture notes on each T&R module D2 – Manual of plasma focus design development strategies using Lee code D3 – Trigger circuit, electric and magnetic probes and their usage manual D4 – Diode X-ray spectrometer and SXR pinhole imaging system design and usage manual to determine SXR yield, T_e and spatial SXR information D5 – Scintillator-photomultiplier detection system and its usage manual for time resolved HXR and neutron emission information D6 – Measurement of nuclear tracks to estimate flux and anisotropy measurements D7 – Estimation of neutron yield D8 – Recording of plasma dynamics in DPF and study of plasma instabilities in DPF device D9 – Understanding deposition and processing dynamics D10 - Publications	Invite researchers and students. Collaboration request: Help in (i) low temp. plasma diagnostics using Langmuir probe, (ii) Energy and thermal flux measurements in DPF devices (iii) Optical emission spectroscopy

GOLEM on-site GOLEM training course GOMTRAIC in March (*FJFI, Czech Republic*)	Onsite training of graduate (and post-graduate students) for ~15 students, Feb.–Apr.	The event advertisement
GOLEM remote (*FJFI, Czech Republic*)	Remote training courses of graduate (and postgraduate students)	Experienced tutor on the remote side.
Course on tokamak engineering, diagnostics and operation (*IST, Portugal*)	Lessons, and practical sessions/experimental work at ISTTOK	3weeks/July 2020 3weeks/July 2021
Training courses for students and young scientist on COMPASS (*IPP Prague, Czech Republic*)	SUMTRAIC	2 weeks/year
Training courses for students and young scientist on COMPASS (*IPP Prague, Czech Republic*)	EMTRAIC	2 weeks/year
Activity 2: Practical campaigns		
Organization and practical usage of the International Training Centre	Core and edge plasma turbulence studies, PSI and plasma facing material	

4. CONCLUSIONS

Within the framework of this CRP, several research activities were proposed, and they have been grouped into five areas.

1. Startup/New/Upgrade Device contains 6 small fusion devices of different type, planned to build-up and to put in operation. The core of the plan is a cluster of 3 tokamaks (TT-I in Thailand, GLAST-II in Pakistan, ST-40 in UK), the last two of them are spherical tokamaks. They are added by 1 stellarator (SCR-1 in Costa Rica), 1 plasma focus in Malasya and 1 linear device LLPD in Lebanon. Finally, a cluster of 6 new small-to-medium size devices will be put in operation in the framework of this CRP.

2. Activities related to research programmes on participated devices: IR-T1, COMPASS, STOR-M, TJ-II, T-10, Gutta, Uragan-2M, Uragan-3M, Globus-M2, GOLEM, and also performed by other participating institutions in computational modelling, diagnostic results modelling and theoretical studies. Confinement, stability, fast particle physics, edge/SOL, fueling and plasma-wall interaction studies have been performed on the STOR-M, COMPASS, IR-T1, TJ-II, T-10, Globus-M2. Plasma heating, startup and pre-ionization have been studied on COMPASS, SUNIST, T-10, Globus-2M, GOLEM, GUTTA, ST40, Uragan-2M, Uragan-3M. New technologies (i.e. liquid Li, CT and pellet injection, resonant magnetic perturbation coils, wall conditioning, biasing), diagnostics and interpretation of the results have advanced research on several devices. Research as an educational and training tool proved to be very efficient which is one of unique advantages of small fusion devices.

3. Diagnostics and Technology Developments contains a wide number of the innovative diagnostics. They are various types of the edge diagnostics: Langmuir probes (sweep, Rake, triple) and the electronic circuits for the probes, and multichannel core diagnostics: 5 channel Heavy Ion Beam Probe, optical systems to study plasma fluctuations, 5 channel 105 GHz microwave interferometer and the density profile reconstruction method, SXR emission, plasma radiation, high frequency magnetic diagnostics and plasma current profile reconstruction method. In addition, the novel methods to diagnose plasma-surface interaction will be developed and tested. Technology Developments contains innovative HTS coils, Li coating system for the vacuum chamber, Liquid metal divertor, RF antenna for wall conditioning, electron injector for preionization. A set of innovative diagnostics and plasma technologies will be developed in the framework of this CRP.

4. Due to the intrinsic characteristics and nature of small to medium size fusion devices where overall aspects of these apparatus can easily be identified, they are very suitable for training and education. This is demonstrated on this research activity where most proposals included training activities either for masters or for PhD students and some of them are devoted to short term schools. Those activities foresee a proficient training of young researchers and an appeal for new generations to be enrolled in nuclear fusion, and to expand the horizons of fusion to even more countries.

5. Joint experiments on small tokamaks in the framework of the CRP have been performed since 2005. The experimental research topics were selected according to each device peculiarities. These experiments have demonstrated that small tokamaks can be used for

broad international cooperation, providing manpower and environment to conduct joint research programs. Specific outputs in education and training of young scientists and scientists from developing countries already demonstrated significant advances through broadening the geography of the Fusion research. An important output of joint experiments is also in the demonstration of a possibility to organize joint experimental activities under the IAEA umbrella, efficiently and on a regular basis, so future JEs are foreseen. It is proposed to extend research to stellarators and other plasma devices and to extend joint experiments to fusion materials and plasma wall interaction studies that can be performed on plasma focus and linear devices.

The participants recommended that next Joint Experiments take place at TJ- II, at CIEMAT.

The participants recommended that the next RCM take place in Singapore with a foreseen duration of 2.5 days, followed by a joint experiment at the facilities available at NIE-NTU.

LIST OF PARTICIPANTS

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Boonyarit Chatthong, Prince of Songkla University, Thailand

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Shahid Hussain, Pakistan Atomic Energy Commission, Pakistan

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ANNEX I. LIST OF FACILITIES AND EXPERTISE AVAILABLE

2.2.1 Characterization and Optimization of Plasma Produced Inside the SCR-1 Stellarator*, Iván Vargas-Blanco, TEC, Costa Rica*

A new building with an area of 300 m^2 (with a cost of 0.5 M USD) used only as a plasma laboratory, ten workstations where researchers can perform their desktop activities and an industrial warehouse as an experimental space are available.

- Scientific equipment:
  i. One small modular stellarator called SCR-1 (operational);
  ii. One small spherical tokamak called MEDUSA-CR (recommissioning).
- Plasma Diagnostics:
  i. Langmuir probe: A versatile remotely controlled reciprocating Langmuir probe. The probe head that supports the Langmuir probes is easily removed. It consists of a boron nitride head and an array of four tungsten tips.
  ii. Optical spectrometer: iHR550 spectrometer core 3 configured for plasma/emission analysis. The details of spectrometer are as follows.

     Focal length: 550 mm;
     Spectral range: 150 to 1500 nm with 1200 g/mm grating, 150 nm to 40 mm with appropriate gratings;
     Wavelength accuracy: ± 0.20 nm;
     Spectral dispersion: 1.34 nm/mm.

  iii. Heterodyne microwave interferometer: The probing beam has a frequency of 28 GHz, corresponding to a wavelength of 10.71 mm.
  iv. Fast camera: Velociraptor HS high speed field programmable gate array based camera. It is a high-speed camera with 2.2 Mpixel, mono, 333 fps at full resolution, 5 Mpixel, lens f = 16 mm, F1.4 - F22, 2/3", manual iris operation.
- Plasma sources:
  i. Two magnetrons of 2 kW and 3 kW with a frequency of 2.45 GHz;
  ii. Radiofrequency plasma source with 13.6 MHz up to 600 W;
  iii. DC plasma source for glow discharge;
  iv. AC plasma source for dielectric barrier discharge discharges.
- Human resources:
  i. 5 physicists (1 PhD in Plasma Physics and Nuclear Fusion, 2 MSc in Plasma Physics and Nuclear Fusion-Erasmus Mundus and 2 with BSc in Physics);
  ii. 1 mechatronics engineer;
  iii. 1 mechanical engineer;
  iv. 60 undergraduate students.
- Expertise available:
  i. Expertise in stellarator and tokamak fusion engineering, mainly in stellarator engineering.
- Computer facilities:
  i. FIESTA code installed locally for the tokamak;
  ii. EFIT code installed locally for the tokamak;
  iii. Biot-Savart Solver for Compute and Trace Magnetic Fields (BS-SOLCTRA) code, written in C and developed to calculate and display the magnetic surfaces in the SCR-1 stellarator;
  iv. IPF-FDMC full wave code access from the University of Stuttgart;

v. VMEC code access from the Princeton Plasma Physics Laboratory (PPPL) and Institute for Plasma Physics (IPP), Research Centre Jülich, servers;
vi. NESCOIL, ONSET codes access from the PPPL and IPP servers;
vii. COMSOL Multiphysics, Solid Works and Inventor Autodesk software;
viii. Hardware available at the National Laboratory of Advanced Computing in Costa Rica
ix. Specialized and up-to-date hardware, efficient applications and trained personnel to take advantage of all technology.

2.1.2 Plasma Turbulence and Transport Characteristics of Discharges with Different Plasma Species, *Abd. Halim bin Baijan, MNA, Malaysia*

- Plasma focus laboratory of the MNA;
- MNA plasma focus device;
- 15 kV capacitor;
- Lambda TDK capacitor with a high voltage charge of 15 kV;
- LeCroy 10 GHz oscilloscope;
- Edwards RV8 vacuum pump.

2.1.3 Plasma Startup Studies with a Spherical Tokamak, *Shahid Hussain, NTFP, Pakistan*

- High performance computing;
- Vacuum system and accessories;
- Capacitor banks, power supplies and switching electronics;
- Data acquisition system;
- Microwave sources;
- Residual gas analyser;
- Electrostatic probes;
- Network analyzer;
- High speed cameras;
- Spectroscopic systems;
- X-ray spectrometer;
- Small mechanical workshop;
- Equipped electronics laboratory;
- Plasma application laboratory.

2.1.4 Plasma Scenarios and Physics Investigations for Development and Installation of the Thailand Tokamak I Programme, *Boonyarit Chatthong, PSU, Thailand*

Three integrated predictive modelling codes, CRONOS, BALDUR and TASK are installed on computer servers at the Thailand Institute of Nuclear Technology and King Mongkut's University of Technology in Thonburi.

- COMSOL Multiphysics;
- Researchers with expertise in the following areas:
  i. Plasma transport, turbulence and turbulence suppression;
  ii. H-mode and ITB physics;
  iii. Toroidal rotation and its effect on confinement;
  iv. Plasma dynamos;
  v. Simulation of pellet injection in tokamak plasma;
  vi. Energy deposition profile of the lower hybrid current drive;

vii. Hard X-ray measurement and analysis;
viii. Runaway electrons;
ix. The impurities and the resulting radiated power from the plasma in tokamaks;
x. Neutronics investigation of the blanket and shielding of the fusion device using Monte Carlo N-Particle (MCNP) code.

2.1.5. Research and Training in Thermonuclear Fusion Using the Lebanese Linear Plasma Device, *Ghassan Antar, AUB, Lebanon*

At the Physics Department, we have constructed a linear plasma device, called the Lebanese Linear Plasma Device, which is a fusion plasma simulator. It is the first of its kind and the only device in the Arab world and the Middle East. We are proposing to use this device not only for fundamental plasma research but also to train students in this field, taking advantage of the variety of topics we are trying to elucidate. A study on how to increase the plasma density and temperature using a low RF source by adequate design of an antenna is suggested. This will be done first through the numerical simulation, and then the antenna will be built and tested on the LLPD, which will allow us to develop our expertise in this important area. An increase of plasma density leads to an increase in its gradient.

2.1.6. ST40 Experimental Studies, *Mikhail Gryaznevich, TE, United Kingdom*

The operational ST40 tokamak with all infrastructure, one neutral beam injection system under commissioning with a second to be installed in 2019, and diagnostics and control systems are available**.**

2.1.7 MHD Behaviour during Plasma Startup, Current Ramp-Up and Ramp-Down in a Spherical Tokamak, *Gao Zhe, Tsinghua University, China*

- SUNIST device with typical parameters R_0/a ~0.3 m / 0.23 m, $B_{T0} < 0.3$ T, $I_p < 80$ kA, n_e ~1×10^{19} m^{-3}, pulse durations ~10-20 ms, easy operation;
- Major diagnostics: static and reciprocating Langmuir probes, magnetic probes and flux coils, 94 GHz interferometer, 105 GHz interferometer, fast camera, visible spectrometers (200 fps).

2.2.1 Development of New Advanced Diagnostics in the IR-T1 Tokamak, *Sakineh Meshkani, IAU, Islamic Republic of Iran*

- Electromagnetic winding (Mirnov coils); Rogowski coils; 16 channels rack probe (vertical); movable Langmuir probe (horizontal, 4 channels); hard HXR detectors (scintillator); RGA; limiter biasing system (± 400 V); dual channel spectrometer (ava space uls 3648) 400–550 nm; Langmuir and ball-pen probes; capacitive probe; Gundestrup probe; Mach probe; data acquisition system (264 channels); 42 channel amplifier.

2.2.2 Langmuir Probe Diagnostics of the SOL and Tokamak Edge Plasma, *Tsviatko Popov, St Kliment Ohridski University of Sofia, Bulgaria*

There are no tokamaks in Bulgaria. The main experimental work will be carried out in strong collaboration with the Czech COMPASS and Golem tokamaks as well as other tokamaks during the organized joint experiments.

The research group has experience in instrumentation for probe measurements in fusion plasma as well as different techniques for processing Langmuir probe data measured in fusion plasmas, including three and four parameter fits of the ion portion of current–volt (IV) characteristics and FDPT for processing the electron portion.

We have portable two channel electronics for probe measurements, which can be used during joint experiments in different tokamaks. These are the same as 60 channel electronics for probe measurements in the COMPASS tokamak.

2.2.3 Fuelling and Confinement Studies on the STOR-M Tokamak, *Chijin Xiao, University of Saskatchewan, Canada*

The main existing facilities include the STOR-M tokamak (R/a = 45 /12.5 cm, B_t = 1 T, I_p = 25 kA), the USCTI compact torus injector and a host of diagnostics systems. The peripheral subsystems surrounding the STOR-M tokamak include electrode biasing, RMP coils, AC operation and lithium coating. The diagnostics system includes a 4 mm interferometer, 2 cm reflectometer, SXR detectors, ion doppler spectrometer and a host of magnetic and electric probes. The unique features of the compactor torus injector on STOR-M include tangential injection for momentum injection to tokamak plasma and repetitive compact torus operation up to 10 Hz.

The main expertise of the STOR-M group includes Ohmic H-mode studies, repetitive compact torus operation, compact torus–tokamak interaction and plasma diagnostics.

2.2.4 Edge Plasma Studies on the COMPASS Tokamak, *Jan Stockel, IPP Prague, Czech Republic*

The COMPASS tokamak.

2.2.5 Training Centre to Study Core and Edge Plasma Turbulence, Plasma–Surface Interaction and Plasma Facing Materials, *Valery Kurnaev, National Research Nuclear University MEPhI, Russian Federation*

Tokamak T-15MD is under construction at the Kurchatov Institute with the first plasma expected in 2020; small tokomak MEPhIST is under development at MEPhI; a number of research and test plasma and ion beam facilities to study PSI processes (sputtering, H retention, high heat loads, electron emission and radiation damage, plasma turbulence), for development and testing of protective coatings; edge plasma diagnostics and PSI diagnostics; computer codes SOLPS versions, SCATTER; plasma generators (divertor plasma simulator, RF plasma torch); and material test equipment (a powerful electron beam) are available.

2.2.6 Effects of the Radial Electric Field on Transport in the TJ-II Stellarator and T-10 Tokamak, *Cesar Romeo Gutierrez Tapia, ININ, Mexico*

Tokamak T-10, stellarator TJ-II and the cluster Abacus-I are available.

2.2.7 Microwave Preionization in Tokamaks, *Nikolai Timofeev, Saint Petersburg State University, Russian Federation*

The department building, GUTTA tokamak, a magnetron, capacitor bank, vacuum system and gas pumping/filling system, plasma control system and basic diagnostics are available. The staff includes 4 principal members, 3 Bachelor’s students, 1 Master’s student and 2 engineers.

2.2.8 Development of Heavy Ion Beam Probe Diagnostics for Small and Medium Size Fusion Devices, *Alexander Melnikov, NRCKI, Russian Federation*

- The experimental database of T-10 and access to the experiments in TJ-II are available. The creation of a HIBP high voltage test stand is foreseen.
- Creation and scientific exploitation of HIBP in the TM-4 and T-10 tokamaks and TJ-II stellarator are available.
- Studies of plasma potential profile and oscillations in the TM-4 and T-10 tokamaks and TJ-II stellarator are available.

2.2.9 Fusion Physics and Technology Studies at the TJ-II Stellarator, *Kieran Joseph McCarthy, Laboratorio Nacional de Fusión, CIEMAT, Spain*

The TJ-II stellarator, with its main characteristics of high flexibility and almost flat rotational transform profile, is available. Its plasmas are created and heated by ECRH (2 × 300 kW gyrotrons) and two NBIs. It is equipped with a powerful set of plasma diagnostics: three channel Doppler reflectometer for turbulence and flows studies, dual HIBP for characterization of plasma potential and density and their fluctuations, dual fast reciprocating Langmuir probes arrays for long range correlation studies, a dedicated diagnostic NBI system and associated charge exchange diagnostic, Thomson scattering diagnostic for electron density and temperature profiles, multi-filter photodiodes for core electron temperatures, bolometer arrays and a recently installed pellet injection system. TJ-II operation is typically organized in one or two experimental campaigns each calendar year, with a summer shutdown period. However, in 2019 it is envisaged that only a single campaign per year will be undertaken (February – June, inclusive).

2.2.10 Kinetic Approach to Modelling and Measurements in the SOL of Tokamaks, *Jernej Kovačič, Jožef Stefan Institute (JSI), Slovenia*

While the JSI does not possess a tokamak, we have a good working relationship with people at the COMPASS-D tokamak at IPP Prague, and we have also collaborated with other tokamaks through our work with the group of Prof. Tsv. Popov from Bulgaria. We are equipped with experience in processing probe data using various methods and various probes, not least also from our own Linear Magnetized Plasma Device, and we have been active in the fusion projects in various EFDA agreements and now the EUROfusion Consortium.

We also have lengthy experience in modelling complex plasmas using theoretical and simulation models. We mainly work on the plasma–wall/electrode transition with added non-Maxwellian plasmas, magnetic fields and wall emission. For the purposes of simulation, we have two computer clusters at the institute and access to several other powerful computers.

2.2.11 Investigation of Behaviour of RF Produced Plasma in Stellarators Uragan-2M and Uragan-3M, *Igor Garkusha, IPP-NSC KIPT, Ukraine*

The project aims to study experimentally RF power produced plasma in the stellarator type fusion devices Uragan-2M and Uragan-3M.

In the Uragan-2M device the characteristics of magnetic configuration can be varied in a wide range by combining current values in the coils of the system. For plasma production and heating, RF methods are used with antennas of different designs. Two antennas are installed in the vacuum chamber and fed by the powerful RF generators in series with a variable time shift. Additionally, a small antenna connected to a low power generator is used at the stage of wall conditioning. This antenna can be fed both at low (~8 MHz) and high (~140 MHz) frequencies with a power up to 1.5 kW.

A distinctive feature of the Uragan-3M is that the magnetic configuration has a natural helical divertor. The measurements showed that the divertor plasma flows are terminated by the helical coil casings rather far from the plasma column; thus, the influx of metal impurities into the confined plasma is strongly suppressed. Two RF antennas of different designs are installed nearby the plasma confinement volume. The experiments demonstrate electron plasma heating within the Alfvén resonance heating scenario. Initial plasma density $\langle n_e \rangle \sim 10^{12}\ /\mathrm{cm}^3$ is increased by an order of magnitude during the second antenna pulse and controlled by the pulsed gas puff. Electron heating is dominant; however, ions with energies in the hundreds of eV range were also observed confidently. Plasma with a density $\langle n_e \rangle \sim 0.5\times10^{13}\ /\mathrm{cm}^3$ and electron temperature $T_e(0)$ ~0.5 keV was obtained in recent experiments.

2.2.12 Fast Particle and Thermal Energy Confinement in Spherical Tokamak Globus-M2, *Mikhail Patrov, Ioffe Institute, Russian Federation*

- Spherical tokamak Globus-M2, NBI (40 keV/1 MW + 50 keV/1 MW), LHCD (0.5 MW), ion cyclotron resonance heating (0.5 MW);
- Tokamak diagnostic systems: poloidal and toroidal Mirnov probe arrays, fast magnetic probe array, neutral particle analysers, Thomson scattering diagnostic, RF interferometers and others.

2.2.13 Plasma Focus Device and Diagnostics for Plasma and Fusion-Relevant Education, Training and Research, *Rajdeep Singh Rawat, NIE-NTU, Singapore*

The team comprises Profs. Rajdeep Singh Rawat, Paul Lee and Stuart V Springham from Natural Sciences and Science Education, NIE-NTU, Singapore. The research interest and expertise of the team involves performing fundamental studies and plasma/nuclear diagnostics on dense plasma focus (DPF) devices and their application to wide variety of areas. Facilities available with the group include:

- Plasma focus facilities (Six plasma focus facilities -200 J to 40 kJ, single shot to 10 Hz system);
- Laser plasma facilities (Two pulse laser deposition system, 2 units of ns and 1 unit of fs laser);
- Other low temperature plasma facilities (Five RF plasma generators with two auto-impedance matching units for several plasma enhanced chemical vapor deposition (PECVD) systems and one microwave plasma based PECVD system).
- Plasma and radiation diagnostics:
  i. Fast voltage (resistive–divider), current (Rogowski coil) and magnetic probes;
  ii. CCD based computer-controlled laser shadowgraphy and laser interferometry system;
  iii. CCD based magnetic electron energy analyzer (electron beam energy);
  iv. Diode X-ray spectrometer and photoconducting diamond detector (X-ray yield and time-resolved electron temperature);
  v. CCD based pinhole SXR imaging (time-integrated spatially resolved);
  vi. SXR microscopy and HXR radiography setup;
  vii. Transmission grating spectrometer for SXRs;
  viii. Vacuum UV monochromator (up to 150 nm) and extreme UV detectors;
  ix. Photomultiplier–scintillator based HXR/neutron measurement system;
  x. Indium foil activation detector (neutron count from plasma focus);

xi. Neutron bubble detectors;
xii. An axial magnetic spectrometer for ions with automated measuring system for etched ion tracks in CR-39;
xiii. Be activation detector for up to 3 Hz neutron diagnostics;
xiv. ^{3}He proportional counters for high rep rate neutron diagnostics;
xv. Faraday cup (biased ion collector) detector for ion energies and flux measurements;
xvi. Coded aperture imaging of fusion neutron source;
xvii. Spatial Langmuir probe system.

2.2.14 Scientific and Education Activities on the GOLEM Tokamak in the Framework of the IAEA CRP, *Vojtech Svoboda, FJFI, Czech Technical University, Czech Republic*

The GOLEM tokamak at the Czech Technical University is a university based high temperature plasma experiment intended to be partially an educational device for domestic and foreign students and partially a scientific device primarily in the field of edge plasma physics research.

2.4.1 Course on Tokamak Engineering, Diagnostics and Operation, *Horacio Joao Matos Fernandes, IST Lisbon, Portugal*

ISTTOK, its infrastructure and databases are available.