Programme & Book of Abstracts

23rd IAEA Technical Meeting on Research Using Small Fusion Devices

29th - 31st March, 2017
Chile
23rd IAEA Technical Meeting on Research Using Small Fusion Devices

29th-31st March, 2017

Chile, Las Condes

IAEA Scientific Secretary
Ms. Sehila Maria Gonzalez de Vicente

International Atomic Energy Agency
Vienna International Centre
Wagramer Straße 5
PO Box 100
A-1400 Vienna, Austria
NAPC Physics Section
Tel: +43-1-2600-21753
Fax: +43-1-26007
E-mail: Physics@iaea.org

International Programme Advisory Committee
Chair: L. Soto (Chile)

V. I. Vargas (Costa Rica), X. Chijin (Canada), H. Fernandes (Portugal), M. Gryaznevich (UK), J.J.E. Herrera (Mexico), A. Melnikov (Russian Federation), R. Miklaszewski (Poland), Y. Hwang (Korea), J. Stöckel (Czech Republic), R. Rawat (Singapore)

Meeting Website:

https://nucleus.iaea.org/sites/fusionportal/Pages/List-of-TMs-on-RUSFD.aspx
Topics

I. Magnetic Confinement:
   — A-OV Overview;
   — A-SP Specialized Session Magnetic Confinement;

II. Dense Magnetised Plasmas:
   — B-OV Overview;
   — B-SP Specialized Session DPF;

III. Innovative Fusion Technology and Applications;

IV. Fusion Materials Research;

V. Diagnostic Systems and Components;

VI. Control and Data Acquisition Systems and Remote Participation Tools.
<table>
<thead>
<tr>
<th>Time</th>
<th>Session 1. Chair: V. I. Vargas</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.30-10.00</td>
<td><strong>Registration, Welcome and Opening Address</strong></td>
</tr>
</tbody>
</table>
| 10.00-10.45 | **OV-1:** I.E. Garkusha  
Current status of PSI studies at Uragan stellarators and QSPA |
| 10.45-11.15 | **I-1:** H. Fernandes  
ISTTOK as a liquid metal plasma facing component test device |
| 11:15-11:35 | **O-1:** G. Avaria  
Visible spectroscopy of the axial phase in plasma focus discharge of hundreds of joules |
| 11.35-11.50 | **Coffee Break**                                                                             |
| 11.50-12.35 | **OV-2:** A.V. Melnikov  
An overview of the Geodesic Acoustic Mode studies in the T-10 tokamak |
| 12.35-13.05 | **I-2:** V.A. Gribkov  
Experimental investigation of damageability of the plasma-facing materials of nuclear fusion reactors under powerful pulsed ion and plasma streams and laser irradiation |
| 13.05-13.40 | **Lunch Break**                                                                              |

<table>
<thead>
<tr>
<th>Time</th>
<th>Session 2. Chair: H. Fernandes</th>
</tr>
</thead>
</table>
| 14:30-15:15 | **OV-6:** Y.-S. Hwang  
Overview of Versatile Experiment Spheriacl Torus                                           |
| 15.15-15.45 | **I-3:** J.-M. Noterdaemea  
Developments on and Plans for IShTAR                                                            |
| 15.45-16.05 | **O-3:** C. Friedli  
A hybrid subcritical fission system driven by Plasma-Focus fusion neutrons                  |
| 16.05-16.25 | **O-4:** R. González-Arrabal  
Behaviour of nanostructured and coarse-grained tungsten under pulsed irradiation in a plasma focus device |
| 16.25-16.45 | **Coffee Break**                                                                             |
| 16.45-17.15 | **I-4:** J.J.E. Herrera-Velázquez  
Conceptual Design of a Small Aspect Ratio Tokamak of Variable Configuration                   |
| 17.15-17.35 | **O-6:** M.J. Inestrosa-Izurieta  
Diamond-Like Carbon Deposition using a Plasma Focus of Tens of Joules                          |
| 17.35     | **Adjourn**                                                                                 |
### Thursday, 30th March

#### Session 3. Chair: J. Stöckel

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
</table>
| 9.30-10.15 | OV-3: R.S. Rawat  
 *Dense Plasma Focus as a Novel High-Temperature High-Density Pulsed Plasma Facility for Controlled Syntheses of Variety of Materials* |
| 10.15-10.45 | I-5: S. Meshkani  
 *Recent MCF Activities in Iran* |
| 10.45-11.05 | O-7: J. Jain  
 *Hundreds of joule Plasma focus device as a potential source of pulsed x-rays and neutrons for in vitro cancer cell irradiation* |
| 11.05-11.25 | O-8: R. Khan  
 *ECRH assisted Plasma Studies using Ordinary and Extra-ordinary Mode with Hydrogen Plasma in GLAST III* |
| 11.25-11.40 | Coffee Break |
| 11.40-12.25 | OV-4: L. Soto  
 *Small Dense Pulsed Plasma Discharges Program at the Chilean Nuclear Energy Commission Basic Research and Applications to Fusion, Materials and Biology* |
| 12.25-12.55 | I-6: R. Miklaszewski  
 *Review of recent experiments carried out on the IMJ Plasma-Focus PF-1000U device* |
 *Permanent magnet spherical Penning trap as a small fusion source* |
| 13.15-13.35 | O-10: C. Pavez  
 *Plasma Focus Discharge of Low Energy Under Different Regimes of Input Power Density* |
| 13.35-15.00 | Lunch Break |

#### Session 4. Chair: A. Melnikov

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
</tr>
</thead>
</table>
| 15.00-15.45 | OV-5: J. Stockel  
 *Edge Plasma diagnostic on the Compass Tokamak* |
| 15.45-16.15 | I-7: T.K. Popov  
 *From bi-Maxwellian to Maxwellian EEDFs in the divertor region with increasing the plasma density of the COMPASS tokamak* |
| 16.15-16.35 | O-11: V.I. Vargas  
 *Progress on Re-commissioning of the Spherical Tokamak MEDUSA in Costa Rica* |
<table>
<thead>
<tr>
<th>Time</th>
<th>Session, Speaker, Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.35-16.50</td>
<td>Coffee Break</td>
</tr>
<tr>
<td>16.50-17.20</td>
<td>I-8: A. Rivera</td>
</tr>
<tr>
<td></td>
<td><em>Object kinetic Monte Carlo simulations and plasma focus devices to study fuzz formation in tungsten subject to intense ion flux irradiation</em></td>
</tr>
<tr>
<td>17.20-17.40</td>
<td>O-12: C. Ribeiro</td>
</tr>
<tr>
<td></td>
<td><em>The High Field Ultra Low Aspect Ratio Tokamak</em></td>
</tr>
<tr>
<td>18.00-20.30</td>
<td>Laboratory Visit</td>
</tr>
<tr>
<td></td>
<td>Reception</td>
</tr>
</tbody>
</table>

**Friday, 31st March**

**Session 5. Chair: R. Rawat**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session, Speaker, Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>09.30-10.00</td>
<td>I-9: R. Solano-Piedra</td>
</tr>
<tr>
<td></td>
<td><em>Overview of the SCR-1 Stellarator</em></td>
</tr>
<tr>
<td>10.00-10.30</td>
<td>I-10: C. Xiao</td>
</tr>
<tr>
<td></td>
<td><em>Recent Experimental Studies on the STOR-M Tokamak</em></td>
</tr>
<tr>
<td>10.30-11.00</td>
<td>I-11: G. Farias</td>
</tr>
<tr>
<td></td>
<td><em>Image Classification by using a reduced set of features in the TJ-II Thomson Scattering Diagnostic; Applying deep learning for improving image classification in fusion</em></td>
</tr>
<tr>
<td>11.00-11.15</td>
<td>Coffee Break</td>
</tr>
<tr>
<td>11.15-11.35</td>
<td>O-14: A. Tamman</td>
</tr>
<tr>
<td></td>
<td><em>Plasma Sheath Velocity and Pinch Phenomenal Measurements in TPF-II Plasma Focus Device</em></td>
</tr>
<tr>
<td>11.35-11.55</td>
<td>O-15: S. Zapryanow</td>
</tr>
<tr>
<td></td>
<td><em>Evolution of the axial magnetic flux in a Mather type DPF during the rundown phase</em></td>
</tr>
</tbody>
</table>

**Session 6. Chair: L. Soto**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session, Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.55-13.30</td>
<td>Summary and Closing</td>
</tr>
<tr>
<td>13:30 - 17:00</td>
<td>Barbeque and Vegetarian Food</td>
</tr>
</tbody>
</table>
Abstracts

List of Overview Orals:

OV-1: I.E. Garkusha, *Current status of PSI studies at Uragan stellarators and QSPA*


OV-3: R. S. Rawat, *Dense Plasma Focus as a Novel High-Temperature High-Density Pulsed Plasma Facility for Controlled Syntheses of Variety of Materials*

OV-4: L. Soto, *Small Dense Pulsed Plasma Discharges Program at the Chilean Nuclear Energy Commission Basic Research and Applications to Fusion, Materials and Biology*

OV-5: J. Stockel, *Edge Plasma diagnostic on the Compass Tokamak*

OV-6: Y.-S. Hwang, *Overview of Versatile Experiment Spheriacl Torus*
OV-1: Current status of PSI studies at Uragan stellarators and QSPA


1IPP NSC KIPT, 61108, Kharkov, Ukraine
2Laboratory for Plasma Physics, ERM/KMS, Brussels, Belgium
3Nuclear Materials Science Institute, SCK CEN, Mol, Belgium

The paper overviews the recent results of plasma-surface interaction studies performed on Uragan stellarators and QSPA Kh-50 plasma accelerator at NSC KIPT. The stellarator related activity included the following issues: wall conditioning using VHF (very high frequency) discharges, 1-D self-consistent modeling of the RF discharge and development of image quality (I-Q) method for monitoring of the first wall surfaces in magnetic confinement devices. Primary attention in the experiments on plasma-surface interaction on QSPA Kh-50 was paid to experimental simulation of transient events in a fusion reactor and characterization of the PFCs in conditions of extreme heat and particle loads delivered to the material surfaces.

The VHF continuous discharge for wall conditioning with neutral atoms is studied at Uragan-2M. It is driven at frequencies ~140 MHz, i.e. higher than usually used in the RF experiments. In the experiment, the discharge parameters are studied as functions of confining magnetic field and gas pressure. Radial profiles of plasma density and electron temperature have been measured. It is shown that discharge is volumetric: plasma occupies whole confinement volume and even steps out at the edge. The typical density value is $10^{10}$ cm$^{-3}$, electron temperature varies in the range 3-10 eV. The discharge parameters did not reveal any sensitive dependence on neutral gas pressure and the toroidal magnetic field. The wall conditioning effect of the VHF discharge is demonstrated. For this discharge the numerical calculations are made.

A similar RF discharge initiation is tested without the magnetic field. The discharge needs two-order higher neutral gas pressure 0.1-0.01 Torr. It is localized near the antenna and does spread around. The plasma density is of the order of $10^9$ cm$^{-3}$, electron temperature is 2-4 eV. The wall conditioning effect has been confirmed by measurements of the amount of gas captured by the cryogenic vacuum trap, which connected to the device.

A 1D self-consistent model for RF wall conditioning RF discharges is briefly described. Results of numerical modeling of a pulsed discharge used for wall conditioning and sustained by excitation of slow waves at frequencies below the ion cyclotron are presented. The numerical simulations of plasma production have pointed out that at the plasma build-up stage the atoms are generated mainly owing to dissociation of hydrogen molecules by electron impact. When the RF power is off the dissociative recombination of molecular ions with electrons plays an important role being an additional source of the atomic hydrogen.

The Image Quality (I-Q) method has been proposed as a possible way for in-situ monitoring of the state of the first wall surface in tokamaks and stellarators. To demonstrate the feasibility of the I-Q method, it was applied to the mirror specimens coated with carbon film in laboratory conditions and to the mirrors coated with contaminants in natural way during exposure in the fusion devices (TRIAM-1M and Tore Supra), as well as to mirrors of different materials exposed to sputtering by plasma ions in the DSM-2 plasma stand in IPP NSC KIPT.
Behavior of the plasma-facing materials in conditions of powerful plasma impacts simulating ITER ELMs has been studied using QSPA Kh-50 plasma accelerator. Experiments have been performed with different tungsten grades, W coatings as well as with Cr18Ni10Ti and Eurofer steels. For the tungsten-based materials, features of surface damage were analyzed in dependence on the impacting energy loads and the exposition dose. Modifications and alloying of the steel samples with pre-deposited W films in result of mixing processes and following fast re-solidification of the surface layers are discussed.
Geodesic Acoustic Modes (GAMs) as a high-frequency counterpart of Zonal flows are considered as a possible mechanism of the plasma turbulence self-regulation. In the T-10 tokamak, GAMs have been extensively studied by the heavy ion beam probing (HIBP), correlation reflectometry and multipin Langmuir probes.

The regimes with Ohmic, on-axis and off-axis electron cyclotron resonance heating (ECRH) were studied (B = 1.5–2.4 T, I_p = 140–250 kA, n_e = (0.6–3) \times 10^{19} m^{-3}, P_{EC} < 1.2 MW). The recent advances in the HIBP allow us to get the local data in several spatial points simultaneously and make the correlation analysis.

It has been shown that GAM has radially homogeneous structure. In contrast to the theoretical expectations, the radial distribution of GAM frequency is almost uniform in spite of the temperature dependence on the radius, however, it grows with temperature as T_e^{1/2}. The GAM amplitude is about 20–80 Volts on the background steady state values of potential on the level up to -1 keV. GAMs are more pronounced during ECRH, when the typical frequencies were seen in the narrow band from 22 to 27 kHz for the main peak and 25–30 kHz for the higher frequency satellite peak. GAM characteristics and limits of GAM existence were investigated as functions of density, magnetic field, safety factor and ECRH power. GAMs are suppressed with the density increase. The phase shift between the oscillations of potential and density was about \pi/2. The poloidal mode number for GAM observed on the potential is estimated as m=0. Due to this symmetric structure electrostatic turbulent particle flux \Gamma_{E\times B}(t)=\tilde{n}_e(t) \tilde{E}_{pol}(t)/B_i is zero for GAMs, as measured by HIBP.

The bicoherence analysis shows the three-wave coupling between GAM and drift-wave broadband turbulence.

The work was carried out due to the support of RSF project 14-22-00193.
Researchers and industry are always in continuous search of new facilities or methodologies that can be used for material synthesis or processing. There are variety of plasmas that exist over very wide range of plasma densities and temperatures that are currently being used for such purpose. Currently used plasma based material synthesis tools mostly use continuous low-temperature (ranging from 0.1 to few eV) plasmas with plasma density ranging over a very wide range from $10^{13}$ to $10^{22}$ m$^{-3}$. The dense plasma focus, with density and temperature of pinch plasma many orders of magnitudes higher than low temperature plasmas, however has been used on very limited basis for material synthesis as it faces criticism of lack of controlled deposition with desired features. The criticisms include (i) limited type of deposition, e.g. mostly nanoparticle morphology, (ii) limited metal anode based deposition only and (iii) shot to shot variation in operation leading to uncertainty in deposition. In this review paper, I will highlight some of our recent work whereby we have demonstrated the controlled syntheses of variety of materials in plasma focus device by properly selecting (i) the operational parameters of the device, (ii) anode shape, design and tip material, (iii) filling gas species and combinations, (iv) the deposition distance, and (v) the substrate material and substrate temperature. The understanding and control of plasma dynamics and plasma and charged particle beam (ions and electrons) parameters on substrate surface (where deposition occurs) by tuning the above mentioned parameters can provide a very good control over the deposition type, morphology and characteristics. The selected examples will include the controlled depositions of wide variety of materials such as MX (where M=Metal, X=Nitrides/Oxides/Carbides), bi-metals and carbon based materials in many different morphologies ranging from nanoparticles, nanoparticle agglomerates, nanoparticle chain, nanotubes, nanosheets, and few micrometer thick stacked layers to highly-smooth particle-free ultra-thin layers. In addition, the added advantage of very high deposition rate, depositions using plasma species with much higher ionization states, and higher energy and number flux of plasma/ions on substrate surface leading to dense packing of deposited material will be highlighted to prove that the dense plasma focus device is indeed a versatile device with enormous potential in controlled synthesis of variety of materials.
Pinch plasma discharges are pulsed sources of dense plasmas, ions pulses, X-rays pulses, neutron pulses, plasma shocks and supersonic plasma jets. The duration of the pulses is in the range of ns to hundreds of ns. At the Chilean Nuclear Energy Commission, pinch discharges as z-pinches, x-pinches, wire arrays, and plasma focus are being studies since some years ago. Several diagnostics have been developed in our laboratory to characterize the plasma and their emissions: a) voltage and current monitors, b) visible plasma images with temporal resolution used an ICCD camera, c) neutrons detection: total yield and temporal resolution using photomultiplier and plastic scintillator, d) x-rays: images using pinhole cameras with filters in time integrated mode and with temporal resolution using a MCP camera, temporal detection using photomultiplier and plastic scintillator, and total doses, e) ion beams: Faraday cup and Thomson mass spectrometer, f) visible and x ray spectrometer, and g) digital optical refractive diagnostics. Recently a theoretical and simulation research line is being implemented to complement the experimental studies.

On the one hand, the plasma focus experiments have been extended to sub-kilojoules devices and the scales rules have been stretched up to region less than one joule. A brief review of the most recent results using tabletop plasma focus devices for basic research and applications is presented: a) scalability, similarities and differences in plasma focus devices, b) studies of filamentary structures, toroidal singularities, plasma bursts and plasma jets generations, c) pulsed radiation applied to biological studies, d) the use of plasma focus devices as plasma accelerators for studies of materials under intense fusion-relevant pulses, e) synthesis of DLC materials, and f) the conditions to use a plasma focus as a neutron seed for a hybrid fusion-fission generator have been calculated. On the other hand, the development of compact pulsed power generator to drive wire arrays and x-pinchi discharges, and recent results of plasma dynamics and x-ray pulses are presented. Possible applications of are discussed.

The authors acknowledge the ACT-1115 PIA-CONICYT and FONDECYT 1151471 grants for financial support.
OV-5: Edge Plasma diagnostic on the Compass Tokamak

Stockel, Jan, Adamek, Jiri, Dejarnac, Renaud, And The Compass Team

Institute Of Plasma Physics, Prague, Czech Republic

The main diagnostic tools to study phenomena at the plasma edge in the COMPASS tokamak will be presented, focusing on electric probes. A variety of different electric probes designed and tested on the COMPASS tokamak for measurements of important plasma parameters will be described in the talk, as well as selected examples of achieved experimental results.

— Direct measurement of the plasma potential by the Ball Pen Probe (BPP);
— Fast measurement of the electron temperature by the combined BPP and Langmuir probes;
— Measurements of plasma parameters by means of arrays of probes embedded in divertor tiles;
— Measurements of the parallel heat flux;

Some specific technology aspects related to the exploitation of probes in high performance plasmas in tokamaks, such as high heat loads of probe heads, or the design of reciprocating manipulators, will be described.
Versatile Experiment Spherical Torus (VEST) was built as an educational device for the study of spherical torus in 2011.[1] Initial ohmic operations with various start-up methods are successfully performed and a new start-up scheme utilizing trapped particle configuration is developed as a reliable and efficient way of low loop voltage start-up with electron cyclotron heating (ECH).[2] Plasma currents of up to 100kA are generated with low toroidal magnetic field of ~1kG in low aspect ratio geometry, providing a good basis for high beta experiments. The VEST research is currently moving toward the advanced tokamak operation regime. A neutral beam injection system with beam power of 500kW is under preparation for high-beta and high-bootstrap current operation. The existing ECH system for the pre-ionization will be another important heating system operating in X-B mode conversion from low field side injection. The present VEST experiments focus on the preparation of the target ohmic plasma for better coupling of the high power neutral beam to the plasma. A programmable power supply for the poloidal field coil system is being prepared to provide an increased control capability on the plasma current and position, to better utilize the limited volt-seconds during an Ohmic discharge. The glow discharge cleaning system with boronization capability is prepared for the wall conditioning. The diagnostic capabilities are also being upgraded, incorporating an interferometry, a charge exchange / beam emission spectroscopy, a Thomson scattering system, and a complementary set of magnetic diagnostics.

References:
**List of Invited Orals:**

**I-1:** H. Fernandes, *ISTTOK as a liquid metal plasma facing component test device*

**I-2:** V.A. Gribkov, *Experimental investigation of damageability of the plasma-facing materials of nuclear fusion reactors under powerful pulsed ion and plasma streams and laser irradiation*

**I-3:** J. J. E. Herrera-Velázquez, *Conceptual Design of a Small Aspect Ratio Tokamak of Variable Configuration*

**I-4:** S. Meshkani, *Recent MCF Activities in Iran*

**I-5:** R. Miklaszewski, *Review of recent experiments carried out on the 1MJ Plasma-Focus PF-1000U device*

**I-6:** T. K. Popov, *From bi-Maxwellian to Maxwellian EEDFs in the divertor region with increasing the plasma density of the COMPASS tokamak*

**I-7:** A. Rivera, *Object kinetic Monte Carlo simulations and plasma focus devices to study fuzz formation in tungsten subject to intense ion flux irradiation*

**I-8:** R. Solano-Piedra, *Overview of the SCR-1 Stellarator*

**I-9:** C. Xiao, *Recent Experimental Studies on the STOR-M Tokamak*

**I-10:** J-M. Noterdaeme, *Developments on and Plans for IShTAR*

**I-11:** G. Farias, *Image Classification by using a reduced set of features in the TJ-II Thomson Scattering Diagnostic; Applying deep learning for improving image classification in fusion*
I-1: ISTTOK as a liquid metal plasma facing component test device


Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, 1049-001 Lisboa, Portugal

E-mail of Corresponding Author: hf@ipfn.tecnico.ulisboa.pt

The high power loads impinging on the first wall and particularly the divertor of fusion reactors is a decisive factor to the success of nuclear fusion. An alternative to solid plasma facing components (PFC) is the use of liquid metals such as lithium, gallium or tin due to the "self-healing" properties of the liquid surface and the "vapour shielding" effect. However, the use of these materials in future fusion reactors depends on several compatibility factors such as deuterium retention and impurity contamination of the plasma (which can lead to degradation of the discharge performance). One of the advantages of ISTTOK device is the fact that it can be operated in AC-mode, that is, each discharge consists of several alternated pulses (with opposing plasma current direction). This was made possible due to improvements in the real-time control system of ISTTOK. Such operation mode prolongs the length of discharge decreasing the time it takes to attain the desired sample exposure time. Regularly the discharge spans 250 ms with each shot consisting of ten pulses lasting each one ~25 ms. The number of pulses can be increased up to 1s discharge time. Comprehensive work on the utilization of liquid metal PFC exists in the literature but it is mostly focused on utilizing lithium. However it has been claimed that the maximum wall temperature is limited by its high evaporation rate which introduces a operational constraint. Whereas for gallium and tin less is known despite those elements have promising properties. Notwithstanding some studies on gallium's behaviour under tokamak conditions were made previously at ISTTOK. Moreover, the combination of tin and lithium in an alloy (Sn with 20-30 at.% Li) displays additional beneficial properties, which also qualify it as a suitable candidate. The evaporation rate of this material is at least three orders of magnitude lower than that of pure lithium while keeping an effective charge similar to lithium’s.

In this paper we will review main ISTTOK results concerning exposure of Sn, Li-Sn and Ga using visible spectroscopy, facing pyrometers and ex-situ analysis.
I-2: Experimental investigation of damageability of the plasma-facing materials of nuclear fusion reactors under powerful pulsed ion and plasma streams and laser irradiation

V.A. Gribkov\textsuperscript{1,2}, A.S. Demin\textsuperscript{2}, E.V. Demina\textsuperscript{2}, E.E. Kazilin\textsuperscript{2}, S.V. Latyshev\textsuperscript{2}, S.A. Maslyaev\textsuperscript{2}, E.V. Morozov\textsuperscript{2}, M. Paduch\textsuperscript{3}, V.N. Pimenov\textsuperscript{2}, E. Zielinska\textsuperscript{3}

\textsuperscript{1}State Scientific Center of the Russian Federation – Institute for Theoretical and Experimental Physics of National Research Centre “Kurchatov Institute”
\textsuperscript{2}A.A. Baikov Institute of Metallurgy and Material Sciences, Moscow, Russia
\textsuperscript{3}Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland

The report presents results on the new Dense Plasma Focus (DPF) device “Vikhr’” that is now operational at the IMET. The description contains new experimental results on tests of a number of materials perspective for the first-wall components of Nuclear Fusion Reactors (NFR) with inertial and magnetic plasma confinement. The data are obtained with powerful plasma streams and fast ion beams generated by “Vikhr’”, PF-6 and PF-1000 facilities as well as with laser beams generated by free-running and Q-switched Nd-glass lasers. Analytical results on damageability of specimens (surface and bulk) are presented in dependence on surface areas irradiated, aggregate fluence obtained in different number of shots, distance from the radiation sources, pulse shapes and their durations, and some other characteristics. Radiation effects were modelled numerically for all the above emission types from lasers and DPF influencing the target in different surroundings and at dissimilar conditions of irradiation. Discussion of damageability is provided with taking into account zones and mechanisms of absorption of different radiation types, their power flux densities, specific phenomena (as heating, melting, evaporation and ablation of materials, production of secondary plasmas, generation of shock and rarefaction waves, validity of damage factor, etc.). Conclusions on damageability representativeness of these tests of plasma-facing materials for NFR provided by dissimilar radiation sources will be exhibited.
I-3: Conceptual Design of a Small Aspect Ratio Tokamak of Variable Configuration

J. Julio E. Herrera-Velázquez¹, Ismael Arroyo Díaz¹ and Esteban Chávez²

¹Instituto de Ciencias Nucleares
Universidad Nacional Autónoma de México
²Instituto Nacional de Investigaciones Nucleares

E-mail of Corresponding Author: herrera@nucleares.unam.mx

We show the preliminary work being done in order to propose a mid-term project for a Mexican nuclear fusion programme, with the necessary flexibility to produce original results. The idea is to be able to provide a flexible testbed for the study of tokamak physics. For such purpose, the feasibility of a medium size, low aspect ratio tokamak, with the capability of actively controlling the shape and position of the plasma column is studied. Its objective would be to explore the necessary operational conditions for high $\beta$ and high bootstrap currents. The 3D-MAPTOR code is used in order to estimate the magnetic field surfaces behaviour. The TEMEX tokamak would consist of a stainless-steel toroidal vacuum chamber with rectangular cross section, with external toroidal and poloidal field coils. The central post would include the central solenoid, as well as inner control coils. The toroidal magnetic field is produced by 10 rectangular coils, made out of 40 turns of water cooled copper conductor. Six poloidal field coils have been included, distributed in two groups of three, one on the upper, and another one on the lower side of the torus.
I-4: Recent MCF Activities in Iran

S. Meshkani, 1M. Ghoranneviss, 2Ch. Rasouli and H. Rasouli

1Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
2Plasma Physics and Nuclear Fusion Research School, Nuclear Science and Technology Research Institute, AEOI

This paper aims to investigate the recent magnetic confinement fusion research on Iranian Tokamaks as IR-T1 and Damavand. IR-T1 Tokamak is a small size and low Beta Tokamak with a circular cross section and Damavand is an active Tokamak with elongate cross section that is able to produce plasma cross section similar to ITER plasma. Improving plasma confinement and developing plasma diagnostics can be considered as the essential aim of IR-T1 research. For this purpose, different plasma diagnostics such as Ball-pen probe, capacitive probe, Mach probe, hard and soft x-ray detectors and Doppler spectroscopy were designed, fabricated and upgraded. Study of turbulent transport and plasma impurities, measurement of ion and electron temperature and the control of energy loss in plasma are the recent research in IR-T1 group. Moreover, different techniques such as biasing systems and resonant helical magnetic field (RHF) have been utilized to grow plasma confinement improvement. Results show that external electric and magnetic fields produced by biasing systems and RHF have effective role in plasma confinement. Plasma control algorithm and control of runaway electrons can be considered as the main research on Damavand Tokamak. More details of research results will be discussed in full paper.
Plasma-Focus is still one of the most intense pulsed neutron sources (>5·10\textsuperscript{11} neutrons/discharge) with promising experimental and theoretical scaling laws to higher values. Strong bursts of other ionising radiation: soft and hard X-rays, streams of electrons and ions as well as plasma streams (with velocity higher than 100 km/s) accompany discharges. Dense (up to \(10^{20} \text{ cm}^{-3}\)) and hot (~1 keV) current carrying plasma, created on the device axis, is also a very interesting object for different fundamental as well as applied investigations and attracts interest of research workers from many countries. Experiments reported in the presentation are elements of scientific exploitation of one of the world’s largest Plasma-Focus device PF-1000U (1MJ) operating within the framework of the International Center for Dense Magnetised Plasmas at the IPPLM, Warsaw, Poland. The Plasma-Focus laboratory at the IPPLM is equipped with very modern diagnostic system that consist of e.g. 16-frames laser interferometer (frame duration <1 ns, time delay between frames 10-20 ns) and developed recently ultra-fast four-frame camera capable to record pictures of the plasma in the soft X-ray range (8eV – 6 keV). This kind of equipment allows to perform detailed studies of plasma behaviour during the most interesting phases of the Plasma-Focus phenomena.

In the presentation results of the following experiments will described in details:

1. Study of the plasma dynamics during the pinch formation, transformation and disintegration with connection to bursts of neutron and X-ray radiation.

2. Influence of the external magnetic field on the pinch evolution and neutron production in Plasma-Focus discharge.

3. Influence of the gas injection into the pinch area (gas puffing) on the pinched plasma parameters and the neutron yield.

4. Modification of the inner electrode (anode) tip geometry and its influence on the pinch formation dynamics and neutron yield characteristics.

5. Astrophysics relevant experiments with plasma jets formation.
I-6: From bi-Maxwellian to Maxwellian EEDFs in the divertor region with increasing the plasma density of the COMPASS tokamak

Tsv. K Popov\textsuperscript{1}, M. Dimitrova\textsuperscript{2,3}, J. Kovačič\textsuperscript{4}, S. Costea\textsuperscript{5}, R. Dejarnac\textsuperscript{2}, J Stöckel\textsuperscript{2}, R. Panek\textsuperscript{2} and the COMPASS team

\textsuperscript{1} Faculty of Physics, St. Kl. Ohridski University of Sofia, Sofia, Bulgaria
\textsuperscript{2} Institute of Plasma Physics, The Czech Academy of Sciences, Prague, Czech Republic
\textsuperscript{3} Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria
\textsuperscript{4} Jožef Stefan Institute, 39, Jamova, 1000 Ljubljana, Slovenia
\textsuperscript{5} Institute for Ion Physics and Applied Physics, University of Innsbruck, Austria

E-mail of Corresponding Author: tsvpopov@yahoo.com

This work presents the results from the swept probe measurements in the divertor region of the COMPASS tokamak \cite{1} in D-shaped, L-mode discharges with plasma current from 140 to 260 kA, toroidal magnetic field $B_T = 1.15$ T and varying line-average electron densities from $3 \times 10^{19}$ to $8 \times 10^{19}$ m$^{-3}$ during the discharge. The current-voltage characteristics data were processed using the first-derivative probe technique \cite{2,3}. This technique allows to evaluate the plasma potential and the real electron energy distribution function (EEDF), respectively the electron temperature and density.

The EEDF was studied during the density scan. At low line-average electron density of $4 \times 10^{19}$ m$^{-3}$ in the whole divertor region the EEDF is bi-Maxwellian with low-energy electron population with temperatures 4-5 eV and high energy electron group with temperatures 11-18 eV. With increasing the line-average electron density in the high field side the EEDF appears to be Maxwellian, while in the low field side it remains bi-Maxwellian. Above $7 \times 10^{19}$ m$^{-3}$ line-average electron density the EEDF is found to be a Maxwellian in the whole divertor region. Possible reasons for the phenomenon observed is discussed on the base of model calculations.

References:
\cite{1} PANEK R. et al. 2016 Plasma Phys. Control. Fusion, 58 014015
\cite{2} POPOV TSV. K. et al. 2009 Plasma Phys. Control. Fusion 51 065014
\cite{3} POPOV TSV. K. et al. 2016 Plasma Sources Sci. Technol. 25 033001

This research has been partially supported by the Joint Research Project between the Institute of Plasma Physics of the CAS and the Institute of Electronics BAS BG and by MSMT project # LM2015045.
Tungsten subject to bombardment by an intense flux of He ions undergoes a dramatic morphology change resulting in a highly underdense nanostructuration (“W fuzz”) of the surface region. Experimental evidence shows that this only occurs in the temperature window 900–2000 K. Making use of an object kinetic Monte Carlo (OKMC) simulations parameterized from first principles, we show that fuzz formation stems from He and point defect clustering, subsequent, cluster growth and detrapping reactions. Summarizing the main mechanisms: (i) SIA emission (trap mutation) and (ii) coalescence of small $\text{He}_n\text{V}_m$ clusters due to emission of He atoms and formation of new $\text{He}_n\text{V}_m$ clusters in their vicinity. The simulations fairly agree with experiments and show how these mechanisms predominantly occur in the experimental temperature window giving rise to fuzz formation. Small plasma devices, such as the plasma focus setup installed at CCHEN (Santiago de Chile) turn out very appropriate to study fuzz formation. They are flexible, affordable and cost effective, yet providing intense ion pulses with a high repetition rate. In this presentation we will show preliminary irradiation experiments and the capabilities of the CCHEN setup to study not only fuzz formation in realistic fusion confinement conditions but tungsten resistance to irradiation once fuzz is unavoidably formed. The prominent role of our successful OKMC methodology as a tool to understand tungsten response to irradiation will be highlighted.
I-8: Overview of the SCR-1 Stellarator


*Plasma Laboratory for Fusion Energy and Applications, Instituto Tecnológico de Costa Rica, Cartago, P.O.Box 159-7050, Costa Rica
**Max Planck Institute for Plasma Physics, D-85748 Garching, Germany

E-mail of Corresponding Author: risolano@itcr.ac.cr

On June 29, 2016, the Stellarator of Costa Rica 1 (SCR-1) produced its first hydrogen plasma, becoming the first Stellarator in Latin America and one of the few operatives in the world. This fusion research device was fully designed, constructed and implemented in Costa Rica. SCR-1 is a small-size, modular Stellarator (R=0.247 m, <a>=0.040 m, R/a=6.2, plasma volume ≈ 0.0078 m³, 10 mm thickness aluminum torus shaped vacuum vessel) [1]. The magnetic field strength at the center is around 43.8 mT which is produced by 12 copper modular coils with 4.6 kA-turn each. This field is EC resonant at R with a 2.45 GHz as 2nd harmonic, from 2 kW and 3kW magnetrons.

Small Stellarators have clear advantages related to total cost of the project which allows to, with a relatively low investment, train human resources and contribute to the physics and engineering of such devices within the fusion scientific community. This contribution provides an overview of the SCR-1 Stellarator from the simulation and physics point of view with emphasis on VMEC code and preliminaries full-wave simulations using the IPF-FDMC code to develop different electron Bernstein waves heating scenarios. Using an experimental electron density profile, it is expected to identify in the future where in the plasma the conversion O-X-B occurs, as well as calculate electrostatic Bernstein wave conversion efficiency and identify the main regions in the SCR-1 Stellarator where it might be located an antenna for a Bernstein heating system.

Finally, magnetic mapping experiments results and first electron temperature and density measurements using Langmuir probe also will be shown.

References:
I-9: Recent Experimental Studies on the STOR-M Tokamak*

C. Xiao, A. Rohollahi, S. Elgriw, J. Adegun, M. Patterson, J. Zhang and A. Hirose

Plasma Physics Laboratory, University of Saskatchewan, Canada

In this presentation, momentum injection from an accelerated compact torus into the STOR-M discharges and effects of lithium coating of the STOR-M vacuum chamber wall on the STOR-M discharge properties will be reported. The details of these improvement and upgrading of the RF systems and development of the termination avoidance scenario related to the RF heating are discussed.

Compact tori at velocities in the range of 80-210 km/s were injected into the STOR-M discharges with normal (counter-clockwise (CCW), top view) and reversed discharge current directions [1,2]. Ion Doppler Spectroscopy (IDS) has been used to measure the toroidal flow velocities of the impurity ions in the STOR-M discharges in the outer region (C\textsc{III} line, \(r\sim7\ cm\)) and in the core region (O\textsc{V} at \(r\sim3\ cm\) and C\textsc{VI}, \(r\sim0\ cm\)) [3]. The CTs were injected tangentially in the fixed CCW direction during the experiments for both normal and reversed STOR-M discharge current directions. As expected, the intrinsic flow direction of the impurity ions reverses from CCW to CW direction in the outer region (C\textsc{III}) and from CW to CCW direction in the core region (O\textsc{V} and C\textsc{VI}) when the STOR-M discharge direction is reversed from CCW to CW direction. After CT injection, the flow velocities always change towards the CT injection direction (CCW) for a period of a few milliseconds, independent of the initial intrinsic flow directions. It has been estimated that a CT carries a momentum approximately ten times the tokamak plasma toroidal flow momentum, demonstrating CT momentum injection into the STOR-M discharges.

The STOR-M tokamak chamber wall has been recently coated with Lithium via the physical vapor deposition technique. Compared to the discharges without Lithium coating under the otherwise same discharge conditions, following phenomena have been observed: significant reduction in the electron density due to reduced recycling, reduction of impurity contents in the plasma, and increase in the discharge current and in the hard x-ray (HXR) radiation level. The latter two phenomena can be attributed to the enhanced run-away suprathermal electrons in the discharges with low density and lower impurities. Suprathermal electrons contribute to plasma current and enhance the HXR emission when they strike on the chamber wall.

References:

* Supported by NSERC, CRC, SFCCNI, and General Fusion Inc.
I-10: Developments on and Plans for IShTAR

J-M. Noterdaeme$^{a,b}$, K. Crombé$^{a,d,b}$, R. D’Inca$^{b}$, S. Devaux$^{c}$, E. Faudot$^{c}$, H. Faugel$^{b}$, H. Fünfgelder$^{b}$, S. Heuraux$^{c}$, J. Jacquot$^{b}$, A. Kostic$^{a,b}$, J. Moritz$^{c}$, A. Nikiforov$^{a}$, R. Ochoukov$^{b}$, M. Tripský$^{a,d}$, M. Usoltceva$^{a,c}$, T. Wauters$^{d}$ and the IShTAR team

$^{a}$ Department of Applied Physics, Ghent University, Ghent, Belgium
$^{b}$ Max-Planck-Institut für Plasmaphysik (IPP), Garching, Germany
$^{c}$ Université de Lorraine, Nancy, France
$^{d}$ LPP-ERM-KMS, TEC partner, Brussels, Belgium

IShTAR (Ion Sheath Test ARrangement) is a linear magnetic facility developed by and operated at the Max-Planck-Institut für Plasmaphysik (IPP) in Garching in cooperation with several universities and institutes. It is equipped with a helicon plasma source and an ICRF (Ion Cyclotron Resonant Frequency) single strap antenna. It is used to investigate the interactions between the launched wave and a plasma that is representative (plasma density, temperature and wave propagation) for a tokamak edge.

The plasma source is 0.4m in diameter and 1m long, it is designed to reach the helicon discharge mode with a helical antenna in a magnetic field of 0.1T with five magnetic field coils. In the present configuration a RF power of up to 3 kW is delivered at 11 MHz, with a gas pressure between $10^{-3}$ and $10^{-5}$ mbar in argon or helium (all safety measures to also use hydrogen have been implemented).

The source is connected to a cylindrical vacuum chamber, 1m in diameter and 1m long, where the ICRF antenna is located and where plasma conditions representative of a tokamak’s edge are recreated: two main coils build a static magnetic field up to 0.2 T, the plasma (created by the external source) has a density around $10^{17}$ m$^{-3}$ for argon $10^{16}$ m$^{-3}$ for helium and a temperature between 5 and 10 eV. The antenna is powered with a 1 kW generator at 5 MHz. It could also be connected to a 2MW generator with a frequency range between 30 and 120 MHz.

The test bed is equipped with an array of cylindrical Langmuir probes on the back flange, a movable manipulator with a set of B-dot probes and Langmuir probes to get the radial profiles, video cameras and optical fibers connected to a high-resolution spectrometer equipped with an iCCD camera able to follow fast events with high spectral resolution. The test bed offers, in comparison with a tokamak, better accessibility for the diagnostics, a higher flexibility for the control of the plasma parameters, more dedicated experimental time (IShTAR can have up to 60 discharges of 8 s per hour) and, for modifications (e.g. to the antenna), a much faster turn-over (opened, closed and pumped down within a day).

Whereas the device was originally meant to develop the tools to measure the electric field produced by the ICRF wave inside the sheath on the antenna limiters in order to provide data to check and benchmark the RF sheath models, it can actually provide major contributions in many other areas related to plasma production and RF-plasma interactions. Just to name a few:

- helicon physics: the helicon has one of the largest diameter in the world and will soon be equipped with a major power upgrade (up to 750 kW generator power between 3.9 MHz and 26.1 MHz);
- refinement of RF fields measurement methods: by comparison of the modelling the electromagnetic field distribution (including eigenmodes and superposition of the fields of helicon and RF antenna) inside the vessel with the measurements;

- RF plasma production and modelling: the device was used to test plasma production for RF wall cleaning, and to investigate for which conditions the plasma is initiated inside the antenna box. It is essential to avoid such phenomenon in high power ICRF system on tokamak, but IShTAR provides the liberty for detailed investigations of the conditions under which these to-be-avoided phenomena occur.

IShTAR is further designed as an experimental platform dedicated to international co-operations: to improve remote access for participants, it is equipped with an intranet to manage the operations and the documentation. The processing system has sharable notebooks and remote access to the discharge database is possible.

With these activities, IShTAR is developing into a complete experimental platform for students and international collaborators who need not only to investigate phenomena between the ICRF antenna and the plasma but also to validate their codes with data in simplified geometries or their diagnostics in flexible conditions before implementation on an operational tokamak.
During the past few years, machine learning has been increasingly applied for developing pattern recognition systems in massive thermonuclear fusion databases. Several solutions can be found in the literature for fast retrieval information, classification and forecasting of different types of waveforms [1]. Images in fusion are not the exception, there are some data-driven models that have been successfully implemented to classify Thomson Scattering images in the TJ-II stellerator [2-3]. Most of these image classifiers were developed by using data mining techniques such as neural networks and support vector machines. One advantage of these techniques is that they only require a set of inputs (images) and their corresponding outputs (the class of each image) to learn a function that outputs the class to a new input image. This decision function is so complex and non-linear that it is normally called a black box model, and although this approach could perform a one hundred percent of success classification, it is not able to provide a clue of the reason for such output.

This work proposes the use of boosting algorithms to build models that provides very simple IF-THEN rules to classify Thomson Scattering images. Boosting is a way to improve the model by adding a simple rule that assigns correctly classes to some previously wrong classified samples. Thus, the obtained model is an explicit weighted sum of several simple rules that could provide useful information about why an image has been assigned to a particular class. The article also shows that even using a reduced set of pixels (less than 0.1% of the original image) the classifier is able to keep a high success rate (over 95%). As it will be shown, such aspect produces three important benefits: i) a reduction of the computational time for classification, ii) a more robust performance in noisy conditions (stray light), and finally iii) a way to support knowledge discovery from the five different classes of the TJ-II Thomson Scattering images.

References:
Applying deep learning for improving image classification in fusion

G. Farias¹, J. Vega², S. Dormido-Canto³, K. Hidalgo¹, S. Vergara¹, E. Fábregas³

¹ Pontificia Universidad Católica de Valparaíso, Av. Brasil 2147, Valparaíso, Chile
² Laboratorio Nacional de Fusión, CIEMAT, Av. Complutense 40. 28040 Madrid, Spain
³ Dpto. de Informática y Automática, UNED, Juan del Rosal 16. 28040 Madrid, Spain

E-mail of Corresponding Author: gonzalo.farias@pucv.cl

Deep learning has emerged as one of the most encouraged approaches in recent past years. One of the main applications of deep learning is the automatic feature extraction with autoencoders. Feature extraction is a very critical stage in machine learning that can reduce drastically the dimensionality of the problem, making easier the process of classification [1].

This article addresses the assessment of including autoencoders for automatic feature extraction in the massive thermonuclear fusion databases. In order to show the performance of autoencoders in a practical way, the problem of the classification of a set of 981 images of the TJ-II Thomson Scattering diagnostic has been selected. Similar to other pattern recognition problems, in this case there are two main stages: i) the pre-processing of the data, and ii) the application of a classification algorithm to get a model [2]. Thus, the autoencoders are just added between both two stages to extract features from the pre-processed images. The classification has been performed by the algorithm of support vector machines, but it should be clear that the selection of a different method for this step should produce similar results. The work evaluates three main questions of using autoencoders for the classification of images: i) are the models more accurate? ii) are the predictions computed faster?, and iii) are the models better fitted for new images?

The results show that the use of autoencoders produces models with higher success rates, reaching in some cases up to 96% in average, which is 2% over the performance without autoencoders. The results also show that model predictions can be computed in less time when autoencoders are used. The models can be twice faster than the cases without autoencoders, although it could require parallel programming of autoencoders for operation in real-time. Finally, in order to confirm that the classifiers with autoencoders are more robust and better fitted for new images, a conformal predictor was developed to add confidence values to the classification. The results show that classifiers with autoencoders are able to make predictions for new images with up to 50% more of confidence and credibility.

References:
List of Regular Orals:

O-1: G. Avaria, *Visible spectroscopy of the axial phase in plasma focus discharge of hundreds of joules*

O-2: J. Batra, *Observation on wide energy range of ions emission and their correlation with neutrons emission in a Plasma Focus device* (Cancelled)

O-3: C. Friedli, *A hybrid subcritical fission system driven by Plasma-Focus fusion neutrons*

O-4: R. Gonzalez-Arrabal, *Behaviour of nanostructured and coarse-grained tungsten under pulsed irradiation in a plasma focus device*


O-6: M. J. Inestrosa-Izurieta, *Diamond-Like Carbon Deposition using a Plasma Focus of Tens of Joules*

O-7: J. Jain, *Hundreds of joule Plasma focus device as a potential source of pulsed x-rays and neutrons for in vitro cancer cell irradiation*

O-8: R. Khan, *ECRH assisted Plasma Studies using Ordinary and Extra-ordinary Mode with Hydrogen Plasma in GLAST III*

O-9: D. R. Knapp, *Permanent magnet spherical Penning trap as a small fusion source*


O-11: V.I. Vargas, *Progress on Re-commissioning of the Spherical Tokamak MEDUSA in Costa Rica*

O-12: C. Ribeiro, *The High Field Ultra Low Aspect Ratio Tokamak*

O-13: V. Svoboda, *Measurements of plasma parameters by the Ball Pen and Langmuir probes on the GOLEM tokamak* (Cancelled)

O-14: A. Tamman, *Plasma Sheath Velocity and Pinch Phenomenal Measurements in TPF-II Plasma Focus Device*
O-15: S. Zapryanov, *Evolution of the axial magnetic flux in a Mather type DPF during the rundown phase*

O-16: Z. Ahmad, *Plasma Current Enhancement with vertical and Horizontal Coils in Glast-III* (Cancelled)
O-1: Visible spectroscopy of the axial phase in plasma focus discharge of hundreds of joules

G. Avaria\textsuperscript{1}, A. Clausse\textsuperscript{2}, O. Cuadrado\textsuperscript{3}, N. Villalba\textsuperscript{4}, J. Moreno\textsuperscript{1}, C. Pavez\textsuperscript{1}, B. Bora\textsuperscript{1}, S. Davis\textsuperscript{1}, M. J. Inestrosa-Izurieta\textsuperscript{1} and L. Soto\textsuperscript{1}

\textsuperscript{1}Comisión Chilena de Energía Nuclear and Center for Research and Applications in Plasma Physics and Pulsed Power, P4, Casilla 188-D, Santiago, Chile
\textsuperscript{2}CNEA-CONICET and Universidad Nacional del Centro, 7000 Tandil, Argentina
\textsuperscript{3}Universidad Austral de Chile, Valdivia, Chile
\textsuperscript{4}Universidad Metropolitana de Ciencias de la Educación, Santiago, Chile

E-mail of Corresponding Author: gavaria@cchen.cl

The plasma sheath evolution in the axial acceleration phase of Plasma Focus discharges is of interest for fundamental studies of the ionization and density evolution of the plasma, at the early stages of pinch formation. Plasma Focus devices have several capabilities as self-scaling plasma devices, neutron sources, pulsed X-ray sources, plasma shock and ultrasonic jet generators and as sources for material testing for future fusion reactor walls, amongst others. Improvement of these capabilities is related to the characterization of the plasma conditions at the plasma sheath formation and initial acceleration in the inter-electrode space. In order to study these conditions, experimental observations were developed at the low energy plasma focus device PF-400J (176-539 J, 850 nF, 20-35 kV, ~300 ns quarter period), operated between 9 and 15 mbar of D\textsubscript{2}. A 0.5 m Czerny-Turner imaging spectrometer coupled with a 3 ns integration time ICCD detector was used to characterize the plasma at the axial acceleration phase of the discharge. Spatially and spectrally resolved images allow the characterization of the plasma sheath velocity and electron density through D-alpha broadening. The evolution of the emission with space and time resolution, with respect to the current onset, can be observed in the sequence below, allowing the determination of a plasma sheath velocity around 43.6 km/s. Comparison of these measurements with numerical calculations based on a lumped parameter model show excellent correspondence. Preliminary calculations of electron density considering H-alpha line broadening indicate densities in the order of $\sim 10^{18}$ cm\textsuperscript{-3}. Opacity effect corrections are underway. Gas impurities inclusions, in order to characterize the evolution of the ionization degree during this phase of the discharge, are also under development.

Work funded by FONDECYT Iniciación 11121587 and CONICYT PIA-Anillo ACT 1115.
O-2: Observation on wide energy range of ions emission and their correlation with neutrons emission in a Plasma Focus device

Jigyasa Batra, Ram Niranjan, R.K Rout and T.C Kaushik

Applied Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai-400 085, India

E-mail of Corresponding Author: jigyasa@barc.gov.in

The Plasma Focus (PF) devices, being pulsed sources of electromagnetic radiations, have been of keen interest in a number of studies because of their various demonstrated or emerging applications. The device is a rich source of radiations like ions, electrons, X-rays and neutrons. As pulsed neutron sources, they have potential applications in neutron activation analysis, medical field and material inspection etc. The pulsed poly energetic ion beams find applications in various technological areas including ion implantation, surface modification, ion assisted coating, carburizing, thin film deposition etc. Measurements of ions, neutrons flux at variable experimental parameters and their correlation could help in understanding the dynamics of PF device and thereby operate it for desired application. This study investigates the effect of poly energetic deuterium ions fluence and discharge current profile on fluence of neutrons at different filling gas pressures (0.5-5 mbar, deuterium gas) in a 11.5 kJ Mather type PF device (MPF12) operated at 7.5kJ. The temporal study of neutrons and deuterium ions fluence has been carried out using Plastic scintillator detector and Faraday Cup (FC) respectively. Effect of anomalous resistance due to instabilities on fluence of ions and neutrons with increasing pressures has been observed. This study could help in understanding the dynamics of ions emission in the PF device, obtaining optimising pressure for efficient yield of ions in desired energy range depending upon intended applications and also in neutron yield optimization.
O-3: A hybrid subcritical fission system driven by Plasma-Focus fusion neutrons

Carlos Friedli ¹, Alejandro Clausse ², Leopoldo Soto ¹,³ and Luis Altamirano ⁴

¹Center for Research and Applications in Plasma Physics and Pulsed Power, P4, Chile
²CNEA-CONICET and University of Central Buenos Aires, 7000 Tandil, Argentina
³Comisión Chilena de Energía Nuclear, Casilla 188-D, Santiago, Chile
⁴Dicontek Ltda., Santiago, Chile

The concept of hybrid nuclear reactors combining fusion and fission processes was first proposed in the decade of 1950 (see reference [1]) and was reactivated later in the 70’s [2]. After that, the interest in the hybrid idea waned, not so much because of technical difficulties but for lack of economic incentive. This remained so until the last two decades, during which the interest in hybrids has again increased for their possible application in energy production, either using Uranium fuel or combining breeder systems with Thorium fuel cycles, and also for the destruction of nuclear waste [3, 4].

The central concept of hybrids is to surround a fusion source of neutrons with fissile fuel configured in such a way that the whole system is subcritical. The neutrons injected by the source, usually as a train of pulses, are then multiplied by fissions, generating a total energy that in principle should be larger than the input energy required for the fusion process.

A feasibility analysis of a hybrid fusion-fission system consisting of a two-stage spherical subcritical cascade driven by a Plasma Focus [5] device is presented. The analysis is based on the one-group neutron diffusion equation, which was appropriately cast to assess the neutronic amplification of a spherical configuration. A design chart was produced to estimate the optimum dimensions of the fissile shells required to achieve different levels of neutron amplification. It is found that this type of cascades driven by Plasma Focus of tens of kJ is feasible [6]. The results were corroborated by means of Monte Carlo calculations.

References:

The present work was supported by the bilateral Chilean-Argentine project CONICYT-ACE01 ANPCyT-PICT2697.
O-4: Behaviour of nanostructured and coarse-grained tungsten under pulsed irradiation in a plasma focus device

R. Gonzalez-Arrabal¹, M. Panizo¹, A. Rivera¹, G. Balabanian¹,², M.J. Inestrosa-Izurieta³,⁴, J. Moreno³,⁴, G. Avaria³,⁴, B. Bora³,⁴, S. Davis³,⁴, J. Jain³,⁴, C. Pavez³,⁴, L. Soto³,⁴, and J. M. Perlado¹

¹ Instituto de Fusión Nuclear, ETSI de Industriales, Universidad Politécnica de Madrid, Madrid, Spain.
² Carl Zeiss Microscopy GmbH, Oberkochen, Germany.
³ Comisión Chilena de Energía Nuclear, Santiago, Chile.
⁴ Center for Research and Applications in Plasma Physics and Pulsed Power, Santiago, Chile.

E-mail of Corresponding Author: raquel.gonzalez.arrabal@upm.es

One of the bottle necks for fusion to become a reality is the lack of materials able to withstand the harsh conditions occurring in a reactor environment. In particular, plasma facing materials (PFM) have to resist large radiation fluxes and thermal loads. Nowadays, tungsten is one of the most attractive materials proposed for PFM. However, it is known that the irradiation of tungsten with light species (H and He) leads to surface blistering and subsequent cracking and exfoliation which is unacceptable. In particular, these effects have been observed to be more severe when W is subjected to pulsed irradiation.

One possible option to improve the radiation-resistant of PFM in relation with the atomistic damage and light species behavior is the use of nanostructured materials. On this point, we will report about experimental and computer simulation data showing the role of grain boundaries in the atomistic damage and light species behavior. From these data we deduce that nanostructured W exhibit a better radiation resistant than coarse grained W in the studied temperature range.

The other main concern is related to its capability to withstand large thermal loads. This is especially a key point for nanostructured materials because of its metastable behaviour. On this subject, we will show the microstructural and light species behavior for nanostructured and coarse grained W samples irradiated under different conditions (heat flux parameter and number of pulses) in a small plasma focus device located at the Comisión Chilena de Energía Nuclear (CCHEN).
The MNA-PF device is operating at slow focus mode since it has high impedance and high inductance. The device is being tested using argon as the filling gas to find its optimum operational parameters. Four different types of Rogowski Coils were designed and constructed to measure discharge current and the results show that response frequency of Rogowski Coil can affect signal time resolution and delay which can change the discharge circuit inductance. Experimental results for 0.5 mbar to 5.5 mbar argon which are captured by 630 MHz Rogowski coil in correlation with Lee Model Code are presented. The optimum pressure to obtain a good pinch and the best fit using Lee Model Code for argon was found to be at 1.5 mbar. Proper current fitting using Lee Model Code shows that the speed factor for MNA-PF device working with 1.5 mbar argon is 84 kA/cm.torr1/2 at 12 kV and thus verified that the device is operating at slow focus mode. Model parameters mass swept factor for axial, $f_m$ and mass swept factor for radial, $f_{nr}$ predicted by Lee Model Code during current fitting for 1.5 mbar argon at 12kV were 0.0223 and 0.37 respectively. Using these results as reference and changing the gas with deuterium, the MNA-PF was used to generate neutron through D-D fusion reaction. Model parameters $f_m$ and $f_{nr}$ predicted by Lee Model Code for 13 mbar Deuterium at 14kV were 0.025 and 0.31 respectively. Microspec-4 Neutron Detector was used to obtain the dose rate which was found to be maximum at 4.78 $\mu$Sv/hr and also the maximum neutron yield calculated from Lee Model Code is 7.5E+03 neutron per shot.
Different types of plasma sources are used in thin film fabrication and surface modification of materials. In particular, the plasma focus device is characterized by being a rich source of electromagnetic radiation and particle beams that benefit material surface improvement with wide range of ion species and energy. In this work, a dense plasma focus of tens of joules has been successfully used to fabricate diamond like carbon (DLC) coating at plasma radiation. The experiments were made according to a statistical experimental design using a very thin wall anode with a pure carbon insert, to evaluate the carbon deposition and possible DLC formation, under the main parameters found through previous studies: distance from the anode and number of pulses. The samples were morphologically characterized by SEM and structurally by XRD, as well as by Raman spectroscopy, given their sensitivity with the corresponding bonds to the presence of DLC in the film.

With the results of a statistical experimental design, we observe that distance from the anode is the main cause of the amount and distribution of deposit. In addition, despite the low reproducibility present in the discharges, it was possible to determine that lower and more pulses promote a relative increase of the sp$^3$/sp$^2$ ratio complemented by the down-shift of the G band position owing to reduced vibrational frequency under Ion induced stresses [1] which can be extrapolated to a higher mechanical hardness [2,3].

References:

The authors acknowledge the financial support of project PAI-CONICYT 79130026.
In vitro experiments play important role in order to understand the biological processes on cellular level. Plasma focus devices could be useful in the area of pulsed irradiation of cancer cells for in vitro experiments. Present study contains the preliminary results of pulsed irradiation on colon cancer cell line DLD-1. A plasma focus device, namely “PF-400J”, is used for this purpose. The advantage of PF devices is that they can emit particles (neutrons) as well as x-ray radiation, depending upon the filled gas. X-rays and neutrons measurements were performed using photomultiplier tubes in axial and radial directions, simultaneously. The neutron energies were estimated using time of flight (ToF) methodology. In order to study the origin time of neutrons a methodology, namely, time history analysis (THA) is developed. Using THA, neutrons origin time with respect to x-rays is estimated. It was found that in most of the discharges the neutrons are originated prior to x-rays in axial direction. However, in radial direction the neutrons originated after x-rays in most of the discharges. The average energy of neutrons in axial direction was obtained ~ 2.14 ± 1.0 MeV. Neutron and x-rays emission was found more frequent in axial direction. Henceforth, this direction was chosen for in vitro cancer cell irradiation experiments. Fifty pulses of x-rays and fifty pulses of neutrons are used to irradiate the cancer cell lines. Studies of DNA damage and cell death have been performed post irradiation. The DNA damage analysis was carried out for 30, 60 and 120 minutes, while the cell death analysis during 24, 48, and 72 hours. It was found that the DNA damage, with significant statistical value, was present for 30 minutes post irradiation in case of pulsed x-rays. In this case, the cell death was absent. On the other hand, neutron irradiation provides the cell death but the DNA damage was with poor statistical significance.
O-8: ECRH assisted Plasma Studies using Ordinary and Extra-ordinary Mode with Hydrogen Plasma in GLAST III


National Tokamak Fusion Program, P.O Box 3329, Islamabad, Pakistan

E-mail of Corresponding Author: khan.riaz.pk@gmail.com

Glass Spherical Tokamak (GLAST) is a small limiter based spherical tokamak with an insulating vacuum vessel. The key parameters are R= 20 cm, a= 10 cm, κ=2, Ip=8kA, BT=0.2 T, and τp=2ms. The purpose of GLAST is to understand the consumption of ohmic flux and the mechanism responsible for current penetration during start-up phase. The insulating vacuum vessel can cause the vertical instability, which need to be explored thoroughly.

In this work, we will explore the different possible plasma start-up scenarios by varying the polarization of the incident RF waves (2.45 GHz frequency, 1.6 KW power). O-mode, X mode and O-X mode conversion are observed for the parallel, perpendicular and oblique angle of the electric field vector with respect to the B_T, respectively. Resonance layer is observed at a spatial position where the Toroidal field is 875 Gauss. The resonance layer gets shifted by varying the Toroidal field. A detail comparison of the hydrogen plasma characteristics for different B_T, filled gas pressure and polarization will be presented. Most importantly, the effect of polarization on the plasma current will be discussed.

References:
A solenoid Penning trap was previously explored as a potential fusion reactor [1]. We are studying by theory, simulation, and experiments whether a useful fusion output can be produced in a small (1 cm radius) permanent magnet spherical Penning trap. Following the previous work [1], we have observed a sharp focus of electrons at the spherical center when the applied voltage is adjusted to a magnetic field dependent value. This focus forms a virtual cathode which can confine ions, and if the applied voltage is several kV, these ions may achieve a thermonuclear temperature, leading to controlled fusion reactions with a fractional energy gain. Theory predicts that injection of electrons and collection near the cylindrical center of the end cathodes can lead to a steady state with strong spherical convergence. Very low power is required to maintain such a state because electrons are sourced and collected at very low energy compared with the total well depth of the system. Additional theory arguments show that major instabilities (e.g. two-stream) are avoided if little space charge is neutralized by trapped ions, that low frequency ion/electron instabilities are also absent, and that moderate neutralization fraction leads to a reasonable ion density and temperature such that fusion output is expected.

A small experiment has been constructed to access these physics. A 1 cm radius trap with hyperbolic electrodes is placed inside a permanent magnet system. The magnet system is engineered to produce a uniform (nonuniformity less than $10^{-3}$ over spherical volume) magnetic field and the field strength can be varied from several hundred Gauss to nearly 2 kG by adding additional permanent magnets. Axial holes in the two end cap cathodes allow injection of electrons which are produced by a hairpin tungsten filament. The entire assembly is placed inside a room temperature vacuum chamber which is capable of a base pressure below $10^{-7}$ Torr.

In a scan of anode voltage, we have observed the spherical focus at the resonant point predicted for the measured magnetic field by measuring the anode current. Increasing magnetic fields exhibit resonances at the theoretically predicted higher anode potentials. We are working to reach anode potentials sufficient to achieve nuclear fusion while maintaining the voltage standoff necessary to maintain these potentials. The current status of this work will be presented.

References:
The Plasma Focus (PF) device corresponds to a kind of plasma accelerator driven by a pulsed discharge that is developed between two concentric electrodes. The interaction between the formed current sheet and its self-magnetic field (the Lorentz force) accelerates the plasma sheath towards a small region on the axis, forming a dense and hot plasma column (pinch phase), near the maximum current. This last phase is characterized by its high energy density and the region involved in this time becomes a source of intense radiation, high-energy particles, and copious nuclear fusion products, when isotopes of H\textsubscript{2} is used as filling gas. While there are enough studies of the phenomenology observed in the PF discharges, there are still open problems that do not have consensus evaluation, one of them is the correlation between the inhomogeneity of the plasma sheet and the evolution of the plasma column. In particular, the effect of this on the X-ray and neutron yields. In this direction, this work describes a set of experimental observations, carried out in a plasma focus device of hundreds Joules under different regimes of input power density, which give an account of the morphology of the current sheet and the dynamic characteristics of the plasma, in addition to X-ray performance. The study was conducted by means of side-on refractive optical diagnostics, magnetic probes, in addition to traditional diagnostics, voltage divider, Rogowski coil and scintillatorphotomultiplier system. The experiments were carried out on a Multipurpose generator, operated in the plasma focus mode. This small capacitive generator produces currents about of 120 kA when capacitors are charged at 24 kV. The discharges were generated in H\textsubscript{2} as working gas. In order to modify the input density power, two different anode and insulator sizes, in addition to different load voltages were tested. The obtained results both in the X-ray performance and the dynamics characteristics of the discharge, are contrasted with the understanding of the scaling rules established by other authors.

The authors acknowledge the FONDECYT grant 1151471 for financial support.
O-11: Progress on Re-commissioning of the Spherical Tokamak MEDUSA in Costa Rica


Plasma Laboratory for Fusion Energy and Applications, Instituto Tecnológico de Costa Rica, Cartago, P.O.Box 159-7050, Costa Rica

E-mail of Corresponding Author: ivargas@itcr.ac.cr

The low aspect ratio spherical tokamak (ST) MEDUSA (Madison EDUcation Small Aspect ratio tokamak) is currently being re-commissioned in Costa Rica and was donation to Instituto Tecnológico de Costa Rica by University of Wisconsin-Madison, USA. The major characteristics of this device are [1]: plasma major radius $R_o < 0.14$ m, plasma minor radius $a < 0.10$ m, plasma vertical elongation 1.2, toroidal field at the geometric center of the vessel $BT < 0.5$ T, plasma current $I_p < 40$ kA, $n_e(0) < 2 \times 10^{20}$ m$^{-3}$, central electron temperature $T_e(0) < 140$ eV, discharge duration is $< 3$ ms, top and bottom rail limiters, natural divertor D-shaped ohmic plasmas). In addition to training, the major objective of renamed device MEDUSA-CR is to address relevant physics for spherical and conventional tokamaks, taking advantage of the insulating vessel which allows plasma real time response to applied external electrical or magnetic fields.

The major topics for the scientific programme are 1) Comparative studies of equilibrium and stability between natural divertor D and bean-shaped ST plasmas [2]; 2) Study of an ergodic magnetic limiter [2,3,4]; 3) Alfvén wave heating and current drive and; 4) Transport. Advances in some of these topics will be presented in this work, in addition to the technical tasks of machine re-commissioning involving the re-design of energy, gas injection, vacuum system and control systems.

References:
A small High toroidal magnetic Field Ultra Low Aspect Ratio Tokamak (HF-ULART) is proposed. The major objective of this is to explore the highest beta limit possible in such configuration under the maximum toroidal field (limited by engineering constrains) to have also high plasma pressure, using present day technology and achievements of tokamak fusion performance. This is the right pathway scenario to initiate studies for the potential most compact pulsed neutron source based on the spherical tokamak concept, which later, may lead to more steady-state neutron source or even to fusion reactor, via realistic design scaling.

The major characteristics of this device are: plasma major radius $R_o = 0.52m$, plasma minor radius $a = 0.42m$, aspect ratio of $A=1.24$, plasma vertical elongation $\kappa \approx 2$, triangularity $\delta \approx 0.8-0.9$, toroidal field at the geometric centre of the vessel of $B_T < 1T$, plasma current of $I_p < 0.5MA$, density of $n_e(0) \approx 1x10^{20}m^{-3}$, central electron temperature from $T_e(0) \approx 1keV$, discharge duration of $\tau_d \approx 100ms$. The vessel is spherical and made of stainless-steel, which is insulated from the natural diverted plasma by thin (few centimetres) tungsten (W) spherical limiters. No internal poloidal field coils or solenoid is envisaged. This helps the plasma compactness (relative close plasma-vessel fitting in order to capitalized of potential wall stabilization as envisaged in the RULART proposal [1]) and also to easy plasma/neutron shield via a thin W bored rod of about 2mm thickness covering the cooper made central stack. This might be the only designed component pre-cooled by external liquid nitrogen flow if engineering constrains really require, thus maintaining the overall design simple and cheap.

The major source of initial heating is provided by the plasma current generated from RF in combination with Coaxial Helicity Injection (CHI) techniques, as both have been successfully demonstrated separately: RF in LATE and QUEST and CHI in NSTX and Pegasus spherical tokamaks. After a very high beta configuration is attained (potentially in H-mode as observed in Pegasus ohmic H-mode in natural divertor configuration using inboard gas fuelling), adiabatic compression (AC) technique is applied via raising $B_T$ to higher values (possibly up 2T) and possibly synchronised with the raise of $I_p$ up to 1MA, both for short period (few milliseconds) in a similar way was successfully conducted in former TUMAN-3 high aspect ratio tokamak. At the peak of the AC phase, single cryogenic pellet injection followed by neutral beam injection (NBI) heating can be used for further raising the central temperature in a very high density peaked profile target, leading to high neutron yield, with potential similarities to PEP (JET) or super-shot (TFTR) high performance discharges.

This HF-ULART can help also revival of the use of the AC technique in tokamaks, alongside another spherical tokamak, that is, the larger, less compact, and more complex ST-40 device, currently under construction [2]. In addition, the studies in HF-ULART as a compact neutron source help also to test the feasibility of similar compact neutron sources such as by the proposal of a 1MW fusion neutron source based on the spheromak concept, which also uses the AC technique [3].

Preliminary equilibrium and stability simulations prior the use of AC technique will be presented, and possibly some basic neutronic calculations, at the peak of this phase. Constrains
of plasma power load in this optimised vessel, the challenging plasma control and gas fuelling (inboard and outboard) systems, and central stack design, will be also discussed.

References:
O-13: Measurements of plasma parameters by the Ball Pen and Langmuir probes on the GOLEM tokamak

Vojtech Svoboda¹, Jan Stockel², Jiri Adamek², Miglena Dimitrova²

¹Faculty on Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Czech Republic
²Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic

E-mail of Corresponding Author: svoboda@fjfi.cvut.cz, stockel@ipp.cas.cz, adamek@ipp.cas.cz, dimitrova@ipp.cas.cz

The GOLEM tokamak, (R = 0.4 m, a = 0.085 m), operates currently at a modest range of parameters: B_t < 0.6 T, I_p < 8 kA, discharge duration ~ 20 ms [1]. Recently it has been equipped with the probe head combining the Ball-pen probe (BPP) [2] and the Langmuir probe (LP) with the aim to measure directly the plasma potential and the electron temperature with a sufficiently high temporal resolution.

The contribution summarizes achieved experimental results on measurement of the electron temperature and plasma potential by several ways.

— The electron temperature Te is determined from classical fitting of the IV characteristics measured the Langmuir probe;
— Alternatively, Te and the plasma potential are derived from the same data using approach based on the first derivative technique [3].
— Results are compared with the directly measured plasma potential by BPP and Te measurements from the combined BPP+LP.

Agreement is satisfactory, and observed differences are discussed.

References:
O-14: Plasma Sheath Velocity and Pinch Phenomenal Measurements in TPF-II Plasma Focus Device

Arlee Tamman¹, Mudtorlep Nisoa¹, Boonchoat Paosawatyanyong², Noppon Poolyarat³ and Thawatchai Onjun⁴

¹School of Science, Walailak University, Nakhon Si Thammarat 80161, Thailand
²Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand
³Faculty of Science and Technology, Thammasat University, Pathum Thani 12120, Thailand
⁴School of Manufacturing Systems and Mechanical Engineering, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani 12120, Thailand

E-mail of Corresponding Author: nmudtorl@wu.ac.th

TPF-II, the small plasma focus device which is consisted of the 30 μF single capacitor to store the 1.5 kJ of electric energy, is used to study the property of plasma focus. The main diagnostic is consisted of current probe, capacitive voltage divider probe, four channel of magnetic probes and optical emission spectroscopy (OES). The magnetic probes are used to measure the plasma sheath velocity in the acceleration phase. The decreasing of the plasma sheath velocity which is occurred by the increasing of filling gas pressure is observed by the magnetic probes. The current and voltage probes signal are shown the sign of plasma focus pinch. The OES is used to confirm the special wavelengths of the emitting light which are generated by the pinch phase such as Cu-I, Cu-II, Cu-III and Ar-II. The X-ray which is generated by the anode electron bombardment (hard X-ray) and transient mode of high temperature and high density plasma (soft X-ray) are observed by the X-ray films.
Recent investigations [1] suggest correlation between neutron emission and axial magnetic field in the pinch phase of the Dense Plasma Focus (DPF). Toroidal directionality of energetic ions participating in fusion reaction inferred from published data from multiple laboratories [2] also supports the idea that axial magnetic field may be playing some role in achieving the observed unexpectedly high fusion reaction rate. However, not much data exists concerning the temporal evolution of the axial magnetic field [2]. This paper presents preliminary report of ongoing experimental attempts at measuring the azimuthal electric field in the region outside the plasma, which equals the rate of change of axial flux being emitted by the plasma. The results show clear evidence for evolution of axial magnetic flux in the rundown phase, indicating that injection of helicity needed for plasma relaxation [3] occurs right from the beginning of the discharge. This suggests that inferences concerning neutron emission mechanism from theoretical studies [4], which assume at the outset that azimuthal components of electric field and velocity are zero, need to be re-examined.

Direct measurements of the azimuthal electric field in the close vicinity of the electrode system of a Mather type DPF during the rundown phase of the discharge represent strong evidence for the existence of an axial magnetic flux, which in turn has some correlation with neutron emission [1]. A thorough investigation of the spatial structure and evolution in time of the azimuthal electric fields, sensed by various magnetic probes, placed in different locations in and around the electrode system of a real DPF is presented below. Some satisfactorily accurate sense of the distribution of the magnetic flux can be obtained hereby and the picture supports an important conclusion about the consequences of hyperbolic conservation laws, applied to the current sheath [2]. This picture, supported by the experiments presented and by some other recent work worldwide may be an important step along the road of understanding PF phenomena, explaining phenomena with toroidally streaming fast ions and unexpectedly high fusion reaction rates involved.

References:
GLAST-III (Glass Spherical Tokamak) is an operational Tokamak at NTFP, Pakistan which is modified/advanced version of GLAST I & II. It has Major radius R=20 cm and minor radius $a=10$ cm ($A=R/a=2$) and $B_T=0.1T$. The vacuum vessel is made of glass and can achieve vacuum up to $~10^{-7}$ mbar. As the vessel is made of glass (dielectric material), therefore field penetration is rapid as compared with the metallic vessel (conducting materials). This property is useful for maintaining the equilibrium in GLAST-III. It is also well known that spherical tokamaks are more stable due to high natural elongation.

We have created plasma current up to 4kA by varying the vertical coils current and using ECR heating in a Hydrogen gas discharge. Plasma pulse length is increased from 1ms to 2ms using a special technique. This technique involves a horizontal coil around the horn of wave guide and producing a resonance magnetic field in the radial direction just at the edge of tokamak. A Spectrometer (HR2000) is used for emission spectroscopy in the visible region to calculate the average electron temperature. It is found that Nitrogen, Oxygen and Carbon lines are present in the spectrum of discharge which indicates that there is a need to further improve the vacuum level in the vessel to reduce the impurity influx and quality of discharge. Temperature and density of edge plasma is estimated by using triple Langmuir probe. Results from spectroscopic measurement and plasma imagining will be presented.

Moreover we have installed the horizontal filed coils to balance the radial error field. Effect of this improvement on the plasma current pulse length will also be reported during the meeting.