Fusion relevant researches and developments in Ukraine

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## Ukrainian Institutes Involved in Fusion Research

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On the base of Agreements between EU and Ukraine, signed by the governments representatives, the official **Coordination Group, representing Ukraine (mainly NAS of Ukraine, was established):**

**Chairman:**
Corresponding member V.I.Tereshin – Institute of Plasma Physics, NSC KIPT NASU, Kharkov

**Executive secretary:**
Dr. I.E.Garkusha - Institute of Plasma Physics, NSC KIPT NASU

**Members:**
Academisian A.G.Zagorodny – N.N.Bogolyubov Institute for Theoretical Physics, NASU, Kiev

Academisian K.A.Yushchenko – E.O.Paton Institute of Welding, NASU, Kiev
The Main Directions of Fusion Investigations and Developments in Ukraine

1. **Fusion investigations** (theory and experiment)
   1.1. Magnetic confinement of plasma in stellarators and electromagnetic traps.
   1.2. High frequency methods of plasma heating.
   1.3. Diagnostic methods of high temperature plasma.
   1.4. Theory of all aspects of plasmas behavior in magnetic systems of tokamaks, stellarators and in fusion reactor.

2. **Powerful pulsed and quasi-steady-state plasma accelerators** and their applications for fusion.

3. **Problems of fusion reactor ITER**
   3.1. Problems of divertor and its materials.
   3.2. First mirrors of diagnostic systems.
   3.3. Hydrogen recycling etc.
   3.4. Fusion reactor materials.
   3.5. Fusion reactor technologies.
Magnetic Confinement Systems

Stellarators
Electromagnetic Traps
**Stellarator-torsatron Uragan-3M (with poloidal divertor)**

In the Uragan-3M torsatron plasma produced and heated by RF fields in the multi-mode Alfvén resonance regime in the $\omega_? \omega_{ci}$ range of frequencies.

**The main directions of investigations:**

1) **Investigations of the processes, accompanying formation of the inner (ITB) and edge (ETB) transport barriers, and transition to the improved confinement mode of operation.**

2) **Physics of the processes, accompanying the diverted plasma flows:** Vertical asymmetry of diverted plasma. Connection between fluctuations in confined plasma and ones in diverted plasma flows.
Torsatron Uragan 2M with low ripple values of the helical magnetic field (it was put into operation at the end of 2006)

Large radius $R=1.7$ m
Averaged plasma radius – $a \leq 0.24$m
Toroidal magnetic field - $B_0 \leq 2.4$ ?

Configuration with no magnetic Islands
$? \sim 20,5 ??$
for $?_\phi =0.31$, $<B>/B_0 \sim 1.14\%, 1.85\%, 2.55\%$

U-2M torsatron is equipped with two compact RF antennas of frame type. The first antenna has a broad $K_\parallel$ spectrum and is used for plasma production. The second one with narrower $K_\parallel$ spectrum heats plasma in the Alfvén range of frequencies.
A new 4-strap shielded antenna
Presence of a larger number of magnetic coils in Uragan-2M, as compare to conventional stellarators and torsatrons, provides variation of its magnetic configurations in essentially more wide range. So, extensive research program of the influence of magnetic field inhomogeneous in stellarator on its confinement properties can be carried out. The main tasks:

1. Investigation of different methods of wall conditioning: ECR, glow discharge, RF.

2. Development and investigation of different scenarios of RF plasma production and heating (both theoretically and experimentally) at frequencies below the ion cyclotron ones with using portable antennas to be developed and optimized.
3. Achievement of high plasma parameters with magnetic field close to its limit value. Experimental studies of maintenance and heating of dense plasmas (5-10). $10^{13}$ cm$^{-3}$ in Uragan-2M device with using RF methods.

There are 4 RF generators with total power $\sim$ 8 MW, RF-pulse length $\sim$ 100 ms.

4. Study of particle and heat transport in a RF discharge plasma in stellarator system with reduced helical ripple. Correlation between transport properties and electric field distributions and fluctuations in plasma measured with HIBP diagnostics.

5. Experiments on $\beta$ limit in high density plasma.

6. Influence of magnetic islands on the impurity ions transport in magnetic configurations with rotational transform $\iota > \frac{1}{2}$ and $\iota < \frac{1}{2}$ and different sign of ambipolar electric field.
1. HIBP Diagnostic

Heavy Ion Beam Probing (HIBP) diagnostic is practically the only one, which is able to provide the non contact plasma electric potential measurements and its fluctuations in the great bulk of plasma column (with high spatial and time resolution).

The HIBP group of the IPP NSC KIPT (L.I. Krupnik et al) has a long term experience in developing, installation and using of the HIBP diagnostic in different fusion devices all over the world:

- T-10, Tuman-2M, TM-4 tokamaks in Russia,
- TJ-I tokamak and TJ-II stellarator in Spain,
- WEGA- stellarator (Greifswald, Germany).

Uragan-2M (Kharkov) – to be installed.

2. Sensitive magnetic probes for fusion devices (“Lviv Politechnika”, I.A. Bolshakova et al). Unique diagnostic developed for fusion devices Tore Supra, TJ-II, JET, under consideration for ITER.
Theoretical Investigations of Magnetic Confined Systems in Ukraine
1) **Transport processes and plasma confinement in toroidal magnetic systems** (IFP NSC KIPT of the NASU, N.N.Bogolyubov Institute for Theoretical Physics, Institute for Nuclear Physics of the NASU, V.N.Karazin National University (Kharkov)).

2) **Modelling of neoclassical transport, equilibrium currents in plasma and MHD stability in stellarator in $1/\nu$ regime** (IPP NSC KIPT of the NASU).

   Transport coefficients calculations were carried out (in regimes of $1/\nu$) in plasmas of both conventional and improved stellarators on the of NEO code, developed in IPP NSC KIPT.

3) **Investigations of the processes in stellarators, tokamaks and spherical tori, resulted with energetic ions, generated in fusion reactions, injections of neutral and HF heating of plasma** (Institute for Nuclear Research NASU).

   - Alfvénic spectrums and instabilities in plasmas;
   - Fishbone instabilities in tokamaks and spherical torus;
   - Classical transport of energetic ions in tokamaks;
   - Stochastic diffusion of energetic ions in stellarators;
   - Modelling of physical processes in stellarators of Wendelstein type, tokamak JET and ITER etc.

4) **ECR heating and current drive in tokamaks and stellarators** (IPP NSC KIPT of the NAS of Ukraine).
5) Investigations of different scenarios of plasma production and heating in Uragan-2M torsatron and other systems under excitation of electromagnetic waves in the region of ICF (IPP NSC KIPT NASU).

6) Impurity control and their withdrawal from stellarator plasmas with using law-hybrid resonance (IPP NSC KIPT NASU).

7) Alpha particles withdrawal from torsatron reactor with using auxiliary resonant vertical magnetic field ?????????? ???? ?-?????? ?? ?????????????- ???????? (IPP NSC KIPT NASU).

8) Current drive generation due to the conversion of ion-cyclotron frequency for plasma stability control in ITER (IPP NSC KIPT NASU).

9) Theoretical and numerical investigations of the role of dusty particles in the influence of plasma with the first wall of reactor (N.N.Bogolyubov Inst. for Theoretical Physics, Taras Shevchenko Kiev National University).


    The evolution of anomalous transport was analyzed in the plasma region of ETB formation. It was shown creation of strong poloidal shearing flows, resulting to suppression of drift turbulence and transport barriers formation.
Experiments and developments in support of fusion reactor ITER
1) Experimental simulation of ITER transient events and plasma-surface interaction in ITER divertor (IPP NSC KIPT).

   Analysis of the surface morphology, materials structure, element content, erosion characteristics and other properties of different materials (tungsten, graphite, combined W-C targets and other materials, including preliminary heating ones up to the temperature above 650 °C) under their irradiation by plasma streams with heat load typical for current disruption instabilities at the divertor plates \((Q = (10-100 \text{ J/m}^2; t = (1-10) \text{ ms})\) and edge localized modes formation ELM \((0.75 – 1.5 \text{ J/m}^2)\) in ITER.
QSPA Kh-50 – the largest in the world accelerator of plasma with unique parameters:

- Averaged plasma density – $(0.1-7) \times 10^{16}$ \text{cm}^{-3};
- Averaged proton energy – $(0.2-0.9)$ keV;
- Plasma energy density – $(0.1-40)$ MJ/m$^2$;
- Full plasma energy – $(100-500)$ kJ;
- Duration of acceleration – $(0.04-0.25)$ ms.

QSPA Kh-50 is unique device for simulations of conditions at the diverter plates of fusion reactor ITER under transient events:

**Current disruption:**

$$Q = (10-100) \text{ J/m}^2; \ t = (1-10) \text{ ms}$$

**Edge Localized Modes (ELMs):**

$$Q = (1-3) \text{ J/m}^2; \ t = (0.1-1) \text{ ms}; \ \nu = (1-100) \text{ Hz}$$
The surface morphology, material structure and element content, erosion characteristics and other properties of different materials (tungsten, graphite, combined tungsten-graphite target, and other materials) were analyzed under surfaces irradiation with plasma heat loads typical for disruptions and repetitive ELMs in ITER.

Variation of the heat load value provided carrying out the irradiated surface analysis in conditions of its before melting point, melting and evaporation.

Experiments with preliminary heated targets were done also.

Repetitive plasma irradiation of Tungsten with heat loads relevant to ITER ELMs

Two types of cracks were formed at the surface: macrocracks (with the network size ~ 1 mm) and a net of microcracks (mesh ~ 10-20 µm).

Fine intergranular cracks are caused by thermal stresses during fast resolidification of the melt, whereas the large cracks are the result of Ductile-to-Brittle Transition Effects.
First diagnostic mirrors

2) Problems of the first diagnostic mirrors of fusion reactor. The degradation of optic characteristics of the first mirrors of different materials in fusion reactor under surface irradiation with electromagnetic radiation, ion fluxes, neutral particles fluxes and fluxes of neutrons relevant for fusion reactor were carried out (IPP NSC KIPT).

Experimental results were collected in different fusion installations like LHD (JAPAN), one of the most large tokamaks Tore Supra (FRANCE, tokamak with the longest pulse of plasma maintaining TRIAM-1M (JAPAN), and medium size tokamak TEXTOR (GERMANY).

It was shown that in the case, when the surface sputtering by charge exchange atoms prevails the value of deposited impurities, the first mirrors should be manufactured of single crystal materials.
First mirrors of ITER diagnostic systems.

For more than decade, the quite broad program on simulation of behavior of in-vessel mirrors needed for many diagnostics in ITER is provided in laboratory headed by Dr. V.S.Voitsenya.

For the last years the investigations were carried out in the frame of cooperation of IPP NSC KIPT with NIFS, Cadarache, Garching, Juelich, and Basel University.

It was shown that in the case when the surface sputtering by CXA prevails over deposition of contaminants, the first mirrors have to be fabricated from single crystals or as metal film on the metal substrate.

Dependence of mono- and poly-crystal surface reflectance for samples exposed in plasma with wide spectrum of ion energy.

It was shown that W-Pd bilayer systems have high erosion properties and high hydrogen permeability. Principal possibility was found of effective hydrogen removal from hydride-formative metals (Zr and Zr + 1 %Nb) in such bilayer systems. Therefore, one possible to develop a method of decreasing accumulation of hydrogen, in particular tritium, in structural materials.
Materials and Technologies for Fusion Reactor
Institute of Solid State Physics, Materials and Technologies of the NSC KIPT (NAS of Ukraine).

The proprietary constructional materials, pure materials, superconductors, progressive welding processes and so on were developed. In particular,

- The technology of beryllium of high purity manufacture (on the base of powder of spherical form) was developed. The mechanical properties of such beryllium essentially exceed ones for commercial beryllium.

- The methods of high cleaning of vanadium were developed. This is rather perspective for production of vanadium alloys with high radiation resistance.

- The proprietary alloy Cu-Y with high radiation resistance and high physico-mechanical properties was developed.

- The technologies and equipment for production of articles of different forms and sizes from carbon-carbon composite materials (CFC), providing operation with high thermal, neutron and other loadings.
Isotropic compact materials as semi-finished items of Be

General view of Be disks and their elements with prismatic cavities

X-ray snapshots of disk with prismatic cavities
Graphite goods

Dimensions of products are limited only by the sizes of existing facilities. Nowadays the products of the following dimensions have been manufactured:

- **Monolithic type:** length up to 2600 mm; diameter up to 700 mm;
- **Tubular type:** length up to 2600 mm; external diameter up to 2500 mm
The unique technologies of welding of big-volume articles of different materials were developed, tests of weld joints were carried out in the wide range of temperatures (293-4,2 °C) (E.O. Paton Institute of Electrowelding)

Components of superconducting and vacuum elements of fusion magnetic systems

- development of stable austenitic steel 20Cr-16Ni-6Mn-N (δ=2÷40 mm), welding materials and technology;
- technological management during production and building;
- Investigation of properties of welded joints under 293-4,2 °C.
Vacuum systems of large volume

Vacuum vertical chamber
for space imitation

- Total volume: 8500 m³
- Working volume: 3600 m³
- Casing material: Kh18N10T and 03Kh13AG19
- Casing weight: 370 t
- Load-carrying set weight: 530 t
- Weight of screens with trusses: 170 t
- Vacuum: 10⁻⁵ mm Hg, T = 77K

Horizontal vacuum chamber 25000 m³
for space imitation

Participation of Paton Electric Welding Institute:
- development of construction steel, materials and technology for welding and project building;
- COD documentation and technological management
Thank You
for Your Attention!
Alushta-2010

International Conference and School on Plasma Physics and Controlled Fusion, combined with
4-th Alushta International Workshop on the Role of Electric Fields in Plasma Confinement in Stellarators and Tokamaks,

September 13-18, 2010

Alushta (Crimea), Ukraine
Previous Conferences – Schools:

Alushta – 1998
Alushta – 2000
Alushta – 2002
Alushta – 2002
Alushta – 2004
Alushta – 2006
Alushta – 2006
Alushta-2010, Crimea, Ukraine)
The Conference program will include both invited and contributed papers on the following topics and related areas:

1. Magnetic confinement systems: (Stellarators, Tokamaks, Alternative conceptions)
2. Plasma heating and current drive
3. ITER and fusion reactor aspects
4. Basic plasma physics
5. Space plasma
6. Plasma dynamics and plasma-wall interaction
7. Plasma electronics
8. Low temperature plasma and plasma technologies
9. Plasma diagnostics
10. Collisional processes

Workshop program:

1. Role of electric fields in transitions to improved confinement in Stellarators and Tokamaks.
2. Relationship between Edge Plasma Turbulence and Electric Fields behavior.
5. Heavy ion beam probe (HIBP) diagnostic as a key method of potential behavior analysis

Alushta-2010, Crimea, Ukraine)
Sponsors:

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National Science Center “Kharkov Institute of Physics and Technology”
EPS
Science and Technology Center in Ukraine (STCU)
Organizer:

Institute of Plasma Physics of the National Science Center “Kharkov Institute of Physics and Technology”, National Academy of Science of Ukraine

Local Organizing Committee:

Co-Chairman – I.M. Neklyudov, Director General, Acad. of the NASU
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The website of the Conference: http://www.kipt.kharkov.ua/conferences/

The Conference e-mail address: icppcf-2008@kipt.kharkov.ua (Conference Secretary)

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