

PROGRAMME OF COORDINATED RESEARCH ACTIVITIES

Webpage: www.iaea.org/services/coordinated-research-activities

Annual Progress Report for Contracts

Please send the Progress Report to research.contracts@iaea.org

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| CRP code: F13019 | CRP title: Network of Small and Medium Size Magnetic Confinement Fusion Devices for Fusion Research |
| Contract Number: 22782 | Contract title: Scientific and education activities on the GOLEM tokamak in the framework of the IAEA CRP |
| Institute Name: Czech Technical University | |
| CSI: Vojtěch SVOBODA | Alternate CSI: |
| Progress Report for year: 1 (year 1, 2, 3...) | Period covered: (2018-06-28 - 2019-06-27) |

1. Detailed programme of work, as planned at the beginning of the period, taking into account the recommendations given during Research Coordination Meetings (RCMs) and/or through communication with the Project Officer:

2.2.14.1. Main research activities proposed

The scientific activities focus on the field of plasma edge studies using advanced probe techniques and developing diagnostics for runaway studies.

2.2.14.3. Education activities

In the CRP context there are two planned education activities: GOMTRAIC, a week of hands-on experiments at the GOLEM tokamak, and a set of remote participation training courses.

2. Results achieved in comparison with the planned programme of work.

* plasma edge studies using advanced probe techniques

Operational domain in hydrogen plasmas on the GOLEM tokamak

A series of discharges in Hydrogen were performed in two experimental sessions in different tokamak vessel configurations. The vessel was not conditioned before the first session, while inductive heating of the vessel and cleaning glow discharge were applied before the second session. Experimental results from both sessions are compared, and optimum operational conditions for the majority of key plasma parameters are determined. It is found that plasma performance with a properly conditioned vessel is significantly better, as expected. In particular, a noticeable increase of discharge duration, and of the electron temperature is observed. More info at [Svo+19].

* developing diagnostics for runaway studies.

Study of Runaway Electrons in GOLEM Tokamak

High loop voltages and low-density discharges at GOLEM tokamak present favorable conditions for the study of runaway electrons. In this paper, we discuss the interplay between magnetic hydrodynamic (MHD) fluctuations and runaway electrons. In quasi-periodic events, it was observed that tearing modes strongly destabilize during large HXR signals due to the runaways. Tearing modes become stable, when HXR signals are suppressed. Causality of events is still not clear, since during the HXR generation, toroidal electric field also increases, as indicated by loop voltage signal. More info at [Dhy+19] .

Design and Development of Probe for the Measurements of Runaway Electrons Inside the GOLEM Tokamak Plasma Edge

Repeatable discharges with high loop voltage and low-density in GOLEM tokamak present good experimental conditions for the study of runaway electrons (RE). A probe is being designed and developed for the spectral measurement of RE energy inside and near the GOLEM tokamak plasma edge. Probe design is based on simulation results of FLUKA code that estimates the energy absorbed by the filters of high-density materials and scintillating crystals. Simulations performed for the electron beams of energy 1-10MeV suggest that runaways may have energy much higher than 1MeV in the GOLEM tokamak. In the simulations, graphite, stainless steel, molybdenum and tungsten were tested to filter the supra-thermal electrons. Since having low-Z and being sensitive to γ -radiations and electrons, YSO scintillation crystal is chosen for the probe. However, flexible design of the probe allows different scintillating crystal and filter materials inside it. More info at [Dhy19]

* educational activities

Online experimentation at the GOLEM tokamak

The GOLEM tokamak offers students and other interested parties the opportunity to gain “hands-on” experience through online experimentation in the field of plasma physics and controlled thermonuclear fusion in tokamaks. A typical online experiment scenario is outlined. The new web application facilitating safe, easy and efficient online experimentation, including a live, real-time view of the experiment is described in detail. Simple access to the open and extensive database of experimental results is demonstrated. Finally, the wide range of possible experimental topics from past -and applicable to future- online experimentation sessions is reported. More info at [GSS19a, GSS19b]

GoleM TRAIing Course (GOMTRAIC 2019)

GoleM TRAIing Course (GOMTRAIC2019) was held at the faculty of Nuclear Sciences and Physical Engineering in the Czech Technical University in Prague, Czech Republic during March 04-08, 2019. The training course was organized in cooperation with Fusion Education Network (FUSENET) and International Atomic Energy Agency (IAEA). Sixteen students (from undergraduate to doctoral level and ten countries) participated in the course to have hands-on experience of tokamak operation and perform experiments on the GOLEM tokamak. For more detailed info, see in the attachment GOMTRAICFinalReport.pdf

Education and training of students

Experiments related to CRP project triggered bachelor and master thesis at the CTU:

Bachelor projects:

- Filip Papousek: Impact of swept edge plasma potential biasing on turbulence in tokamaks
- Vojtech Fiser: Real time tokamak GOLEM operation.

Master thesis:

• Petr Mácha: Fast measurements of electron temperature on the GOLEM tokamak by means of Tunnel Probe

Hands-on/ on site tokamak GOLEM projects

- For Students (bachelor level) of the FNSPE CTU in the frame of the Basic experimental laboratory.
- SCIWEEK – Science week for high school students from Czech Republic
- September 2018: Night of Scientists for broad public.
- Two projects for extremely skilled high school students: Nela Sedlackova (RE studies) and Daniela Kropackova (Plasma edge studies)

Training of students has also been performed remotely, exploiting a unique feature of the GOLEM tokamak, which can be operated via Internet. Several on-site as well as remote courses were organized in the period 2018 – 2019, among these, major events were:

• Remote workshop for the Eight International Workshop & Summer School on Plasma Physics at Black Sea from Sunday, Kiten, Bulgaria, 10th to Saturday, 17th June 2018.

<https://iwsspp.plasmer.org/>

• Remote practice for Budapest University of Economics and technology, Hungary 19th, November 2018

- Remote practice for Padova University, Italy 23rd, November 2018
- Remote practice for Eindhoven University, Netherlands 18th, December 2018
- Remote practice for Torino University, Italy 20th, December 2018
- Remote workshop for the 5th ASEAN School on Plasma and Nuclear Fusion, 21-25 Jan 2019, Mahidol University, Thailand, <https://sites.google.com/site/fusionschoolth/aspnf2019>
- Remote practice for Fusion Master gathering in Cadarache, France 19th, February 2019
- Remote practice for Charkov University, Ukraine 13th, March 2019
- Remote demo from ASDEX tokamak, Germany 25th, March 2019

- Remote practice for Moscow University, Russia 9th, April 2019

3. Papers published and dissemination at national and international conferences on work performed under this Project (please enter a web-link or attach copies to this progress report):

[Lin+18] V. Linhart et al. "First Measurement of X-rays Generated by Runaway Electrons in Tokamaks Using a TimePix3 Device with 1 mm thick Silicon Sensor". In: 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference Proceedings (NSS/MIC). 2018, pp. 1-9. doi: 10.1109/NSSMIC.2018.8824534.

[Dhy+19] P. Dhyani et al. "Study of Runaway Electrons in GOLEM Tokamak". In: Journal of Instrumentation 14.09 (2019), pp. C09029-C09029. doi: 10.1088/1748-0221/14/09/c09029. url: <https://doi.org/10.1088%2F1748-0221%2F14%2F09%2Fc09029>.

[Dhy19] Svoboda V. Istokskkaia V. Mlynář J. Čeřovský J. Ficker O. Linhart V. Dhyani P. "Design and development of probe for the measurements of runaway electrons inside the golem tokamak plasma edge". In: vol. 2019-July. Europhysics conference abstracts. 2019, P1.1016. isbn: 979-10-96389-11-7. url: <http://ocs.ciemat.es/EPS2019PAP/pdf/P1.1016.pdf>.

[GSS19a] O. Grover, V. Svoboda, and J. Stockel. "Online experimentation at the GOLEM tokamak". In: 2019 5th Experiment International Conference (exp.at'19). 2019, pp. 220-225. doi: 10.1109/EXPAT.2019.8876482. url: <https://ieeexplore.ieee.org/document/8876482>.

[GSS19b] O. Grover, V. Svoboda, and J. Stockel. "Remote demonstration of the GOLEM tokamak". In: 2019 5th Experiment International Conference (exp.at'19). 2019, pp. 239-240. doi: 10.1109/EXPAT.2019.8876584. url: <https://ieeexplore.ieee.org/document/8876584>.

[Kul19] Mácha P. Istokskkaia V. Kropáčková D. Papoušek F. Adámek J. Čeřovský J. Ficker O. Grover O. Jiráková K. Stöckel J. Svoboda V. Kulkov S. "Tokamak GOLEM for fusion education - chapter 10". In: vol. 2019-July. Europhysics conference abstracts. 2019, P1.1068. isbn: 979-10-96389-11-7. url: <http://ocs.ciemat.es/EPS2019PAP/pdf/P1.1068.pdf>.

[Svo+19] Vojtech Svoboda et al. "Operational Domain in Hydrogen Plasmas on the GOLEM Tokamak". In: Journal of Fusion Energy (2019). issn: 1572-9591. doi: <https://doi.org/10.1007/s10894-019-00215-7>.

4. Activities included in the programme of work which were planned, but were not implemented. Please state reason (i.e.: delays, issues encountered):

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5. Detailed programme of work for the coming year, taking into account the recommendations given during RCMs and/or through communication with the Project

Officer (to be used as reference for the next Progress Report):

Main research activities proposed:

The scientific activities continues to focus on the field of plasma edge studies using advanced probe techniques and developing diagnostics for runaway studies.

Education activities proposed:

In the CRP context there are again two planned education activities based on first year experience: GOMTRAIC #2, a week of hands-on experiments at the GOLEM tokamak, and a set of remote participation training courses.

CSI Name and signature:

Date: 4.11.2019

Vojtěch Svoboda

