4. JSPS A3 (China, Japan and Korea) Foresight Program

I. Project title

Study on critical physics issues specific to steady state sustainment of high-performance plasmas

II. Period of cooperation

August 2012 - July 2017

III. A3 foresight program in the field of plasma physics

The three countries, China, Japan and Korea (C-J-K), have recently built large toroidal devices called EAST, LHD and KSTAR having superconducting magnetic coils, respectively, and have successfully started the academic research aimed at the steady-state operation of high-performance plasmas, which is an inevitable subject for realization of the fusion reactor. The EAST tokamak is characterized by a long pulse discharge accompanied with H-mode based on successful current drive and tungsten divertor operation and related edge plasma physics in the long pulse discharge. The KSTAR tokamak is characterized by the study to mitigate high heat load at divertor due to ELM activity during H-mode transition and the transport study of high-performance plasmas represented by H-mode discharge with edge transport barrier. Various methods, e.g., pellet injection and edge magnetic field modification brought by RMP coils, have been attempted to the KSTAR tokamak with extremely low magnetic error field. On the other hand, LHD is the largest HELICAL-type device, which confines the high-temperature plasma with helical magnetic fields generated by external helical coils. It is characterized by the steady state operation without the necessity of toroidal plasma current unlike tokamaks. Therefore, the properties of LHD plasmas are very distinctive and different from those of tokamak plasmas, e.g., characteristic transport of high-energy particles based on three-dimensional magnetic configuration, edge heat and particle transports based on inherently-equipped stochastic magnetic field lines and disruption-free long-pulse discharge sustainment. By conducting a joint research using above-mentioned three world-class superconducting toroidal devices with entirely unique features, various advanced researches on critical physics issues to be resolved for early realization of the fusion reactor are possible based on the long-pulse sustainment of high-performance plasmas. The proposed joint project will be certainly able to promote further development of plasma physics studies and fusion researches conducted by the three countries of C-J-K.

IV. Significant cooperative activities

When a discharge is longer, the handling of high heat load over the divertor and the first wall located near high-temperature plasmas becomes a vital issue because it creates an entirely different situation from what has been studied in normal conducting toroidal devices with the discharge length strictly limited. The issue is a common and challenging subject among the three different devices in the three countries of C-J-K. The study of critical physics for the steady state operation of high-performance plasmas is made possible only by superconducting devices and will produce important results for the first time with the three superconducting devices of C-J-K. Then, as the study focusing only on the critical physics that is revealed for the first time by the steady state discharge of high-performance plasmas, the following three critical physics issues are listed up for the joint research among C-J-K as shown in Fig.1. From 2013 the category IV is newly created for covering three experimental categories of I-III as follows.

(I) Steady state sustainment of magnetic configuration
(II) Edge and divertor plasma control
(III) Confinement of alpha particles
(IV) Theory and simulation

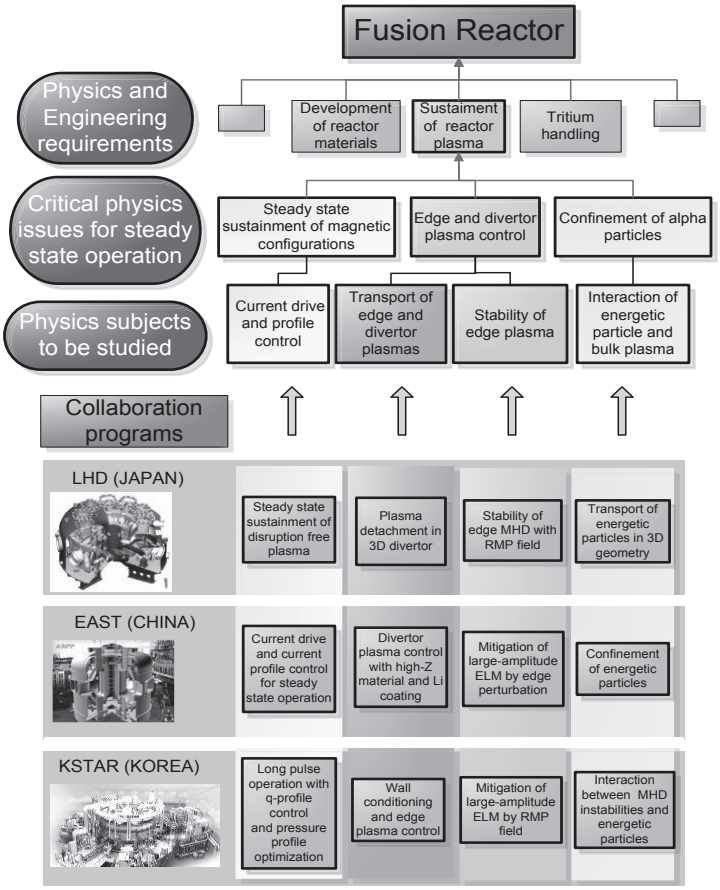

Fig.1 Schematic drawing on Joint Research Project among LHD (NIFS: Japan), EAST (ASIPP: China) and KSTAR (NFRI: Korea). Engineering requirements for the reactor can be reduced through the collaborative studies on critical physics issues specific to steady state sustainment of high-performance plasma. This Joint Research Project quests three 'Critical physics issues' for the steady state operation and these issues consist of four key 'Physics subjects' to be studied. The collaborative research is coordinated among 'Collaboration programs' by considering the characteristics and capability of three devices.

The three issues of (I) to (III) categories shown in Fig.1 still remain as open questions for the steady state discharge of high-performance plasmas, i.e., 'Critical physics issues for steady state operation' in the steady state operation, while the category (IV) can contribute to all the categories of (I) to (III). The issues involved three unresolved subjects, which have to be studied through the present Joint Research. Individual studies should be along with the planned 'Collaboration programs' (also see Fig.1), which consider the characteristics of each of the devices.

V. Activities in FY 2014

The 5th seminar was held in Kagoshima of Japan on 23rd - 26th June 2014 as the scientific seminar to discuss the year's schedule, collaborative results and the education of young scientists. New proposals for the collaboration are also discussed in the seminar. Totally 48 scientists and administrative stuffs joined the seminar. Discussions are also made for understanding the status and encouraging the future activities. The seminar proceeding is summarized as NIFS-PROC-97 [1]. In category I, operation and engineering plan of KSTAR, status of J-TEXT, plan for new diagnostics of EAST, progress of ICRF heating in EAST, cesium-seeded negative ion source for NBI, status and plan of plasma control system for steady state operation in KSTAR, status of MG installation for dummy coils, plasma disruption study in KSTAR, MHD study in LHD, plasma equilibrium reconstruction for real-time control in EAST and local modification of plasma equilibrium for MHD mode study in KSTAR were mainly discussed. In category II, hydrogen isotope retention in EAST and LHD, PSI study at divertor and SOL in KSTAR, PWI and edge plasma studies in KSTAR, study of edge impurity transport in LHD, spectroscopic study of low-ionized tungsten ions in LHD, spectroscopic modeling for tungsten EUV spectra, evaluation of ionization and recombination rates of tungsten ions using tungsten spectra in LHD, spectra from highly ionized tungsten ions in EBIT, study of edge MHD instability using imaging diagnostics in LHD, experiments using RMP coils in KSTAR, experimental studies of pedestal structure and ELM instability in HL-2A and absolute intensity calibration of ECE diagnostics in EAST were presented and discussed. In category III, plan of fast-ion loss detector installation in EAST, experimental results on fast-ion loss in KSTAR, status of present NBI and plan of off-axis NBI in KSTAR and progress in experimental studies of energetic ion driven global modes in LHD were discussed in addition to error field and its correction strategy in tokamaks. In category IV, status of particle-in-cell simulations of interactions with RF waves in plasmas, study of fast ion profile and Alfven eigenmodes in DIII-D, simulation study of energetic particle driven geodestic acoustic mode in LHD and simulation study on runaway electron dynamics in tokamaks were introduced for understanding the existing experiments.

The 6th scientific seminar was held in Nanning of China during 6th - 9th January 2015 with totally 66 participants. Future plans of LHD, EAST, KSTAR, HL-2A, J-TEXT (HUST) and KTX (USTC) were discussed for A3 collaboration. Recent progress and future plan for steady state operation, MHD were also discussed among three devices at category I with technical issues necessary for the long-pulse discharges. Status of J-TEXT and SUNIST experiments were presented for future collaboration. The transport of tungsten including its buildup and accumulation was discussed on the EAST discharge with tungsten divertor at category II in addition to the tungsten PSI and PWI studies. Discussions on the divertor heat load mitigation were made with RMP experiments also at category II. Diagnostics of fast ions and neutrons were discussed for further development of collaboration among three devices. Theory and simulation were also discussed on progress of collaborative study.

Main results of scientific collaboration are listed in the following.

[LHD]
1. Education of Chinese young scientist in LHD
2. X-ray crystal spectroscopy and toroidal rotation

[EAST]
1. EUV spectroscopy in EAST for tungsten divertor study
2. Development of neutron and fast ion diagnostic systems in EAST
3. Edge impurity transport study in EAST
4. Design of diagnostic system for RMP study in EAST
5. Progress of PWI study in EAST for hydrogen retention and material surface structure
6. Edge plasma and dust simulation in EAST
7. Theory and simulation studies on core plasma transport

[KSTAR]
1. Edge MHD instability in KSTAR for ELM mitigation
2. Development of escaping fast ion measurement in KSTAR
3. Design of He beam probe
4. Theory and simulation studies on core plasma transport

Based on the collaboration 51 papers were published in int'l journals and 75 presentations were made in int'l conferences and meetings. A statistical summary for personal exchange between J-C and between J-K listed in Table 1.

Table 1 Statistical Summary of A3 collaboration in FY2014

J→C person (person-day)	28 (201)
C→J person (person-day)	15 (181)*
J→K person (person-day)	6 (30)
K→J person (person-day)	18 (129)**

* included 3 months stay in Japan by young Chinese student
**included 1 month stay in Japan by young Korean scientist

[1] Proceedings of the 4th A3 Foresight Program Seminar, 23-26 June, 2014, Kagoshima, Japan, NIFS-PROC-97 (2014), edited by Morita S., Hu L.Q. and Oh Y.-K.

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